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# Didactical reconstructions in knowledge organization and consolidation in physics teacher education

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**Abstract.** Physics teachers have an essential role in forming the attitudes and conceptions of future citizens toward science and technology, as well as in educating the future generations of scientists. Therefore, the physics teacher education must guarantee the best available education to pre-service physics teachers; sound knowledge of physics should be combined with a good understanding of the didactical and pedagogical aspects of teaching and learning. The situation is often that after university physics courses, the pre-service physics teachers' knowledge is still quite fragmented and incoherent. They also often lack the concept formation perspective to physics knowledge. I discuss here a research-based instruction approach that is developed for pre-service physics teachers for consolidating and organizing their subject matter content knowledge. In the core of the approach are graphical tools called didactical reconstructions of processes (DRoP) and structure (DRoS). The idea behind the reconstructions is that "new" physics knowledge is always constructed on the basis of previous knowledge. This leads to a network of quantities and laws, where the experiments and models construct the connections between the physics concepts. Finally, I discuss the implementation of didactical reconstructions in instruction and show that the didactical reconstructions help students to organize and consolidate their knowledge.

## 1. Introduction

Physics teachers have an essential role in forming the attitudes and conceptions of future citizens toward science and technology, as well as in educating the future generations of scientists. Therefore, the physics-teacher education must guarantee the best available education to pre-service physics teachers. The backbone of physics teacher's expertise is the sound subject matter knowledge of physics. In addition, this should always be combined with a good understanding of the didactical and pedagogical aspects of teaching and learning. However, often after university physics courses, the pre-service physics teachers' knowledge is still quite fragmented and incoherent [1-3]. Physics teacher's subject matter knowledge has also its own requirements compared to the subject matter knowledge of physicists, especially understanding the process of physics knowledge formation, that are not usually addressed in pre-service physics teacher education. Therefore, the main challenge of pre-service physics teacher education is to provide opportunities and resources for pre-service physics teachers to (re)organize and consolidate their physics knowledge into larger, coherent and meaningful structures [4]. In order to meet the challenges discussed above, a teaching approach using didactical reconstructions of physics knowledge were developed. The didactical reconstructions and their implementations are introduced and discussed in detail in previous research [see 5-10] and here, a concise overview of them is given.

## 2. Physics teacher's subject matter knowledge

Besides knowing or understanding the concepts of physics and being able to apply them in problem solving, physics teacher must understand the origin of the concepts or be able to reconstruct it. Often the starting point is the law or the equation, where the concept (quantity) appears and the definition of the concept is the law or the symbolic relation of the concept to other concepts. Then, if student is able to solve problems using the concept, it is interpreted that student understands the concept. For a physics teacher, this is not enough. The physics teacher must understand, how the law at first place was formed or can be formed. Similar idea of teacher's subject matter has been also been expressed by Shulman [11], when he discusses that the structures and organization of knowledge are part of the subject matter knowledge. This raises the epistemological perspective of knowledge formation in the center of teacher's expertise.

Studies that examines expert's knowledge, emphasizes that expert's knowledge is connected and organized around important concepts and ideas that guide thinking [cf. 3, 12, 13]. Likewise, Shulman discusses that teacher must know the essential and central topics of the discipline and also distinguish them from the less important concepts [11]. This is desirable knowledge structure for a physics teacher too. However, how this kind of knowledge structure can be achieved (the epistemological perspective), is less discussed.

In summary, in addition to knowing (understanding) the concepts and facts of physics, a physics teacher must be able to answer the questions:

- How we know what we know?
- How the concepts and knowledge structures are formed or can be formed?
- How the knowledge relates to knowledge within the discipline (or knowledge of other disciplines)?
- What are the most important concepts of the discipline or a specific topic?

Physics teachers' organized and consolidated subject matter knowledge means that teachers' understand how physics concepts can be formed and how they are related to other concepts. This requires that the concepts are introduced in logical order and in relation to each other, this also brings coherence in teaching or what is learned. The coherence also forms from the recurring knowledge forming processes. The main epistemological or methodological processes that forms the concepts or can be used for forming the concepts are experimentation and modelling [5, 8, 10]. Although the phenomenon of interest and the concepts change in different situations or topics, the procedure itself have recurring features. For instance, in case of experiments, one can reconstruct a path from observations of qualitative laboratory experiments through qualitative experimentation and quantifying measurements to experimental laws [8-10]. This path can be seen also in the didactical reconstruction of processes (DRoP), which is discussed below.

## 3. Didactical reconstructions of processes and structures

The didactical reconstructions are reorganizations and simplifications of physics knowledge produced for the purpose of consolidate physics subject matter knowledge in way that it enhances physics teacher's expertise. It means that besides taking into account the physics concepts, they emphasize the processes that (re)construct the concepts and further, support the (re)organization of physics knowledge structures.

The context of pre-service physics teacher education, for which the didactical reconstructions were developed, is such that the pre-service physics teachers have already studied the introductory and/ or intermediate level university physics courses. The pre-service physics major teachers have usually studied the introductory and intermediate physics courses (around 70 cr) and the pre-service physics minor teachers have studied the introductory physics courses (around 25 cr)[1]. Then they enter the physics teacher courses, which include such courses as concept formation of physics, school laboratory course for teachers and history and philosophy of physics. In the course "Concept formation of physics" the didactical reconstructions are introduced to pre-service teachers. In figure 1, the development of physics

[11] The pre-service physics major teachers study physics altogether 130-140 cr and the pre-service physics minor teachers at least 60 cr.

teacher's subject matter knowledge is sketched concerning the didactical reconstructions. As discussed earlier, the pre-service teachers still have a fragmented view of physics: they know different concepts, definitions and laws, but the bits and pieces do not form coherent knowledge structures. They are also unable to explain or justify how a specific concept or law is obtained or can be obtained. The didactical reconstructions are aimed for correcting the situation. A solid and organized view of physics knowledge is needed in teacher's profession in order to plan physics instruction and to adjust the level suitable for the pupils or students. This planning and adjusting of subject matter knowledge are addressed by didactical transpositions [14] or pedagogical content knowledge (PCK) [11]

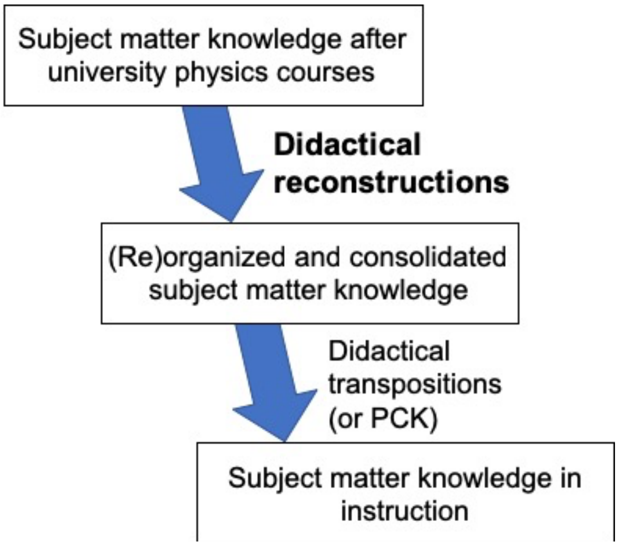


Figure 1. Transformations of subject matter knowledge concerning didactical reconstructions.

The didactical reconstructions are based on the generative knowledge justification, which means shortly that experimentality and modelling are the central procedures or methodologies that construct the physics knowledge and they do it in an intertwined way [5, 10]. For practical purposes, the didactical reconstructions are presented in a visual form of flow charts and concept networks, because the visual representations have proved to be effective in supporting the construction of knowledge structures [e.g. 1, 15].

When the didactical reconstructions are applied to a certain topic, an analysis of content structure is done. Although the didactical reconstructions are not intended to be applied in actual school teaching as such, the important ideas of the topic from the perspective of the future profession as a teacher is kept in mind as Duit, Gropengießer and Kattmann has discussed in the first step of their Model of Educational Reconstruction [16]. Also, the cognitive-historical analysis [17] has been applied didactical way in order to preserve a kind of authenticity of the knowledge formation process [7]. Next, the didactical reconstruction of processes (DRoP) is introduced first and the didactical reconstruction of structures (DRoS) after it, because the processes create the structures.

### *3.1. Didactical reconstruction of processes: DRoP*

Didactical reconstruction of processes represents the knowledge-generation process based on the interplay of experiments and models. The process is simplified into eight steps of knowledge construction. These steps are schematically summarized in the flow chart shown in Figure 2. The eight steps are [5, 6]:

1. *Observation and identification of phenomenon*. A phenomenon is identified through qualitative laboratory experimentation, which is guided by already known theory through models.
2. *Qualitative experimentation*. Experimentation helps to observe and find the changing and constant properties (or qualities).

3. *Qualitative dependency*. The result of the qualitative experimentation is a qualitative dependency, which forms the basis for designing quantifying measurement.
4. *Model system and measurement*. Quantifying measurements are designed based on the qualitative dependencies and the model for measurements. Experiment is modelled.
5. *Representation*. The measurement results are represented in a graph.
6. *Experimental law and model representation*. The new experimental law is justified and interpreted in light of earlier knowledge, i.e., theory, through modelling.
7. *Extension of theory*. The new tentative law is annexed to existing theory though generalization.
8. *Interpretations and predictions*. The law is tested in different situations in order to validate it.

In practice, the DRoP serves as a graphical tool, which helps pre-service physics teachers to recognize the important processes and structural features of knowledge construction and learn to use these features to give ordered form for their learning and also teaching [5]. After applying the DRoP to a certain topic, the pre-service teachers should be able to answer the questions: “How we know what we know?” and “How the concepts are formed or can be formed?”. In practice, the pre-service teachers are filling the boxes and the links at the general level and they supplement it with a detailed description of the steps, for an example of this, see [7].

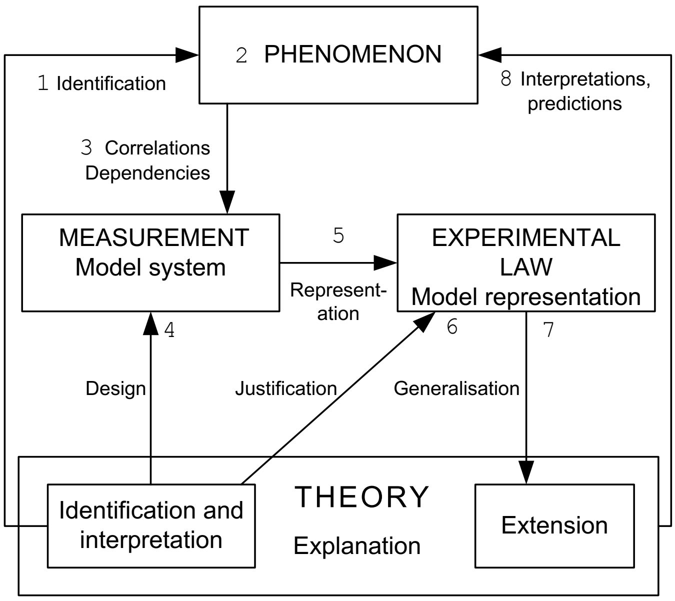


Figure 2. The schematic representation of DRoP [6, p 795]

*3.2. Didactical reconstruction of structures: DRoS*

In DRoP, ”new” physics knowledge is always constructed on the basis of previous knowledge. When the process is repeated or applied to new phenomena, it leads to a network of quantities and laws, where the experiments and models construct the connections (laws) between the physics concepts. This network has a structure and an order, in other words, a hierarchy. The emerging concept network is the DRoS, the forming process of DRoS is tried to capture in figure 3.

The nodes of the network are quantities (presented in rectangular shapes) and sometimes phenomena (rounded corners) and through DRoP (hexagonal shape) the quantities are related forming laws (oval shapes). Often, when the quantities are related in the form of law, a new quantity is established. For example, the relation of electric current and voltage forms the Ohm’s law and at the same a new quantity, resistance, is established [8]. The main features of the DRoS are [5]:

- It is an ordered node-link representation that includes the major quantities and laws of a certain topic. Ordering emerges, because a new quantity or law is constructed based on previous quantities or laws.
- The DRoP defines which concepts are connected, and it gives the direction to the link.

- The different kinds of concepts are distinguished from each other using different node shapes.

In practice, instead of going through the DRoP with its eight steps, the most relevant (quantifying) experiment or modelling procedure is described. In instruction, when pre-service teachers are constructing the concept networks, they describe the nodes in a separate supplement. After applying the DRoP to a certain topic, the pre-service teachers should be able to answer the questions:

- How the knowledge structures are formed or can be formed? Constructing the concept network and its concised form as node-link-representation forces pre-service teachers to think about the forming of the knowledge structure
- How the knowledge relates to knowledge within the discipline? Although the experimentation and modelling concerns different phenomena and concepts, they have recurring features and processes, so there is procedural or methodological coherence within the different topics of the discipline. The concepts' meanings are also augmented within physics, for instance, the force is first introduced in mechanics and later it is applied in electromagnetism.
- What are the most important concepts of the discipline? When the constructed concept networks are examined, it can be inferred, that concepts, which have a high amount of links are central, and concepts with only one link are probably peripheral.

The DRoS makes possible to examine different topics at various depth and range. It can be used for examining the development of a specific concept such as in case on temperature [9] or it can be used for examining a large network of quantities and laws such as in case of electromagnetism [5, 18].

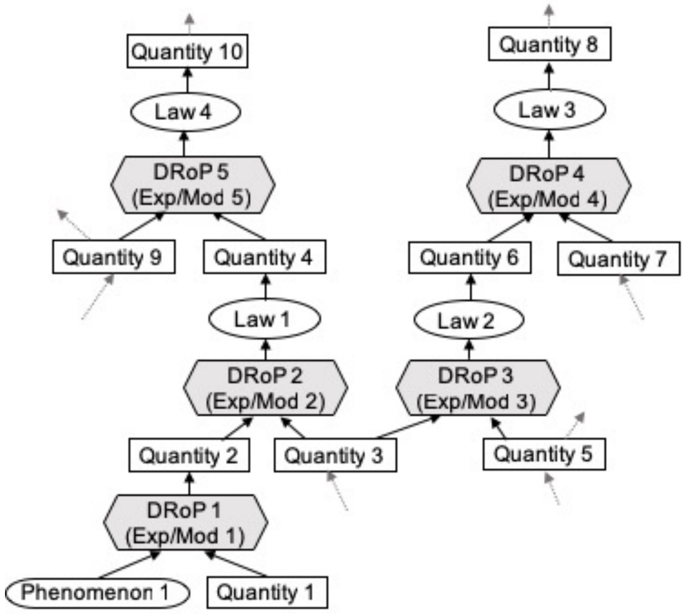


Figure 3. The schematic representation of DRoS.

## 4. Didactical reconstructions in practice: summary of evidence from case studies

The basic implementation of the didactical reconstructions in instruction of pre-service physics teachers is presented in figure 4. The instruction starts with introducing the DRoP and DRoS and discussing the ideas behind them, such as concept formation process in physics. Then pre-service teachers apply the tools in a certain topic or context. In instruction the topic is discussed at a general level, and pre-service teachers have to adjust and apply the information from instruction to their flow charts or concept networks. The pre-service teachers also get feedback from their peers and instructor about their initial flow charts or concept networks. On the basis of these, the pre-service teachers revise and finalise their initial flow charts or concept networks. Usually, the pre-service teachers construct the charts or networks in pairs or in small groups, so that they have a lot of opportunities to discuss and reflect their knowledge. For research purposes, individually done charts or networks with their supplements have been collected.

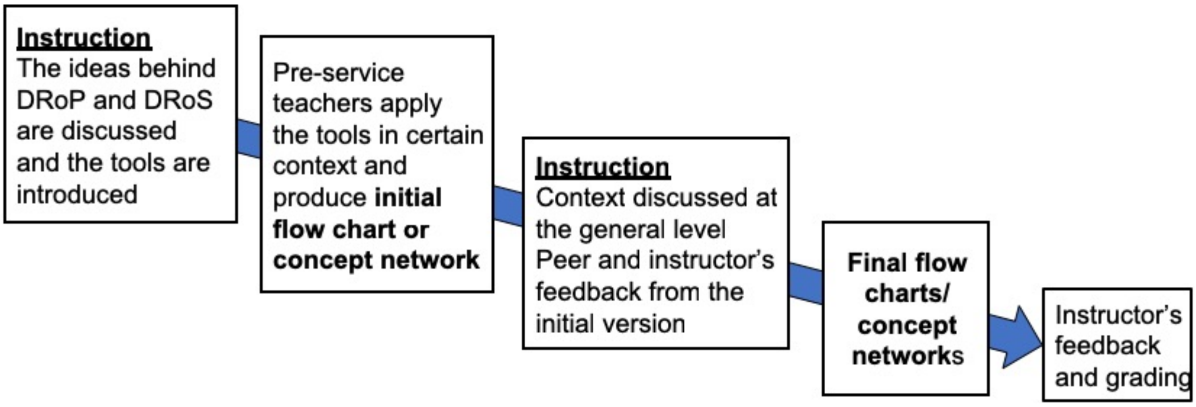


Figure 4. The implementation of the didactical reconstructions in instruction.

*4.1. DRoP in case of electromagnetic induction law*

The DRoP has been applied in case of (re)constructing the electromagnetic induction law [6, 7]. The data consisted pre-service teachers' initial and final flow charts and the written supplements explaining the flow charts. Part of the pre-service physics teachers was also interviewed. The results of the analyses of the initial reports showed that although the pre-service teachers had already studied the topic of electromagnetic induction, it was poorly understood and the descriptions of the forming of the induction law were incoherent and poorly justified. In final reports, in most of the cases, the justifications were improved. Also, the use of experiments and models in the justifications improved greatly and, in many reports, there was a recognizable path from qualitative laboratory experiments of induction current to the electromagnetic induction law. It has to be noted that the final products were not perfect and often, there still was room for improvement. However, most of the times, there was a clear development from initial to final reports.

*4.2. DRoS in case of temperature*

In case of temperature, the DRoS was applied to examine the quantitative development temperature and how new ways of measure (define) temperature augments its meaning [7]. The data consisted pre-service teachers' initial and final concept networks, in addition, few pre-service teachers were interviewed. In figure 5, the schematic structures classified from pre-service teachers' concept networks are shown. Initial network structures were mainly centralized or fragmented, which means, that there was no recognizable development in temperature concept. Most of the final network structures were hierarchical, thus there was a developmental path from sensory experience and measuring the temperature from thermal expansion of liquids to measuring temperature with help of gas laws and defining the absolute temperature. the quality of concepts in the concept networks also improved. The study showed that the idea of evolving meaning of a concept was at first, unfamiliar to pre-service teachers; the concepts just exist. The DRoS in case of temperature helped pre-service physics teachers to understand the progressive nature of physics concepts and the role of experiments and models in it.

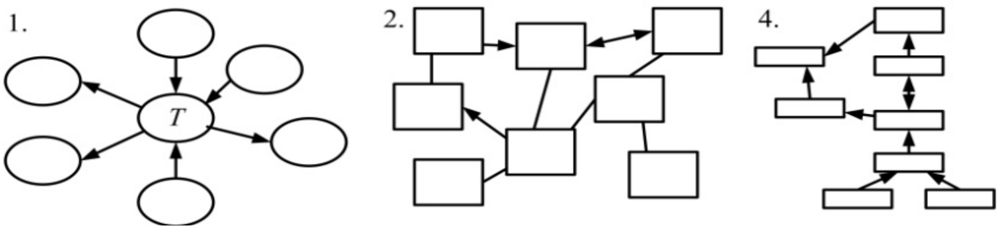


Figure 5. The schematic structures of pre-service physics teachers' concept networks. 1. Centralized, 2. Fragmented, (3. Mixed (1. or 2. and 4.)) and 4. Hierarchical.

*4.3. DRoS in case of the network of electromagnetism*

The idea of DRoS has also been applied to capture the order and relations of electromagnetism concepts [5, 18]. The data consisted pre-service physics teachers' concept networks of electromagnetism. The concept networks were classified to three different structures: webs (richly connected), necklaces (loosely connected) and chains (poorly connected). Most of the networks were either loosely or poorly connected and expert-like web-structures formed only one fifth of the structures. The analysis of pre-service physics teachers' explanations and justifications of the relations of the concepts also showed that pre-service teachers struggled in providing sound explanations and justifications. In this case, the knowledge structure to be covered was larger, which could explain that the development and consolidation in knowledge was more moderate than in the cases discussed above.

## 5. Discussion and conclusions

The didactical reconstructions and their visual formulations function as metacognitive tools that forces pre-service teachers to think physics and its concepts from the perspective of what is it about and how the concepts are formed or used in physics concept formation. This goes beyond typical textbook definitions based on equations (laws). At the end, the laws can be treated in deterministic way and it improves the applicability of physics knowledge. However, in the beginning, when the learning process of physics concepts is still on, it is essential to approach the concepts and their relations in causal way and starting from the phenomena that they relate to. The didactical reconstructions provide order and hierarchy to physics concepts that can be utilized in teaching physics. However, it has to noted, that there is not just one right way of organizing the concepts, instead there are several good ways to do that. The didactical reconstructions help to find to answers to the subject matter knowledge questions introduced earlier and the pre-service physics teachers also appreciate them:

> This is useful in a way that it is important for a teacher to perceive these big pictures and a kind of hierarchy of laws and their relations…and a sort of order in knowledge construction. [6]

> Learning physics is like climbing upwards step by step, and every step is needed. This is useful [making concept networks] because it organizes thinking and one easily recognizes in what step something is missing. It is possible to build a whole structure of what one has learned. [9]

The results show that the opportunities and resources invested in these case studies of applying the didactical reconstructions improve the pre-service physics teachers understanding on physics subject matter knowledge of the topics covered in pre-service teacher education. However, there is no time or resources to cover all topics. Yet, the feedback from pre-service teachers encourages us to think that the time invested in few carefully chosen topics helps pre-service physics teachers to develop their thinking from fragmented collections of definitions towards more coherent knowledge structures. The pre-service teachers have also learned more deeply the topics covered using the didactical reconstructions; besides the factual and definitional knowledge, they have learned to (re)construct their knowledge and reflect the forming knowledge structures. The pre-service teachers have learned to understand the role of experiments and models in knowledge production and they have improved in their knowledge justification. In short, the didactical reconstructions have helped pre-service physics teachers to consolidate and (re)organize their subject matter knowledge.

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