THE IMPACT OF CONCEPT MAPPING ON HIGHER COGNITIVE LEVELS IN TEACHING THERMODYNAMICS TO MECHANICAL ENGINEERING STUDENTS

Bhalachandra L. Tembe, Indian Institute of Technology Bombay, India
S. K. Kamble, Datta Meghe College of Engineering, Navi Mumbai, India
Email: bltembe@chem.iitb.ac.in

Abstract. This paper describes the use of concept maps as a supportive form of instruction and assessment in a mechanical engineering course at Mumbai University, India. The main objectives of this study are: (1) examine whether the construction of concept maps by students improves their achievement and ability to solve questions at different cognitive levels in the topic of the second law of thermodynamics, (2) explore the relationships between performance in the scores on concept maps and achievement in thermodynamics tests and (3) evaluate students' perceptions towards concept mapping as a teaching-learning strategy. The participants are 60 second year undergraduate mechanical engineering students enrolled in the thermodynamics course at a college of engineering of the University of Mumbai in India. Our results indicate that there are significant differences between the experimental group and the control group in the scores at the comprehension level, the applications level as well as the total scores. There are no significant differences in the achievements at the knowledge level questions between the two groups. The correlations between students' scores in all cognitive levels and total concept map scores are weak. Finally, students reacted positively to the tool of concept mapping.
Keywords: Concept maps, The second law of thermodynamics, Knowledge level, Comprehension level, Application level.

1 Introduction

In the era of fast technological developments, engineering practice has been transforming but engineering education has not changed significantly (Lang, Cruse, McVey, & McMasters, 1999). An engineering education is expected to enhance students' problem solving capacity and establish their ability to question a process or procedure (Mahajan, McDonald, & Walworth, 1996). In traditional teaching methods, engineering students cannot transfer their knowledge of theory to solve real life situations. In the last decade, engineering education has started to use concept maps as an assessment technique for knowledge evaluation and knowledge integration (Turns et al., 2000; Cho et al., 2012). Concept maps are used to represent and analyze the student's understanding of concepts and to transform traditional instructions into students centered learning (Minkyu, 2013). Concept maps provide multiple individual views and representation of views (Ali Saeedi et al., 2013). Concept maps were developed by Novak (Novak 1982). He developed this research tool of concept maps based on the meaningful learning theory of Ausbel (Ausbel, 1968). He used concept maps to enhance meaningful learning and assess and organize knowledge (Novak 1982). A concept map is a graphical diagram that shows relationship among different concepts. These concepts are related with each other by means of linking words called prepositions (Novak and Gowin, 1988; Novak et al., 2000; Novak et al., 2006; Novak et al., 2008; Kumar et al., 2013). Concept maps could be created in different ways – on computer, by pen and paper, with labels etc. (Katrin Soila, Priit Reiska 2013). Concept maps can be used as empowering method to enhance learning, thinking, teaching and research in education (Ahlberg, 2013).

In mechanical engineering curriculum, thermodynamics is one of the core subjects and it plays important role in our lives (Hassan and Mat., 2005; Abu-Mulaweh, 2004; Forbus et al., 1999). The second law of thermodynamics has impacts which are even more profound than the first law of thermodynamics as far as the behaviour of matter in natural (irreversible) processes is concerned. The students of thermodynamics find difficulties in learning thermodynamics because in this subject, the concept are abstract and it is hard for students to establish the connections between concepts (Huang and Gramoll, 2004). Cox (2003) suggested that majority of students face difficulties in understanding the basic concepts in thermodynamics (Patron, 1997; Cotignola et al., 2002; Meltzer, 2004; Anderson et al., 2005; Junglas, 2006).

In order to improve the teaching and learning of thermodynamics, various researchers have moved from traditional teaching to more active learning methods (Mulop, 2012). In the past few years, many researchers have taken efforts to develop and utilize innovative methods in teaching engineering thermodynamics (Anderson 2005; Mulop, 2012). Cobourn and Lindauer (1994) at the University of Louisville designed a thermodynamics course on the web using a slide-show format. Ngo and Lai (2003) at the University of Oklahoma have also created modules for teaching specific topics in engineering thermodynamics. Mulop (2012) developed a visual courseware for enhancing the learning of thermodynamics.

The research questions investigated in this study are: i) Is there any effect of concept mapping strategy on students' achievement scores in the topic of the second law of thermodynamics? ii) Is there a correlation between students' scores in creating concept maps and their achievements in different cognitive levels? and iii) What are students' perceptions towards concept mapping as a teaching-learning strategy?

2 Methodology

A total of 60 undergraduate mechanical engineering students from University of Mumbai, India participated in the study. They were randomly divided into two groups. One group of 30 students (n = 30, 21 boys and 09 girls) was randomly assigned as the experimental group; the other group of 30 students (n = 30, 25 boys and 05 girls) was used as the control group. The experimental group utilized concept maps in teaching and learning, while the control group maintained normal traditional teaching method. The teacher and the textbooks for both groups were the same to avoid confounding effects in the experiment. No student in the groups reported previous experience in concept mapping.

The distribution of participants according to gender and groups is as shown in Table 1.

Table 1: The distribution of participants according to gender and groups

	Experimental group		**Control group**	
Gender	n	%	n	%
Male	21	70	25	83.33
Female	09	30	05	16.66
Total	30	100	30	100

The dependent variable in this study is the students' achievement in the tests on the second law of thermodynamics. The present study used two objective tests to measure achievements of the students. Pre test measured students' pre-requisite knowledge in topics of thermal science. The post test measured students' achievement in the second law of thermodynamics at the end of the study. A satisfaction questionnaire was given to the students at the end of the study to evaluate the attitude of students towards concept mapping to learn the topic of the second law of thermodynamics. The questionnaire comprised 10 items and was rated on a five-point Likert scale from 'strongly disagree' to 'strongly agree'. The Cronbach Alpha coefficient of the instrument was 0.82. Bloom's taxonomy (1969) was used in placing test items at different cognitive levels (Bloom, 1969; Anderson et al., (2001). The reliability KR-20 of the pre test was 0.77 while that of the post test of the second law of thermodynamics was 0.80. The distribution of the questions according to Bloom's taxonomy is as shown in Table 2.

Table 2: Distributions of the questions according to Bloom's taxonomy

Level	The number of questions on the second law of thermodynamics
Knowledge level	15
Comprehension level	18
Application and above level	11
Total	44

2.1 Concept map scoring rubric

Novak and Gowin (1984) stressed that concept maps should be hierarchically structured. The concept mapping scoring method was proposed by Novak and Gowin (1984). It is based on the elements and structure of the concept map. In this method, 1 point is assigned for valid prepositions, 5 points are assigned for each level of hierarchy, and 10 points are for each valid cross link and 1 point for each specific example. This scoring method developed by Novak and Gowin is time-consuming, but it gives great information about the students' knowledge structure (Ruiz-Primo & Shavelson, 1996).

2.2 Procedure

This study was conducted over 12 teaching hours extending to four weeks. The experimental (concept mapping) and control (traditional teaching) groups were pre-tested using a teacher-constructed thermal science achievement test. The material covered was the second law of thermodynamics which includes the statements of the second law of thermodynamics, the Kelvin-Planck statement, the Clausius statement, the principle of increase of entropy, thermodynamic temperature scale, entropy, Carnot theorem, Clausius inequality and criteria of reversibility. Both the control group and the experimental group were taught the subject related to the second law of thermodynamics with the traditional teaching method by the same teacher. The material covered was taken from the textbooks on engineering thermodynamics by P. K. Nag and R. K. Rajput. During the course of lectures, block diagrams indicating the flow of heat and work were drawn on the board and all definitions and derivations were explicitly written on the board giving enough time for the students to make their own notes on these topics. At least one problem illustrating the principle was solved in each class and enough time was given for question answer sessions. In the first week, the experimental group was introduced to the characteristics, usefulness and creation of concept maps as suggested by Novak and Gowin (1984) in two lectures. At the end of four weeks of lectures, the experimental group was provided with the list of concepts that was generated in the class discussion. The students in this experimental group were asked to submit the concept map generated by them. To make up for the additional time of two hours given to the experimental group, the control group was provided two hours of discussion, question answer and problem solving sessions.

The concept maps drawn by the experimental group were scored by using Novak-Gowin criteria. At the end of the treatment period, both the experimental and control group students took the post test at the same time. The experimental group was also administered concept maps attitude questionnaire.

3 Results

The mean score of the pre test for the experimental group was found to be 11.26, while that of the control group was found to be 10.00 out of a maximum possible score of 30. A t-test for independent samples showed that there were no significant differences between the two groups ($t = 1.28$, $p > 0.05$).

As there were no significant differences in the pre test scores of the experimental group and the control group, it was assumed that the above two groups were having equivalent means. Table 3 presents the means and standard deviations of the post test results for the experimental and control groups. These results include the scores on the Knowledge Level (KL-post), Comprehension Level (CL-post), and Application Level-and-above level (AL-post) questions along with the total scores on the second law of thermodynamics achievement post-test (TL-post). The division of the number of questions was as follows: knowledge level questions: 15, comprehension level questions: 18, application Level-and-above questions: 11 and the second law of thermodynamic achievement post-test questions: 44. Each question carries one mark.

Four t-tests for independent samples was carried out to test whether the experimental and control groups differed significantly on the post-test achievement in the second law of thermodynamics. The results of the t-tests are shown in Table 3. No significant difference was found for the questions at the knowledge level (KL-test ($t = -0.40$, $p > 0.05$). Significant differences were found between the experimental and the control groups in the other cases; the comprehension level (CL-post, $t = 3.09$, $p < 0.05$), application-and-above level (AL-post, $t = 3.63$, $p < 0.05$) and total performance level (TL-post, $t = 2.90$, $p < 0.05$).

Table 3: Means and standard deviations of the experimental group and the control group

	Experimental Group			Control Group			t- value	p- value
	N	Mean	SD	N	Mean	SD		
KL-post	30	8.90	2.02	30	9.16	2.99	-0.40	0.688
CL- post	30	8.00	2.85	30	5.86	2.47	3.09	0.003
AL- post	30	6.70	1.55	30	5.40	1.19	3.63	0.010
TL- post	30	23.60	4.42	30	20.43	4.00	2.90	0.005

3.1 Correlation between scores in the second law of thermodynamics and scores in the creation of concept map

The test scores of the experimental group were correlated with the corresponding concept map scores on the second law of thermodynamics constructed by them. Results show these two are weakly correlated. (Pearson correlation coefficient = 0.23). Next, the concept map scores were correlated separately at the knowledge level scores, the comprehension level scores and the application level scores (Table 4). Table 4 shows correlation between concept map scores and the achievement post test scores at various levels.

Table 4: Correlation between concept map scores and the Achievement post test scores

	KL	CL	AL	TL
Concept map score	0.179	0.24	0.210	0.23

The concept map generated by the teacher is shown in Figure 1.

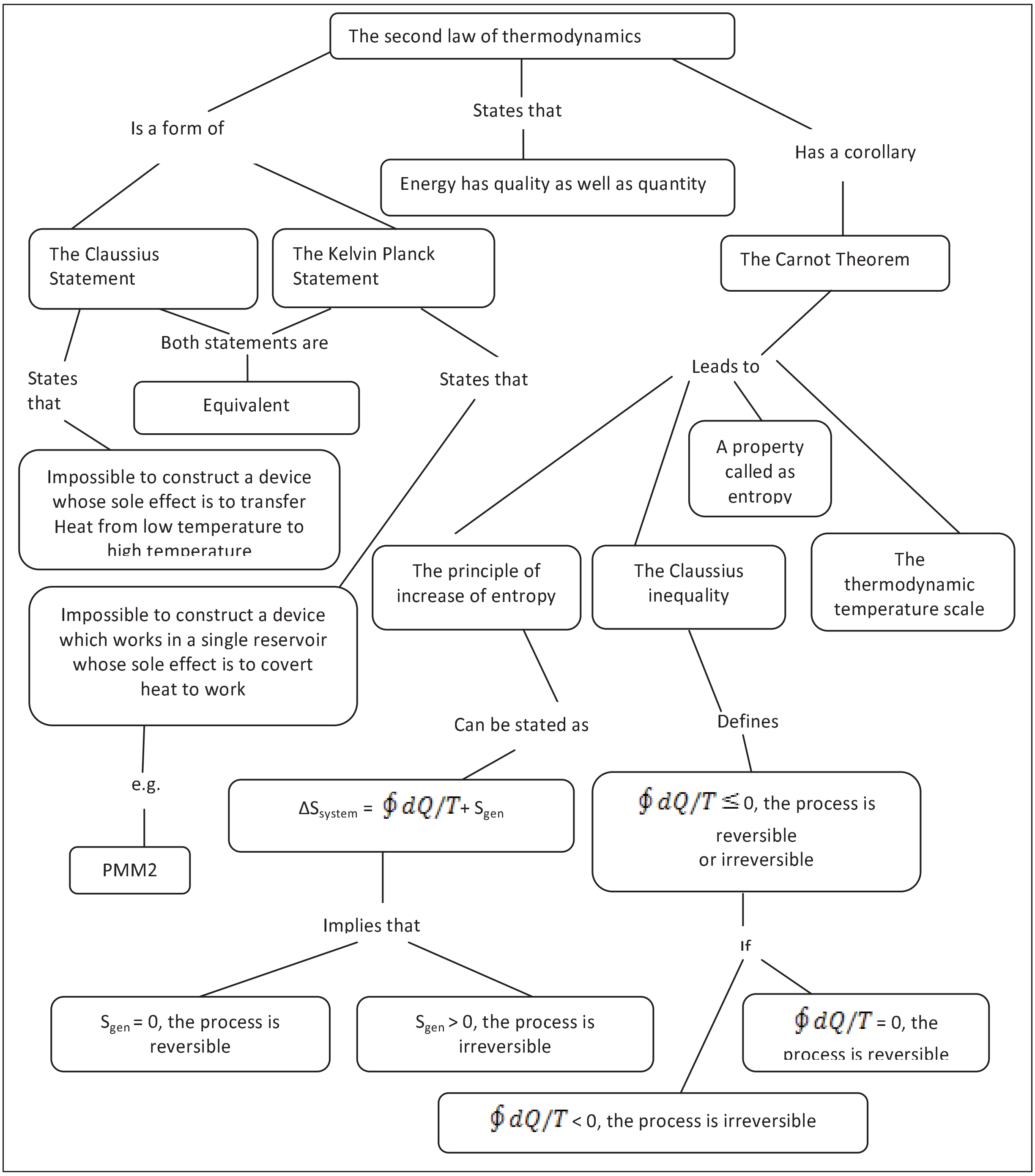

Figure 1. A well-developed concept map for the second law of thermodynamics

3.2 Student's perceptions towards concept mapping

To evaluate the students' attitude towards concept mapping and the use of this tool in the topic of the second law of thermodynamics, questionnaires were administered to the students. The students were questioned on i) the utility of concept maps to connect various concepts, ii) the help of concept maps in problem solving iii) the use of concept maps as a tool for study and revision and iv) the help of concept maps in recalling the concepts.

The reliability estimate for the questionnaire based on the Cronbach alpha method is 0.82, which is consistent with reliability estimates of perceptions questionnaires from other such studies (Ellies et al., 2004). Most of the students were in favour for the use of the concept maps in the classroom. Nearly 90 % students were in favour of the use of concept mapping in thermodynamics, 91 % students were of the opinion that concept mapping is useful for study and revision and 84 % students said that concept maps helped them to connect various concepts.

4 Discussion and Conclusions

4.1 Discussion

The results of the present study show that use of concept maps in the classroom teaching of the second law of thermodynamics improves students' performance in the total score of the experimental group. However, there is no significant difference at knowledge level questions between the experimental and control groups. There is a statistical difference between two groups at comprehension and application and above level questions. The concept map of the students of the second law of thermodynamics reveals that majority of students are able to write statements of the second law of thermodynamics. They are not able to connect the Clausius inequality, the principle of increase of entropy and the criteria of reversibility. The correlation between the thermodynamics total post test score and concept map score is weak. The correlation between the thermodynamics knowledge level post test scores, comprehension and application level scores and concept map scores is also weak. The strength of the correlations depends upon three factors: the type of conventional test, the type of concept map format and the scoring rubric of the concept map (Stroddart et al., 2000).

The correlations between the scores of concept map and conventional achievement test have been found to vary with type of the conventional achievement test (Stroddart et al., 2000). Lower correlations are found between scores of concept map and conventional achievement test scores which measure recall of knowledge (Novak, Gowin & Johansen, 1983). Most of the learners were able to apply various concepts in different situations but were unable to establish the relationships among these concepts.

Thus, using concept map as an assessment method provides a supplementary role to the conventional achievement test (Jonassen, 1997; Moreira, 1985). It measures other aspects of learning that conventional achievement tests do not measure, such as relationships among different concepts, incorrect conceptions, etc. The use of concept maps as an assessment technique provides a focus on conceptual understanding and processes of learning. Concept maps might give the teacher a clear picture of students' understanding by encouraging students to connect and relate ideas in the subject at hand (Wallace et al., 1990; Walker et al., 2010). With the creation of concept maps, students can look into the knowledge structure they have constructed. Students can recognize possible shortcomings in their knowledge structure and can identify unconnected concepts. Concept maps can be used throughout the teaching-learning process. They can be used at the start of instructions to establish what a student already knows about a topic. Concept maps can be used during the instructions to show the learning progress. Concept maps can be used at the end of instructions as a measurement of what the student has learned.

4.2 Conclusion

It is seen in the present study that concept maps can be used for teaching a lot of difficult concepts in the second law of thermodynamics. The achievement of the experimental group was found to be significantly higher than that of the control group which was taught with the traditional teaching methods. The result of the study also supports the use of concept maps in active learning, recalling and exploring their knowledge structure.

Our results supports the use of concept mapping at high cognitive levels (comprehension, application and above). Concept maps are successful in helping students to improve their grades at comprehension, application and above level questions. The students are comfortable with the creation of the concept maps and they reacted positively to the tool of concept maps. Since creation of concept maps requires a reasonable depth of understanding as well good reasoning skills, the impact of concept maps seem to be more significant on the comprehension and higher levels rather than on the knowledge level. Concept maps and Vee diagrams have been generally considered as metacognitive tools that facilitate meaningful learning. Our present results need to be further strengthened and quantified by additional studies in this subject as well as on a wider range of subjects. Such studies may also help in developing more standardized patterns in concept maps.

The correlation between students' mastery of creating concept mapping and their achievement needs to investigated in different topics of thermodynamics. Additional studies need to be undertaken to test further the effect of concept mapping strategy in groups with a gender difference, groups with different backgrounds and groups in different types of colleges.

References

Abu-Mulaweh, H. I. (2004). Portable experimental apparatus for demonstrating thermodynamics principles. International Journal of Mechanical Engineering Education, 32, (3), 223-231.

Ahlberg, M. (2013). Concept mapping as an empowering method to promote learning, thinking, teaching and research. Journal for Educators, Teachers and Trainers, Vol. 4 (1), pp. 25 – 35.

Ali Saeedi, Ali Akbar Saif, Hassan Asadzadeh and Soqra Ebrahimi Qavam, (2013) . Comparing effectiveness of methods of presentation and providing concept maps on reading comprehension, European Journal of Experimental Biology, 2013, 3(2):545-550.

Anderson, L. W. (Ed.), Krathwohl, D. R. (Ed.), Airasian, P. W., Cruikshank, K. A., Mayer, R. E., Pintrich, P. R., Raths, J., Wittrock, M. C. (2001). A Taxonomy for Learning, Teaching and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives. Longman, London.

Anderson, E. E., Taraban, R., & Sharma M. P. (2005). Implementing and assessing computer-based active learning materials in introductory thermodynamics. International Journal of Engineering Education, 21, (6), 1168-1176.

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

Bloom, B. (1956). Taxonomy of Educational Objectives. McGraw-Hill, New York.

Cobourn, W. G., & Lindauer. G. C. (1994). A Flexible multimedia instructional module for introductory thermodynamics. Journal of Engineering Education, 83(3), 271–277.

Cho, S., Yi, M. Y., & Jackson, J. D. (2012). A Study on the comparative advantages of concept map construction and self-explanation. Proceedings of the SWDSI Conference, New Orleans, LA, USA.

Cotignola, M. I., Bordogna, C., Punte, G., & Cappannini, O. M. (2002). Difficulties in learning thermodynamic concepts: are they linked to the historical development of this field? Science & Education, 11, 279-291.

Cox, A. J., Belloni, M., Dancy, M., & Christian. W. (2003). Teaching thermodynamics with Physlets® in introductory physics. Physics Education, 38(5), 433-440.

Forbus, K.D., Whalley, P. B., Everett, J. O., Ureel, L., Brokowski, M., Baher, J., & Kuehne, S. E. (1999). CyclePad: An articulate virtual laboratory for engineering thermodynamics. Artificial Intelligence, 114, 297-347.

Ellies, G. W., Rudnitsky, A. L., & Silverstei, B. (2004). Using concept maps to enhance understanding in engineering education. International Journal of Engineering Education, 20(6), 1012-1021.

Huang, M., & Gramoll, K. (2004). Online interactive multimedia for engineering thermodynamics. American Society for Engineering Education Annual Conference & Exposition. Salt Lake City.

Jonassen, D. H., Reeves, T. C., Hong, N., Harvey, D., & Peters, K. (1997). Concept mapping as cognitive learning and assessment tools. Journal of Interactive Learning Research, 8(3/4), 289-308.

Junglas. (2006). Simulation programs for teaching thermodynamics. Global Journal of Engineering Education, 10(2), 175-180.

Katrin Soika, Priit Reiska. (2013). Large scale studies with concept mapping. Journal for Educators, Teachers and Trainers, Vol. 4 (1), pp. 142 – 153.

Kumar, R., Sarukesi, K., & Uma, G V. (2013). Exploring concept map and its role as knowledge assessment tool (2009-2012). International Journal of Advanced Research in Computer Engineering & Technology, 2(4), 1534-1540.

Lang, J. D., Cruse, S., McVey, F. D., & McMasters, J. (1999). Industry expectations of new engineers: A survey to assist curriculum designers. Journal of Engineering Education, 88 (1), 43-51.

Mahajan, A., McDonald, D., & Walworth, M. (1996). General engineering education for non-engineering students. Proceedings of the 26th Annual Frontiers in Education Conference, 3, 1264-1266.

Meltzer, D. E. (2004). Investigation of students' reasoning regarding heat, work, and the first law of thermodynamics in an introductory calculus-based general physics course. American Journal of Physics, 72 (11), 1432-1446.

Minkyu Kim (2013). Concept map engineering: methods and tools based on the semantic relation approach. Educational Technology Research and Development, December 2013, Vol. 61, Issue 6, pp 951-978.

Moreira, M. A. (1985). Concept mapping: An alternative strategy for evaluation. Assessment & Evaluation in Higher Education, 10(2), 159-168.

Ngo, C. C., & Lai. F. C. (2003). An online thermodynamics courseware. Computer Applications in engineering education, 11(2), 75-82.

Mulop, N. (2012). A Review on enhancing the teaching and learning of thermodynamics. Procedia - Social and Behavioral Sciences, 56, 703-712.

Novak, J., & Gowin, D. (1984). Learning how to learn. New York: Cambridge University Press.

Novak, J. D. (2000). The theory underlying concept maps and how to construct them. http://cmap.coginst.uwf.edu/info/

Novak, J. D. & Cañas, A.J. (2008). The theory underlying concept maps and how to construct and use them. Technical report, IHMC CmapTools 2006-01, Rev 01-2008, Florida Institute for Human and Machine Cognition, Pensacola Fl.

Novak, J. D., & Canas, A. J. (2006). The origins of the concept mapping tool and the continuing evolution of the tool. Information Visualization, 5, 175-184.

Novak, J. D., Gowin, B. D., & Johansen, G. T. (1983). The use of concept mapping and knowledge vee mapping with junior high school science students. Science Education, 67(5), 625-645.

Novak, J. D. (1998). Learning, Creating and Using Knowledge: Concept Maps as Facilitative Tools in Schools and Corporations. Trenton, NJ: Lawrence Erlbaum Associates, Inc.

Hassan, O., & Mat, R. (2005). A Comparative study of two different approaches in teaching Thermodynamics. Regional Conference on Engineering Education. Johor.

Patron, F. (1997). Conceptual understanding of thermodynamics: A Study of undergraduate and graduate students. Ph. D. Thesis, Purdue University.

Ruiz-Primo, M. A., & Shavelson, R. J. (1996). Problems and issues in the use of concept maps in science assessment. Journal of Research in Science Teaching, 33(6), 569-600.

Stoddart, T., Abrams, R., Gasper, E., & Canaday, D. (2000). Concept maps as assessment in science inquiry learning - a report of methodology. International Journal of Science Education, 22(12), 1221-1246.

Turns, J., Atman, C. J., & Adams, R. (2000). Concept maps for engineering education: A cognitively motivated tool supporting varied assessment functions. IEEE Transactions on Education, 43(2), 164-173.

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(10), 1033-1052.

Walker, J. M. T., & King, P. H. (2010). Concept mapping as a form of student assessment and instruction. Journal of Engineering Education.