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# MAKING CONCEPT MAPS USEFUL FOR PHYSICS TEACHER EDUCATION: ANALYSIS OF EPISTEMIC CONTENT OF LINKS

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**Abstract.** *In physics teacher education the use of graphical knowledge representation tools like concept maps are abundantly used because they are known to support the formation of organised knowledge. It is widely assumed that certain structural characteristics of concept maps can be connected to the usefulness of content. In order to study this relationship, the concept maps made by pre-service physics teachers are examined here. The design principles of the concept maps are based on quantitative experiments and modelling as the basic procedures in physics concept formation. The epistemic plausibility of justifications written in links is evaluated by using a four-level classification introduced here. The results show that the epistemic analysis of links affects remarkably to the acceptability of knowledge. The advantages of such concept mapping technique in supporting the conceptual understanding in physics teacher education are discussed as well as their usefulness in making plans for teaching.*

**Key words:** *concept maps, epistemic content, physics teacher education, science education.*

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### Introduction

In physics teacher education the main goal is to facilitate development in teachers' professional qualifications. In that, two main issues are first, supporting pre-service teachers to form a good command of the content knowledge and second, forming an organised view of physics, which both are vital requirements for a qualified teacher in order to reach an expert-like knowledge (cf. Chi, Feltovich, & Glaser, 1981). This is a demanding task since many recent studies have pointed out that even in advanced levels of studies students' knowledge structures are fragmented (Reif, 2008; Koponen & Mäntylä, 2006).

Rich and well-organised content knowledge is needed in order to construct good teaching approaches; the teacher needs to know how the concepts can be introduced in teaching in a well-motivated and justified manner. In addition, a physics teacher needs to know the processes which produce new concepts in physics to be able to understand how knowledge is constructed and justified (Reif, 2008; Mestre, 2001; Mäntylä, 2011). Such knowledge helps teachers to make the teaching plans so that the way the concepts are introduced in teaching has certain continuity and contingency so that what was learned before is the basis for learning new ideas. Consequently, good teaching and well-made teaching plans can be recognised from some very basic features: clear exposition of new concepts, clear direction of progress and clarity in how concepts become related.

Organised knowledge structure needs specific means of representation to be useful for purposes of teacher education. One flexible way to represent knowledge is based on concept maps where knowledge is represented graphically as connected

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concepts, laws or of other forms of conceptual knowledge. The advantage of concept maps is that they very clearly visualise the ways how concepts are connected to each other by links, and can be therefore used to picture the interconnectedness of knowledge structures as a whole. Because of their many advantages concept maps are widely used in the teaching and learning of physics (Ingeç 2009; van Zele, Lenaerts & Wieme, 2004; Vanides, Yin, Tomita & Ruiz-Primo, 2005), chemistry (Zoller 1990; Nicoll, Francisco & Nakhleh, 2001) and biology (Kinchin, Hay & Adams, 2000; Kinchin, De-Leij & Hay, 2005), as well as in different levels of education from the elementary to advanced levels. Concept maps have also been used as tools of assessment and as tools of monitoring conceptual development during learning (Ruiz-Primo and Shavelson, 1996; van Zele et al., 2004; Yin, Vanides, Ruiz-Primo, Ayala & Shavelson, 2005).

Concept maps have proved to be a valuable tool in our teacher training courses to support the learning and reflection of knowledge. However, in order to make the concept maps really useful for purposes of higher education, some essential modifications in the design principles are needed. The traditional way to make concept maps is to use simple rules for making the connections, so that the connections are simple propositions. The content of such propositional forms of node-link-node connection is often very shallow. Moreover, the reasons to establish the links belong rather to personal cognitive domain than in inter-subjective epistemic level of knowledge. In order to overcome these severe limitations such design principles are opted that links shown in the concept maps are based on procedural rules (either experimental or modelling) of making connections between physics concepts and laws. The goal is to organise the physics concepts for purposes of teaching i.e. consider the order and justification in which new concepts are introduced. The procedural rules expand the possibilities to express knowledge in comparison to standard propositional rules (cf. Kharatmal & Nagarjuna, 2008) since they engage the learners to discuss and reflect the knowledge in much deeper level than in propositional level; learners need to justify the procedural principles and their adequacy on basis of epistemic criteria.

This study discusses the method to produce and examine physics concept maps. First it is discussed how to formulate the design principles, which attach more meaning to links, and how these design principles are used  to produce the maps. Second, a method is introduced which allows to analyse both structure and content of concept maps in a meaningful way. The new design of concept maps as well as the ideas about their structural qualities has been introduced recently (Koponen & Pehkonen, 2010; Nousiainen, 2010) but the ways to evaluate the content and impacts of this possibility on teaching and learning have not been discussed before. This study suggests a method to analyse the knowledge content of links, emerging from the linking procedures, and introduces a set of epistemic and normative criteria as basis of the evaluation. Finally, the advantages of such concept maps in physics teacher education are discussed both from students' and instructors' point of view. The detailed research questions are then the following ones:

1. How the quality of the concept map is affected by the epistemic acceptability of each single connection (link)?
2. How useful pre-service physics teachers find the concept maps in organising knowledge?

The first question is answered by comparing the purely structural features of relations between concepts to relations when the different (four) levels of epistemic justification of each link are taken into account. This is done so that  first the epistemic credentials of each link is evaluated, and second, it is examined qualitatively how the changes in the epistemic levels affects the whole structure and how high epistemic levels students manage to represent in the links;  more high level links means higher quality. Finally the second research question, it is discussed how the new design principles of  the concept maps help students to organise their knowledge because this kind of tool forces students to share, show and justify their thoughts with peers and students found such interaction really useful.

**New Design of Concept Maps**

Understanding the structure of scientific knowledge is to large degree based on understanding what the key concepts are and how and why these concepts are connected. Structure also affects how concepts are introduced in teaching scientific knowledge, how concepts are acquired through teaching, and how the conceptual knowledge can be represented and transferred forward (Novak, 2002; diSessa, 2008; diSessa & Sherin, 1998). The advantage of concept maps is that they visualise the ways how concepts are connected, and they illustrate the interconnectedness of knowledge structures as a whole. For purposes of higher education the connections between concepts need to be more complex and to contain information of how the concepts are connected.

*Different Aspects of Knowledge*

In an expert's approach on knowledge processing and acquisition different aspects of knowledge are involved. Of these aspects at least the 1) factual knowledge, 2) procedural knowledge, 3) functional knowledge and 4) justification of knowledge need closer attention (see e.g. Reif, 2008). These different aspects form also the basis to evaluate the level of epistemic justification of the links student use in their concept maps.

Factual (or declarative) knowledge consists of understanding about concepts, laws, principles and other types of relations and here it means the primary ability to identify and remember the meaning concepts which is a pre-requisite for the utility of concepts i.e. procedural knowledge. Factual knowledge forms the basis for students to handle the given concept mapping task in a sense that the most elementary structure of maps consists of nodes (concepts) and connections between them represent factual knowledge. One should be able to know the facts (experimental or theoretical) which are relevant for connection between concepts together. It should be noted that knowing the facts does not yet mean that it is possible to give a proper argument of how the connection is established in the procedural level; in some cases students were only able to state that a connecting relation exists, but were not able to tell its form or content. Of course, factual knowledge is contained in all other, more sophisticated links where also the procedure of forming new concepts is described since factual knowledge forms the bedrock of more advanced knowledge.

Procedural knowledge can be understood as the ability to perform certain things, it can be acquired through its application, and expertise can be seen as production of "if-then" relations (Chi, 1984; Reif, 2008). Procedural knowledge is a part of metacognitive knowledge and contains knowledge about the usefulness of procedures in specific situations. Procedural knowledge here means the methodological dimension of knowledge including especially the procedural nature of the experiments and model development which is needed to make connections between physics concepts and laws (Koponen & Pehkonen, 2010). The goals set for the teacher education require that students master such knowledge enough for purposes of making plans for teaching. In this sense, the choice of procedures is here traditional and the organisation of the knowledge in the maps reflects the way these procedures affect the ways the physics knowledge becomes introduced and organised in teaching.

Functional knowledge is related to the ability to re-organise structure when new concepts are added into the network. The certain co-variation between concepts occurs, i.e. when one concept is changed or affected, other concepts become affected, too. This kind of interdependency has been argued to be an essential feature of dynamic, functional knowledge (Safayeni, Derbentseva & Cañas, 2005; Derbentseva, Safayeni & Cañas, 2007). Functional knowledge is contained in the holistic relational structure, i.e. what kinds of larger linkage patterns are formed in the concept map.

Justification of knowledge means skills to give ontologically correct, factually acceptable, and methodologically plausible arguments. Justification of knowledge consists of logical argumentation so that stated claims (in the written explanation of the linking procedures) proceed in a sound order (cf. warrant of explanatory claims introduced by Sandoval & Millwood, 2005). Justified knowledge in physics must be "true" in the sense that it gives real explanations to the real phenomena or observations. Justification of knowledge is contained on written reports of the contents of the linking procedures. Students were asked to write down a short description of each experiment or model connecting two concepts. Their ability to give adequate justifications can is on basis commitment to evidence and critical thinking (Jiménez-Aleixandre & Erduran, 2008).

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*Establishing the Links*

Design principles discussed here rest on the use of quantitative experiments and models which are the traditional and important parts of procedural knowledge as discussed in school science (see e.g. Koponen & Pehkonen, 2010; Koponen & Mäntylä, 2006). In the quantitative experiment, the concept is operationalised, that is, made measurable through pre-existing concepts. For example, the operationalisation of Coulombs' law requires the concept of force and charge, whereas the concept of the electrical field rests on force, charge and Coulomb's law, and so on. This mutual dependence of concepts means that a network of concepts is woven through operationalisation. In such experiments, a new concept or law is always constructed sequentially, starting from those that already exist and which also provide the basis for an experiment's design and interpretation.

In addition to experiments, models are also core components of knowledge structures. For example, the definition of the electrical field can be seen as a model which breaks the force between two interacting charges into one part which causes the field (the charge as a source) and another part which experiences the field (the other charge). Another example is the model of a homogeneous field, extensively used as a model in introductory electricity. Typically, a model may be an idealised and symbolic representation or a description of dependencies found in an experiment or that should provide explanations and predictions of regularities found in experimental data (Koponen, 2007; Sensevy, Tiberghien, Santini, Laube & Griggs, 2008).

The use of experimental and modelling as linking procedures makes a close connection to a recent study about the steps involving in didactical reconstruction of knowledge construction where experimental and modelling processed are combined to produce new conceptual knowledge (Mäntylä, 2011). The way the procedural knowledge becomes coded in the links in concept maps studied here takes place much along the same lines as described by Mäntylä. However, here in the construction of concept maps simplified to few basic steps, which form the basis of design principles to be introduced next. Consequently, the design of concept maps discussed here is based on a special type of selection of concepts and special types of links connecting the concepts. The concepts can be:

1. Concepts or quantities.
2. Laws.

Of these elements, laws could be taken as particular experimental laws or law-like predictions in specific situations (derived from a theory). General laws are more fundamental principles (e.g. principles of conservation). In both cases, laws can be expressed as relations between concepts. The links are thus:

3. Experimental procedures (an operational definition).
4. Modelling procedures, which can be deductive models or definitions in terms of model type relations.

This design method has been in use in physics teacher training course for some years and it has given a promising framework for students' to develop their conceptual understanding. The basic idea is that the design principles guide the construction process of the map. It should be noted that students must ensure that every link they draw on the map is a procedure (either experimental or modelling) and justify them separately.

*Level of Epistemic Plausibility of Links*

In concept maps studied here, the students were asked to explain the aforementioned linking procedures in a written report. The degree of justified knowledge in student's concept map is studied by evaluating the level of epistemic plausibility of all links. It should be noted that since the nature of the links is required to be procedural, all links represented in the maps represent "correct" knowledge in the sense that students have been able to justify the connections. Therefore, finding physically unacceptable connections in the students' concept maps is therefore unlikely: rather, their maps would contain connections with a variable degree of justification as the poor quality reflects lack of connections and vagueness in justifying them. At this level the present study has contact with the traditional evaluation method for concept maps: compared to propositional knowledge represented in traditional concept maps, all the maps studied here would score very good points if scored by calculating the amount of appropriative links (as suggested by e.g. Novak & Gowin, 1984; Ruiz-Primo & Shavelson, 1996) which will be shown in what follows. Here, however, the interest is focused to the *method* which produces new connections by scrutinising the justification of procedural knowledge contained in the links. The degree of justification varies from case to case, thus affecting the overall justifiability and credibility of the concept map.

The written reports consisting of short descriptions of the procedures are treated as argumentation schemes since students are asked to justify connections between concepts (cf. Sampson & Clark, 2008). The epistemic justification of argumentation can be discussed much along the same lines as previously done by Kelly and Takao (2002), who note that the epistemic argumentation model can be used as a methodological tool, they present an argument structure according to epistemic levels, and Kelly, Regev and Prothero (2008), who introduce credentials to assess written reasoning. In a similar way, Sampson and Clark (2008) discuss how Toulmin's (1958) scheme can be augmented and generalised to an analytic framework to assess and characterise the nature or quality of scientific arguments. Sampson and Clark (2008) highlight two different approaches to the classification of argumentation schemas: domain general or domain specific frameworks. The latter type of framework can be divided into two subcategories: arguments specific to science (content and justification) and epistemic levels of knowledge. However, here only the last one is paid attention in setting up the normative criteria for epistemic justification. Nevertheless, the classification makes close contact with forming the basis of argumentation analysis, when the epistemic aspects of the argumentation are of interest (Sampson & Clark, 2008; Kelly & Takao, 2002; Sandoval & Millwood, 2005).

When discussing the epistemic viewpoint to assess justification, Krathwohl (2002) provides an interesting contribution as he presents taxonomy for knowledge. Within similar ideas, a four-level scale to evaluate the epistemic justification presented in linking procedures has been set up. Kelly and Takao (2002) discuss the difficulties of making judgements of quality since according to their findings assessment made by expert is often tacit. In order to overcome this problem the normative criteria are here made explicit. The levels are here suggested to consist of following dimensions for 1) ontology, 2) facts, 3) methodology and 4) the valid justification. The criteria are such that they are nearly self-evident pre-requisites for acceptable knowledge in physics, and they make contact to the four aspects of knowledge discussed previously in this study. Therefore, these four levels are suitable as the basis for classifying the levels of epistemic plausibility of links (in what follows, this will be referred as *epistemic levels* to be brief).

1. Ontology. Ontological knowledge refers to ontologically correct entities and the concept referring to them are used, for example, in the case of particles (with the property of mass, charge etc.) and fields (with the property of extension, strength etc.). Ontology requires also that such concepts are correctly related. For example, classical physics particles create a field but fields do not create particles. Ontology can also be understood that concepts are linked in a logical way in the sense that they are presenting standard physics.

2. Facts. Factual knowledge is connected to the properties of phenomena, events or observations. Making a correct factual statement thus requires that appropriate and correct quantities and laws are presented and that they are established on an ontologically correct basis. The correctness of factual statements is the necessary basis upon which to be conceived before links can have any plausibility.

3. Methodology. The methodological dimension of knowledge is achieved if the described procedure (experimental or modelling) is appropriate in the sense that it is performable, feasible or doable and correct from the physics point of view. Methodological knowledge is highly central in physics and here it means a methodical approach to acquiring, justifying and using knowledge so that steps in the process can be followed and the plausibility and the performability of the steps can be assessed. It should be noted that methodology does not refer to a "recipe" for doing science.

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The most important methodologies or methodical approaches discussed here concern quantitative experiments and modelling (Koponen & Pehkonen, 2010; Koponen & Mäntylä, 2006).

4. Validity. Valid justification can be seen as the logical order in which the argued facts are presented. In this study, the validity dimension is achieved if acceptable premises are used, and if methodology is adequately described and inferences about the results are discussed at some length. Structurally it means that an argument has *if-then-therefore* form as also noted by Lawson (2009); or it includes *claim, evidence* and *reasoning* as in framework presented by McNeill and Krajcik (2007). Valid justification refers to the consistency and logic of the argument.

This classification is cumulative and forms hierarchical ladders and thus the numbering (1-4) tells the order in which the above "norms" should be fulfilled. It is evident that one first needs know the ontological basis to be able to know and use the suitable relations (facts). A relevant and useful way to introduce new concepts (through experiments or modelling) can be achieved only if one has good command over the factual (or declarative) knowledge. In fact, the above scheme emphasises how factual or declarative knowledge, after all, forms the bedrock of more advanced forms of knowledge. Valid justification means that justification (in addition to the three former levels) is logically acceptable and that there is cogency in the reasoning. The distances between all four epistemic levels are "evenly distributed", which means that they all are equally important. It should be highlighted that this method of analysis is developed to capture the student's epistemic level of justification skills, but also keeping in mind the desired properties of the good scientific argumentation, where epistemic justification is most central.

## Methodology of Research

The design principles explicated above served to construct concept maps during physics teacher education courses over years 2006 to 2010. The courses were similar; of seven weeks' duration each and focused on questions concerning the conceptual structure of physics. Here the concept maps made during the course in the context of electricity and magnetism are discussed. During the teaching sequence, the students first produced an initial concept map, and later, after instruction and group discussions, the final version of the map. Students produced the maps for purposes of teaching and the planning of teaching physics in the level expected for teaching in high school. In constructing the maps, the choice of concepts was restricted to a given set of elements, chosen to be $n = 34$ most important concept and law in the field of electricity and magnetism. The number of linking procedures was not restricted; they were only required to be either experimental or modelling procedures. The visual outlook of the maps is shown in Figure 1. It should be noted that students produced the maps in a rather advanced stage of their studies. The students were familiar with basic physics and the basic concepts. Concept mapping as a learning tool to organise the content and to transform previous knowledge into a more functional form was already familiar to the students.

### *How Students Make the Maps*

Students worked both individually and in small groups (about 2-4 persons in each). Each student constructed an own representation but during lectures students had opportunities to discuss and compare maps in small groups. The teaching sequence was planned in such manner that first students drew an initial version of the map and they got feedback from an opponent (i.e. other student's peer review). Students found the possibility for peer reviewing very useful since it advances also their own learning process. According to this feedback students revised the map and often the changes were quite substantial. In addition to student feedback, instructor gave feedback and also guided and helped during the whole construction process by asking conversational questions and justifications to tentative drawn connections.

It should be noted, that each connection shown on the maps has required detailed discussions of the procedures creating the connection, whether the procedure is empirical or model-based, and how it can be justified. It is evident that in order to be able to concentrate to these demanding cognitive tasks, the tool needs to be flexible and easy to use i.e. as invisible as possible. Therefore, most of the student used CmapTools-software to draw the maps and usually students had their laptops during lecture times in order to have a flexible opportunity to construct the maps by using CmapTools. In general, students found CmapTools an easy and helpful tool in organising knowledge.

*How to Evaluate the Maps*

The process of doing concept maps is meant to foster students' formation of organised physics knowledge. Concept mapping is assumed to give a reflection of the students' knowledge structure but making these kinds of inferences from the maps is challenging task to the evaluator. One possibility to recognise good organisation of knowledge is to pay attention on certain types of structural patterns. It has been suggested that both good understanding and the high quality of students' knowledge is reflected as large scale structures, which are tightly connected sets of several nodes and web-like (Kinchin et al., 2000, Kinchin et al., 2005; Safayeni et al., 2005; Derbentseva et al., 2007; Liu, 2004). Such qualitative methods for analysing the concept maps have thus revealed that global topological features that are chain-, spoke- or web-like carry important information about the quality of knowledge represented in the maps. It is a plausible assumption that the structure of the relations expressed in a concept map is indicative of the richness and quality of the students' knowledge; a richer and more complex structure indicates better knowledge than a structure with very few and simple connections.

In order to visualise the topological features of interest, it is useful to make the visual appearance of the maps comparable by removing any ambiguity associated with the graphical layout. This can be done by redrawing the maps so that the same rules for ordering the nodes are used in all cases; such representations are isomorphic with the original one. Then it is possible to pay attention to comparable structural features and connect the qualitative features of interest to better-defined quantitative features describing the connectedness and organisation. (Koponen & Pehkonen, 2010) Once the bare structure of concept maps is made comparable it is possible to consider the quality of the linking procedures. In this mode of representation the four levels of epistemic justification are displayed as link weights from one to four. A combination of the bare structure (connections between concepts), and the grading of links is visually informative since the thickness/thinness of the linking arrows represents the quality/vagueness of the described procedure. This kind of representation instantly gives an overview of the drawn conceptual structure and which parts of it are well-justified and which concepts are poorly understood.

**Results of Research**

The concept maps produced by students are rather complex representations of the relations between concepts. Already a visual inspection shows that the global structure is remarkably connected, but in such an ordered way that certain typical repeating patterns can be seen. These structural features (cycles understood as clustering-like interconnectedness locally and branches giving hierarchical ordering) describe the qualitatively defined requirements for well-organised knowledge structures. These are the features that have been essentially brought forward by qualitative analysis of concept maps (cf. Kinchin et al., 2000; Kinchin et al., 2005; van Zele et al., 2004).

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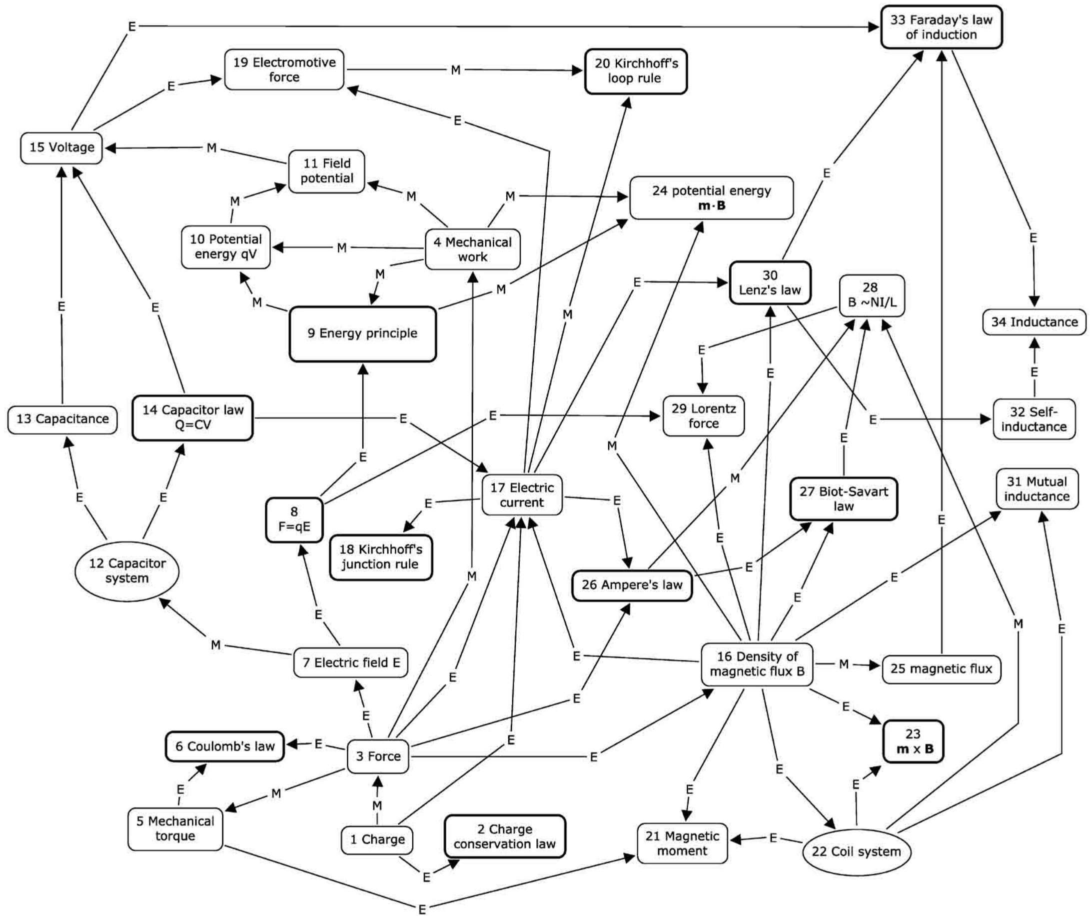


**Figure 1. An example of student-made concept map is illustrated here to show the patterns (cycles and branches) which can be observed through the structure of the maps. For example, a triangle can be found in potential energy, field potential and mechanical work, whereas density of magnetic flux forms a strong branch.**

In all maps the factual (or declarative) knowledge is correctly taken into account and is there an unproblematic issue. However, the procedural and functional knowledge is represented in more or less adequately and there is more variation in success in this.

*Procedural Knowledge Represented as Simple Patterns*

The many triangular-type patterns found in the concept maps in Figure1 can be directly traced back in the design principles of the concept maps. Due to the requirement that links represent procedural knowledge at least three concepts become connected in transitive way. This happens because for example an experimental procedure a new concept is operationalised i.e. made measurable through the pre-existing concepts. In its most idealised (but still sufficiently truthful) form the new concept or law C is formed on the basis of two pre-existing concepts A and B so that the operationalisation creates C on the basis of the relations A→C and B→C, which also requires that A and B can be related as A→B. There is then a triangular and inductive-like mutual dependence A→B→C←A. Very similar way to connect concept takes place when modelling procedures are used (for more details see Koponen & Pehkonen, 2010). In addition to such triangular patterns, there are also different kinds of branches and combinations of them. The simplest of these branches is two-branched, where three nodes are connected by two links. The procedural knowledge can be identified as combinations of hierarchical patterns and cycles.

The epistemic plausibility of arguments given in links can be now represented within the basic structure as different weights of the links. The best justified links can achieve up to four points (all four levels fulfilled) whereas the poorest connections may gain only one (only ontology level fulfilled). This difference in the level of justification of knowledge is illustrated with different thickness of the links. In Figure 2 there are examples showing how weighting on links instantly provides more information of the quality of the students' knowledge. The procedural knowledge can now be presented in terms of the epistemic level of the justification and show how the plausibility of such knowledge can become visible.

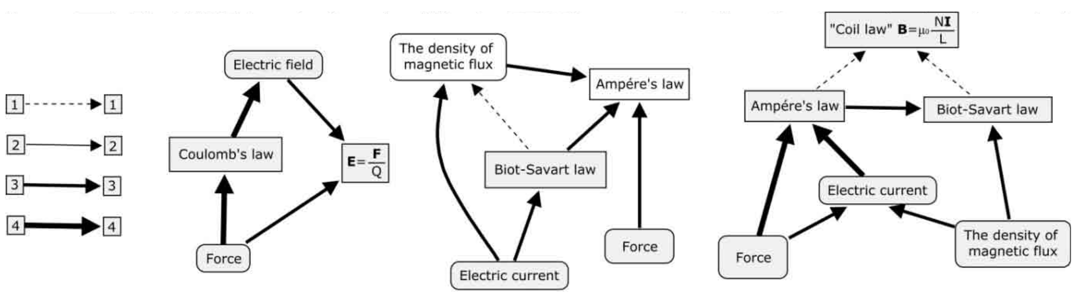


**Figure 2. Examples of knowledge-ordering patterns and how they are affected when epistemic acceptability of links is taken into account.**

In the case of Coulomb's law shown in Figure 2 (left), the links are well-argued and therefore its position in the structure remains as strong as it was in the first place. Instead, the two other cases have more interesting features from the structural point of view. In the right-most case, Ampère's law has quite strong scaffolding but Biot-Savart law is not as much better off. In this particular case, the student has misunderstood the meaning of the coil law and thus the reasoning of it is vague. In the middle case, Ampére's law and Biot-Savart law are equally well-justified, but the connection from Biot-Savart law to the magnetic field is poorly presented.

*Functional Knowledge*

The functionality of knowledge is revealed when the maps are drawn with weighted links because then it is possible to observe to what extent the links are well-justified. In such strongly connected (strong links) structure changing one part in it affects the whole network which means that it passes information effectively. In the Figure 3, there are few examples of concept maps which are evaluated by their epistemic plausibility. To make a clear presentation, the links presenting different epistemic levels are drawn in individual pictures because the concept maps studied here are so massive that combining all the differently emphasised links in the same network would have been messy. For example, in the first column from the left, all the ontologically sufficient links (epistemic level 1) are drawn with bold line. It's worth noticing that ontologically wrong links were not found in these concept maps. In the second column, all the ontologically acceptable links which also present relevant factual knowledge (epistemic level 2) are drawn with bold line. In the third column, in addition to ontologically and factually correct statements also adequate description of the used procedure is acquired (epistemic level 3). In the right-most column, the links presenting valid justification and sound argumentation (epistemic level 4) are drawn with bold line.

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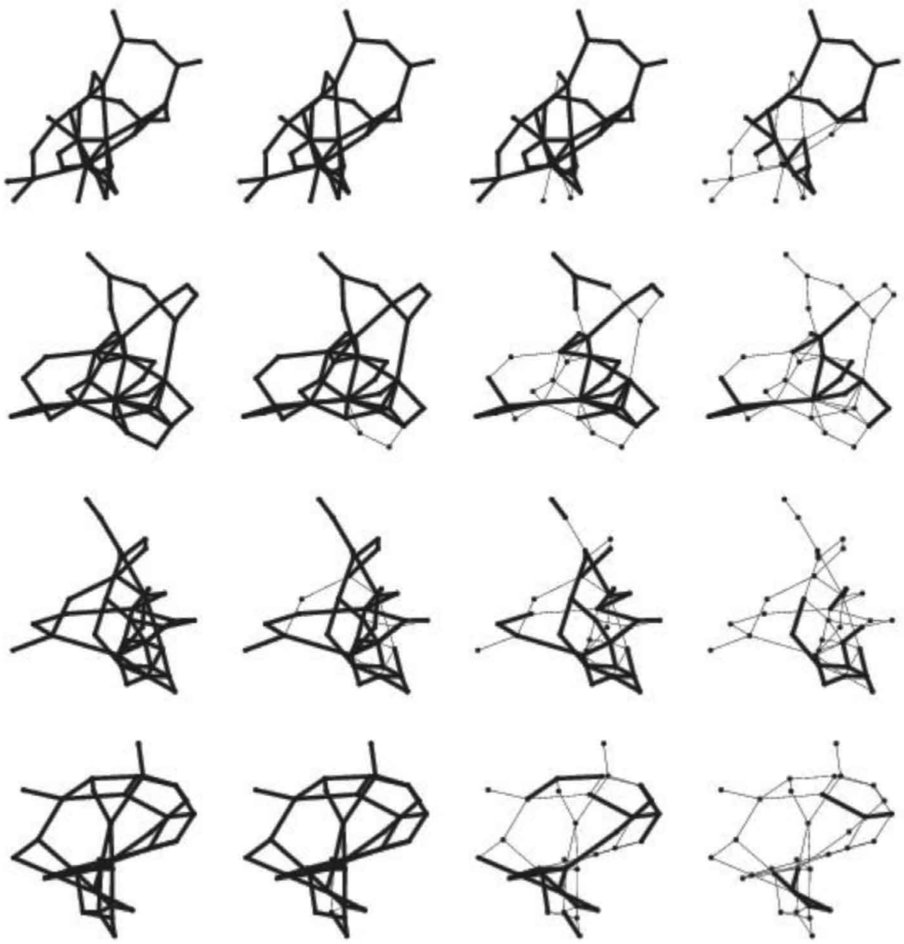

**Figure 3. Weighted links for four different cases (concept maps). Note that each row presents the same map: the links with different epistemic level are presented as four separate webs. From the left to the right level: bold links presenting ontologically sufficient knowledge (1), factually acceptable knowledge (2), methodologically correct knowledge (3), and valid and sound justification (4).**

Weighting the links gives instantly more information about the functionality and navigability in such network. In all cases, as supposed before, there were no ontologically incorrect links. In the topmost case, almost all links reach methodologically correctly justified knowledge and valid justification is given in some amount of links. In the second and third case, the students have been able to justify some links in the methodologically correctly and in the lowest case most links reach the methodological level. In general it is easy to see that the knowledge is clearly presented more effectively in the topmost case since compared to other cases; where lower epistemic level of knowledge is presented as most of the links are classified at the level of methodological knowledge. Strong connections mean that the knowledge structure is well-justified and thus it is easy to navigate, meaning that knowledge is easily "reachable". Such a consolidated structure seems, however, to be a demanding task for students to achieve, even though they admit its advantage in usability of knowledge.

## Discussion: Implications for Teaching and Learning

The main goal in physics teacher education is to foster the formation of organised knowledge structures which is often mentioned to be characteristic of expert-like knowledge (Chi et al., 1981). Concept mapping is widely used as a helpful tool for organising knowledge structures. The advantages of such representations and ideas how they can be utilised in teaching physics are shared in many previous studies (Yin et al., 1996; Ruiz-Primo & Shavelson, 1996; van Zele et al., 2004; Ingeç, 2009). However, the relational structure between physics concepts is much easier to present by using procedural connections (Koponen & Pehkonen, 2010) instead of traditionally used propositional links. The principles in which concept maps are produced need to be revised in order to make them useful for physics teacher education since design principles based on procedural rules may actually help students to achieve expert-level knowledge (cf. Kharatmal & Nagarjuna, 2008).

The new method to evaluate links by their level of epistemic justification introduced here is suitable to visualise the degree of organisation and knowledge (cf. method to evaluate the quality of students' arguments by Sandoval and Millwood, 2005). The recently introduced method for structural analysis of concept maps (Koponen & Pehkonen, 2010) has identified structural characteristics for well-organised knowledge structures. Structural analysis gives good scaffoldings but if done alone it is too shallow since it does not pay enough attention on content. However, the whole knowledge structure (content and structure) can be only as good as its bare structure is. In this study structural inspection of concept map is supplemented by the epistemic content analysis of links which offers a more reliable and transparent method to analyse physics concept maps. Moreover, the content analysis based on four epistemic levels is fine graded enough to reveal interesting differences. Compared to traditional method to analyse propositional knowledge represented in traditional concept maps, all the maps studied here would have scored very good points if scored by calculating the amount of appropriative links, level 1 and 2 (e.g. Novak & Gowin, 1984; Ruiz-Primo & Shavelson, 1996). However, when now two more levels (3 and 4) are taken into account, it is revealed that the highest epistemic level is very demanding to reach and only a fraction of students manage to have command to that aspect of knowledge. The cases examined here show that even in the advanced level of studies, the knowledge structures are still somehow fragmented and the overall justification skills are not as organised as they could be. Also, if one remembers that the concept maps represent the connections which are thought to be related to teaching all this means also how information becomes introduced in teaching. Good and strong links mean good information flow, poor links disruptions in flux of valid and justified information. These strengths/weaknesses of the basic structure are important for practical teaching, because they prerequisite of good teaching and cannot be remedied by some other means (e.g. didactical, class room dynamical etc.)

The method for producing the concept maps discussed here has been applied in physics teacher education; feedback from the students on its use has been appreciative, many students have noted the advantages of being able to visualise complex conceptual connections by using the concept maps. Most students found concept mapping a really helpful tool to organise pieces of information and constructing a clear picture about physics. They commented the usefulness of concept mapping for example in this way:

> "The content of the course has been very good. Especially, making the concept map with other [students] has helped me to perceive the hierarchy within physics concepts. Electromagnetism which I have found to be the most difficult subject in physics has begun to come across pretty convenient."
> "[Concept mapping is] really useful also in future, they nicely tie things together, and it is easier to perceive and remember things with a concept map."
> "They [concept maps] made me think how physics [knowledge] is really made up and how things are connected, it gathered up the bit fragmented knowledge I already had about those things."

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Some students were not too pleased with concept mapping because it felt somehow troublesome and laborious way to work. But despite that, they still found it useful.

> "Even though it [making the map] was sometimes very tedious, I think that eventually the electromagnetism has been organised in our heads much better than before making the map."
> "After some resisting at first I found them [concept maps] useful and I even learned to like them. When constructing a map you detected things you would not even catch on to think without a map."

In summary, the feedback shows that the mode of working fulfils many of the requirements for a successful organisation tool. In reaching this objective it has been highly important that the students are motivated to work towards common goal.

**Conclusions**

An overview of the utility of concept mapping in physics teacher education is discussed in this study. New design principles and analysing methods are suggested in such manner that concept maps are made useful in organising physics knowledge in higher education. The aim of such presentations is to consolidate the knowledge structure so that students are able to justify the procedural nature of the connections between physics concepts and laws. Focusing on the procedures certainly makes the students' command of the subject area visible, but also helps to foster reflective thinking during the learning process. The cases (concept maps) studied here covered the basic concepts and laws in the context of electrostatics and electromagnetism. The maps were produced by students, who attended on a course for physics teachers in a teacher preparation programme. The suggested design principles based on procedural rules, which are the basic procedures to form new concepts in physics, actually help students to achieve expert-level knowledge. The method for producing the concept maps discussed here has been in use in physics teacher education for some time and students have noted the advantages of using concept maps to visualise complex conceptual connections.

The first research question can be now answered on basis of the weighted structure. The analysis of justification of arguments shows that the structure and content of a concept map, so that the graphical structure is a reflection of contents dependence on structure, can be analysed. Such an analysis shows the fine-grained nature of epistemic justification and how students manage to fulfil the different levels of justification. It turns out that the highest levels are very demanding to reach and even in the advanced level only a fraction of students manage to reach there. The cases examined here show that even in the advanced level of studies, the knowledge structures are still somehow fragmented and the overall justification skills are not as organised as they could be. The links are quite plausibly justified, but they do not build up a consolidated overview of this subject matter. The results of the study provide a reliable and transparent method to monitor the students' advancement in their skills in introducing new concepts in physics teaching and in building the convincing justification schemes for the purposes of teaching and the planning of teaching. The structural characteristic and the accompanying epistemic levels of justification, and how they interplay in order to produce well-justified knowledge-ordering patterns, provide also the means to define and recognise the organised knowledge, and to make transparent how such organisation becomes established.

The second research question about the utility of such organisation tool is answered through the answer in the first research question and student feedback. The analysis of maps and the positive results which show that students manage to organise their knowledge so that the epistemic requirements are fulfilled shows that from instructors' point of view the goals are reached. The student feedback shows that student themselves also noted the advantages and their development in knowledge organisation, and the role of maps in facilitating it. This, of course, is important for self-reflection and meta-cognition. With this kind of deeper understanding of what the organisation of knowledge might mean and how it will be recognised, educators and instructors are better equipped to foster and also to monitor learning, which aims at supporting the formation of well-organised and ordered knowledge structures in teacher education.

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