The Use of Concept Maps in the Physics Teacher Education[1]

Jukka Väisänen and Kaarle Kurki-Suonio

Department of Physics, University of Helsinki

Abstract

The use of concept maps has been studied as a presentation of conceptual structures of physics, in order to develop a tool for learning and assessment in physics teacher education. The work is based on a comprehensive theoretical framework combining the principles arising from the conceptual and processual structures of physics with the modern principles of learning. It has been accomplished during 4 years of development of the course on Processual Structures in School physics in connection of the didactical physics program of physics teacher education. The work has resulted in a general scoring system for analysis and evaluation of concept maps on widely different areas and themes. The experiences indicate that the concept maps provide a powerful and sound tool for physics teaching and learning.

Theoretical framework

Most studies concerning the use of concept maps as a tool for learning and assessment underlie the role of cognitive and constructivistic theories of knowledge and learning in argumentation for potential of concept maps (e.g. Novak and Gowin, 1984; Ruiz-Primo and Shavelson, 1996; Markham, Mintzes and Jones, 1994; etc.). Development and research in this project has started from a highly different theoretical framework. It arises from the conceptual and processual structure of physics. The problems of teaching and leaning physics have been approached from viewpoint of this structure. Very far-reaching conclusions on learning physics have been achieved.

---

[1] In "Undervisning i naturvetenskap ur kultur- teknologi- och miljöperspektiv. Ed. Leena Aho ja Jouni Viiri. Det Sjätte Nordiska Forskarsymposiet om Undervisning i Naturvetenskap i Skolan. Joensuu 12.–16.7.1999. Joensuun yliopistopaino 2000, 280–286.

The fundamental idea is that learning and science are hierarchically different stages of the same great process of creating knowledge (*the paradigm of the great process*). Science is a unique great process of mankind. Learning is repetition of this process in individual (Kurki-Suonio Kaarle and Riitta, 1994 and 1998a). Analysis of the structure of this process gives a basis for development of teaching physics (strategies, curricula etc.). It combines the conceptual and processual structure of physics as an empirical science with the constructivistic principles of learning.

Learning has basically the nature of perception leading to the chain: perception ⇒ mental image ⇒ conceptualization. The same hierarchical chain can be identified in concept formation and conceptual structures of physics as a science. The empirical concept formation of physics leads to hierarchical structure. The hierarchical structure penetrates all processual and conceptual elements of physics and learning physics.

A concept map is a structural presentation of knowledge. It is formed of three basic elements: 1. Concept boxes 2. Lines between concept boxes and labels of links 3. Deliberately located concept boxes and lines. By the aim of these elements all essential elements of knowledge can be presented (i.e. concepts, relations between concepts and the structure they form). Particularly the structural nature of knowledge comes up clearly (Jukka Väisänen, 1999). The nature of concept maps as a structural presentation of knowledge offers various chances to utilize concept maps in teaching and learning physics.

The aim of the study

The subject of the research and development project is the use of concept maps in connection of the didactical physics program of physics teacher education (at Department of Physics, University of Helsinki). The program concentrates on perceiving the conceptual structure of physics and the meanings of this structure in physics teaching. The program includes one course (Processual Structures in School Physics) in which concept maps are used systemically as a means of learning and evaluation. The course initiates into characteristics of physics conceptual structure and concept formation by examining their expressions in principal areas of school physics. Special attention is paid to the hierarchy of concepts as it arises as representation of empirical meanings. Another essential standpoint is generalizing development of concepts and to the gradual change of the basic mental images from the concretness of Newtonian mechanics into the abstractions of modern physics, forced by accumulating empirical evidence. The goal is to create a structured general view of physics.

The use of concept maps has been studied as a presentation of conceptual structures of physic, in order to develop a tool for learning and assessment. There are two closely connected aims to be approached.

1. The potentiality of concept maps as tool for learning
2. Concept maps as tool for assessment

The use of concept maps in physics teacher education

On the Processual Structures in School Physics –course learning and evaluation is mainly based on concept maps prepared and developed further during the course by the participants. The participants prepare 12 concept maps on principal areas or basic themes of school physics. During the course participants prepare *diagnostic maps* on every 12 subjects. Diagnostic maps are returned before the lectures concerning the subject referred to. Diagnostic maps are not treated like thesis and they won’t be evaluated even thought they will be analyzed.

The purpose of diagnostic maps is to activate students to think and present their ideas. Thus diagnostic maps prepare students for the lecture. Another purpose is to have practice in preparing concept maps. Concept map technique needs practice exactly as all the other techniques for presenting knowledge, like speaking and writing. From teaching point of view diagnostic maps give a picture (“diagnose”) of students ideas of physics. The information can be utilized in many ways when outlining instruction. Thus analysis of diagnostic maps prepares teacher for the lecture. Experiences indicate that concept maps are appropriate tool for both purposes.

The maps are developed and completed during the course. They are examined as flexible, continually developable and “permanently unfinished”. After (or during) the course participants prepare *resulting maps* on same 12 areas. Resulting maps are returned after the course. Evaluation is based on resulting maps. Resulting maps should reflect the picture participant have constructed of the conceptual structure of physics on the basis of the course.

The subjects (titles) of 12 concept maps to be prepared concern widely different areas and themes of school physics. The titles can be classified in two different kinds of types:

Type A: The areas of phenomena:
1. Mechanics 3.Electric charge and current 4. Magnetism – induction – electromagnetic waves 6. Thermal physics 8. Wave motion – sound – light

Type B: The conceptual themes
2. Interaction 5. Field 7. Energy 9. Absolutism and relativity 10. Structural principle of nature 11. Quantization 12. Characteristics of basic entities of nature

The number before the title tells the order of the treatment.

The conceptual themes include concepts or principles combining and penetrating different areas of school physics. The structural emphases in these two types are highly different. In the maps of type the hierarchical structure, division and order of the concepts, has a commanding position. In maps of type B commanding feature is processual structure (unification and generalization development).

The idea of the use of concept maps came from the contents and aims of the physics teacher education. Thus the guidance and criterions for analyzing and evaluating maps are based on the conceptual structure of physics. Analysis and presentation of structure of physics are not wanted to be limited by the implicit rules or by offering some kind of model maps. The contents should determine the structure of the concept map, not the another way.

Although the resulting maps are looked forward to fulfil norms set to the concept maps, i.e. they should be composed of deliberately located concepts (boxes) and labeled lines denoting the relation between concepts, the forms of the presentations are open. The resulting maps are meant to be a compact presentation of the conceptual and processual structures of the subject concerned, i.e. relations between essential concepts and way and order in which they are formed and how concepts become more general. In physics concepts have certain relations end they form a certain kind of structure. This determines the content and nature of the maps as accurately as it is possible and necessary. (Kurki-Suonio Kaarle, 1998b)

Results

The research and development project of using concept maps in physics teacher education has achieved notable results in both aim areas. Firstly experiences and systematic research work have showed arguments for suitability and potential of concept maps as a tool for physics learning and teaching. Secondly the work has resulted general scoring system and methods for analysis and evaluation of concept maps.

The evidences for potential of concept maps as tool for physics learning are many-sided. Evidences are based on theoretical aspects arising from the conceptual structure of physics. The aspects has been confirmed and reconstructed by the experiences and systematic analyses and comparison of diagnostic and resulting maps. The aspects can be summarized as four essential points:

1. A Concept map is a natural and clear way to represent structures of physic.
2. Useful information about students’ ideas and the structure of their mental images are revealed by the aid of concept maps.

3. Preparing concept maps support and directs the analysis of ideas, i.e. formation of the structured whole (“the big picture”).
4. Concept maps adapt to the needs arising from the presentation of ideas which become more extensive and structured.

(Väisänen, 1999)

On many points these arguments for the potential of concept maps are similar with the results of many other researches concerning the use of concept maps in education (e.g. Åhlberg, 1991; Levävaara, 1993; Novak and Gowin, 1984; Roth and Roychdury, 1993). It has to be emphasized that this study is based on the physics. Results are related specially to the physics teacher education and the course on Processual Structures in School Physics. Structures of physics are starting point of planning and researching the use of concept maps. Pedagogical and psychological aspects are not emphasized

The second result, scoring system for analysis and evaluation, is fundamental to the whole project. The didactical physics program of physics teacher education concentrates on meanings and contents. Thus in case of the concept maps the object of the interest is the contents of the concept maps. Firstly presented results considered the question how concept maps can serve the presentation and perception of the contents. The scoring system summarizes essential points of the content (i.e. criterions for analysis and evaluation) and considers the question of how these points can be fined and analyzed from the concept maps. During the development of the course there have been constructed the general scoring system for analysis and evaluation of the concept maps based on the points of the structure of physics and experiences on analysis of the concept maps. The scoring system is summarized in table 1.

The seven components of criterions are general. The contents of the components are characteristic to each area or theme (title). Every area has its own essential concepts forming characteristic structure. The analysis and evaluation of single map is based on interpretation of the criterion components. The content included (required) in criterion components has been determined for every single title

The criterions are base of the analysis and evaluation. Experiences have resulted also many practical methods and principles for analysis and evaluation. The same methods have been used in qualitative analysis of diagnostic maps and quantitative assessment of resulting maps. The method can be called *cyclic process*. The evaluation is started by examining the map as a whole in viewpoint of the criterions. So the overall view of the contents of the map is formed. The overall view includes the picture of structure, nature, weakness and strengths of the map.

Criterion component	**Description**	**Score**
1. Selecting the concepts	Coverage and essentiality from the viewpoint of mental images and hierarchical structure	0-3 points
2. Structure of mental images	Mental image on cause and effect relations and development of the image	0-3 points
3. Hierarchical structure	Coverage and classification of concepts from viewpoint of hierarchical structure, general view of how quantitative level is based on qualitative level	0-3 points
4. Fastening of the concepts	Connecting the hierarchical levels of concepts, right and essentiality of the fastenings from viewpoint of empirical meanings and conceptual structure	0-3 points
5. Processual structure	Direction and progress of concept formation, quantifications, process of unification and generalization	0-3 points
6. Classifications and analogies	Right from viewpoint of empirical meanings, standing appropriate to field	0-3 points
7. Generalizations	Far-reaching generalizations like the level of atomic models, relativistic and quantization views	0-3 points

Table1. The scoring system for concept maps presenting the conceptual structure of physics (Väisänen, 1999)

Second step is the “true” evaluation of the map, i.e. scoring the map. The map is evaluated thoroughly in separated components of criterion and every aspect is scored. Third step returns the evaluation to the whole. The overall picture of the contents is reflected to the total score, which map has achieved. Moreover the picture of the weakness and strengths of the map is compared whit the scores in the different criterion components. The final step is to compare the map and its scores to the other maps on the same subject. The cyclic method of evaluation is partly planned in advance and partly formed by the experiences.

Inside the method there are few basic principles followed in evaluation. The principles are formed to serve ideas and aims of the program. The forms of the maps are not meant to be evaluated. *The positive spirit* in evaluation tries to minimize the effect of formal aspects. The positive spirit means that the contents of the criterion components are tried to find although they are not present so clearly. The maximum scores in a single criterion component don’t require perfection but the attention paid to the essential aspects. Likewise the maximum mark don’t require very high scores on every criterion component. The experiences indicate that this system is appropriate and just. An excellent map requires all essential aspects to be presented, but everything possible doesn’t have to be mentioned. On the other hand mentioning all possible don’t lead to the excellent map, if some essential aspects are ignored.

The marks of the course on Processual Structures in School Physics are determined according to the scores of 12 concept maps. Self-evaluation has important role in determining the final scores. Students choose six maps, which they want to be emphasized in evaluation. The chosen six maps have a weight of three and another six maps weight of one in the total scores. The self-evaluation motivates students to go deep once more to what have been learned. It gives students a chance to diminish the effect of the casual failures. This kind of self-evaluation based emphasis of assessment is fair to students and increase the reliability of evaluation.

The experiences have expressed also few problems on evaluation. The main problem is the reliable identification of the essential aspects. Any simple method or principle can’t solve this problem. Identification is always based on a subjective view, but this view can be so well argued that the identification can be called just and reliable. In physics we are in grateful situation, because the arguments are not open to various interpretations. The reliable identification of the essential aspects is rather a claim for the competence of the teacher than a problem of evaluation.

From a viewpoint of the contents it is problematic that emphasis of the criterion components is highly different in different maps. Criterion components aren't equally essential. Nevertheless criterion components are equal in evaluation. This is not a significant problem. Every subject has so many essential aspects that at all events an excellent map requires attentions paid to the essential aspects. Another problem is setting of boundaries between criterion components (e.g. matters included in processual structure and generalizations). This is not either a significant problem because from a mark point of view, it doesn't matter how the total score is formed.

Discussion

Although we have achieved significant results in main aim areas, new questions have arisen to direct future development and studies. One of the most important question is what kinds of experience did students have? Within this point of view the theoretical framework of the study can be strengthen by studying the role of concept maps in learning physics. Within the main areas of interests, more detailed research is needed (e.g. students ideas on physics revealed by the aim of diagnostic maps, the change in ideas during the education, the role of concept maps in that chance, evidence of validity evaluation etc.). The research and development project on the use of concept maps in physics teacher education is continued.

References

Kurki-Suonio Kaarle ja Riitta (1998a)
Ajatuksia didaktisesta fysiikasta
http://www.physics.helsinki.fi/~didfys/ajatuksia.htm, Accessed 8.4.1999

Kurki-Suonio Kaarle ja Riitta (1994)
Fysiikan merkitykset ja rakenteet (*The Meanings and and Structures of Physics*; in Finnish), Limes ry, Helsinki. The contents and introduction of this book is available in English in http://www.physics.helsinki.fi/~dfcl/english/summary.htm

Kurki-Suonio Kaarle (1998b)
KFR Käsitekartta
http://www.physics.helsinki.fi/~dfcl/2/kfr/karttaohje.htm, Accessed 8.4.1999

Levävaara Hannele (1993)
Käsitekartta tutkimusvälineenä, Dimensio **57**:6, s.38-43

Markham Kimberly M., Mintzes Joel J. and Jones Gail M. (1994)
The Concept Map as a Research and Evaluation Tool:
Further Evidence of Validity, Journal of Research in Science Teaching, vol. **31**, no. 1, pp. 91-101

Novak Joseph D. ja Gowin Bob D. (1984)
Opi oppimaan (*Learning how to Learn*), Gaudeamus. Tammer-Paino Oy, Tampere

Roth Wolf-Mikael and Roychuodhury Anita (1993)
The Concept Map as a Tool for the Collaborative Construction of Knowledge:
A Microanalysis of High School Physics Students, Journal of Research in Science Teaching, vol. **30**, no. 5, pp.503-534

Ruiz-Primo Maria Araceli and Shavelson Richard J. (1996)
Problems and Issues in the Use of Concept Maps in Science Assessment
Journal of Research in Science Teaching, vol. **33**, no. 6, pp. 569-600

Väisänen Jukka (1999)
Käsitekartat fysiikan tietorakenteen esittämisen välineenä (*Concept maps as a tool for presentation of the conceptual structure of physics,* in Finnish), Pro gradu thesis, University of Helsinki, Department of Physics

Åhlberg Mauri (1991)
Käsitekarttatekniikka ja muut graafiset tekniikat opettajan ja oppilaiden työvälineenä, *Dimensio **55**:4, s.35-40*