Conceptual Patterns of Changes in University Students' Explanations During DC-Circuit Tasks

Terhi Mäntylä, University of Tampere, terhi.mantyla@uta.fi
Tommi Kokkonen, University of Helsinki, tommi.kokkonen@helsinki.fi

Abstract: At the advanced level of learning, the ability to use relational knowledge becomes essential. In this study, the changes in the use of scientific concepts in the university students' explanations were examined in the context of direct current (DC) circuits. The students participated in three small group sessions with several predict-test-explain-tasks. The use of scientific concepts and their relations were analysed from session transcripts using content analysis and categories of explanatory power were formed. Then, the changes in explanatory power during DC-tasks were analysed and three categories of conceptual patterns were formed. In first category, no conceptual development occurred, students used simple explanations and were not able to apply relational knowledge. In second category, conceptual development occurred: students explanations became more scientific and their explanatory power increased. In third category, the students have learned to use relational knowledge and the conceptual pattern shows flexibility in providing explanations.

Keywords: concept learning, relational knowledge, explanatory power, cognitive utility, science education

Introduction

One difficulty in learning advanced scientific concepts are that students often have idiosyncratic, intuitive knowledge about the target concepts that can be wrong from the scientific point of view. Hence, learning entails that learner modifies his or her prior knowledge, which is difficult and can take a long time. Furthermore, learning physics, for example, entails learning a complex knowledge system (i.e. theory), which consists of concepts and information about the concepts' covariation, which is embedded in laws and models of physics. Learning of scientific concepts differs from learning everyday concepts (such as "a dog") typically examined in cognitive science in that scientific concepts (or *nomic concepts* in Kuhn's terms) are out of reach of direct inspection; instead complex situations of applying laws and theories (relational knowledge) are used, which means that several scientific concepts are used at the same time (Andersen, Barker & Chen, 2006; Hoyningen-Huene, 1993). Concept learning also typically involves solving gradually more challenging problem situations, which involve the application of the nomic concepts and the related laws (Hoyningen-Huene, 1993). The learning has occurred, when the concept is used correctly, i.e. in the way of the scientific community (Hoyningen-Huene, 1993). An important aspect in this is that the correct use of the concept requires also the correct use of the related concepts, because a concept is always a part of a conceptual network, a "lexicon" of a domain (Hoyningen-Huene, 1993). Here the learning of scientific concepts are examined in the contexts of DC-circuits, where university students solve gradually more challenging tasks, where they have to predict and explain the brightnesses of the bulbs. The research interest is to see how scientific concepts and their relations change in university students' explanations during solving the tasks and how it relates to their developing understanding of DC-circuits.

Background

Within science education, recent research about students' concept learning and understanding has paid attention to students' understanding of the various relational patterns that connect the concepts together. It has been found that students' are often inclined towards simple linear causality and chain-like relational patterns (A causes B which causes C and so forth) instead of more complex patterns needed to learn the concepts (Kokkonen & Mäntylä, 2017; Perkins & Grotzer, 2005). In analyzing university students' explanations concerning concepts related to DC circuits, we identified three generic relational patterns and used these to analyse students' explanations and the concept learning process. It seems that in the university context, the key element in learning the concepts and constructing successful explanations is flexibility in using and modifying different relational patterns (Kokkonen & Mäntylä, 2017).

Furthermore, recent research in cognitive science has focused on the role of relational knowledge in concept learning. It has been suggested that relations and relational knowledge form a fundamental part of our understanding of the world and underlie many of our higher cognitive competences, such as categorization, reasoning and planning (Goldwater & Schalk, 2016; Halford et al, 2010). So-called relational concepts are concepts whose meaning is based on the relational structure of the concept or on the relations the concept bears to other concepts (Gentner, 2005). Goldwater and Schalk (2016) have proposed that research on relational concepts offers a fruitful way to examine concept learning especially in STEM context. For example, in physics, it possible to design authentic problem solving contexts, that are rich and complex regarding the amount of concepts and their relations and at the same time restricted and controllable (only certain concepts can be applied and there are clear results to the problems).

Recent research has only begun to shed light on the cognitive processes related to learning of advanced concepts in science (Authors, 2017). One important open question concerns how the connected, coherent and abstract knowledge structure that is the hallmark of expert knowledge is learned (Goldwater & Schalk, 2016; Kokkonen, 2017). Towards this end we examine learning of concepts regarding DC circuits, which can be taken as an instance of learning a simple theory. In this kind of context, which entails learning multiple concepts and their interrelations, using the whole "lexicon" in explanations is not always effective. Instead, the simpler explanation could work better. This means that at the certain level of learning, the cognitive utility (Ohlsson, 2009) plays a part. Cognitive utility can be described as a trade-off measure between the complexity and the explanatory power of a concept or an explanation model (Ohlsson, 2009). The underlying idea is that in simple situations, simple explanations are adequate and more complex ones are deemed necessary only in contexts that are sufficiently complex. Complexity of a concept (or an explanation) is here thought to arise from its relational complexity (Halford et al, 2010).

Methodology

The research question is: What are the conceptual patterns of students' explanations during the DC-circuit tasks?

The context of the study was a course called "Physics concept formation" aimed at pre-service physics teachers at the physics department. The participants were 2nd to 4th year university students who already had studied the introductory physics courses. The students participated in three small group sessions consisting predict-observe-explain-tasks about the brightnesses of the bulbs in DC-circuits. There was a week between each session. First two sessions consisted of gradually more challenging tasks (e.g. unindentical bulbs instead of identical bulbs). The third session consisted of two repetition tasks and one task in new context, where the connections of batteries were varied instead of the connections of bulbs. The reason for repeating the previous tasks was to make possible the evaluation of the stability of the changes emerged in the explanations during the first sessions.

The sessions were videoed and transcribed. The transcripts were analysed using content analysis, which concentrated on the use of different scientific concepts and their relations in students' explanations. The scientific concepts in this study refers to the relevant quantities related to the DC-circuits: electric current, voltage, resistance and electric power. The analysed data consists of three student groups (two 3 member groups and one 4 member group), altogether 10 students. The three sessions from the four-member group were cross-checked (approximately one-third of the material). Inter-rater agreement of 73 % was considered adequate. The explanations were categorized regarding their explanatory power as it is presented in Table 1. Here the explanatory power is determined by the number of scientific concepts and the relations between the concepts. The explanatory power describes how many different situations can be explained using a certain explanation. The explanatory power is also tied to the complexity of explanation, usually the simpler the explanation (fewer concepts, less relations), the less situations can be explained. In addition, it is also less scientific. The explanation in category of explanatory power at the level 1 does not use a scientific concept and therefore, it has a very limited explanatory power. At the level 5, the explanation contains four concepts, it is the most complex explanation. However, it is also the most scientific one and it explains all tasks. The students' explanations through the different tasks in sessions were presented according to their explanatory power. Further, these representations were categorized through different conceptual patterns of changes that occurred during the tasks.

Table 1: The categories of explanatory power of explanations. The number or letter in the parentheses refers to category of explanation

Category	Description	Example
1	Rule of thumb, very limited explanatory power (Explanation S)	When the bulbs are in a series, they have the same brightness.
2	Only one concept is used, limited explanatory power. (Explanations 1, 3, 5 and 8	There is **current (*I*)** in the circuit, which makes the bulbs burn. There should be same loss of ***voltage (U)***, if the bulbs are similar.
3	Two concepts are used, simple tasks can be explained. (Explanations 2, 4, 6 and 9)	There is **current** in the circuit, which makes the bulbs burn. Its magnitude depends on the **resistance (*R*)**.
4	Three concepts are used, the model is scientific.	There is **current** in the circuit, which makes the bulbs burn. The current depends on the **resistance** of the circuit and the **voltage** between the ends of the battery or component. If they have have the same ***resistance*** and ***voltage***, ***current*** should be the same.
5	Four concepts are used, the model is scientific and the most complex one. All tasks can be explained.	The brightness of the bulbs is determined by their **electric power (*P*)**. Power depends on **current**, **voltage** and **resistance**, which in turn depend on each other.

Findings

In Figure 1, explanations of two students from the same group are presented as examples of results of analysis. As can be seen, in case of student S7, the amount of explanations decreased when the tasks became more challenging. On the other hand, student S8 provided more explanations and in various levels of explanatory power. The emerging overall conceptual patters of changes in explanations were identified and categorized on the bases of the individual analysis such as presented in Figure 1.

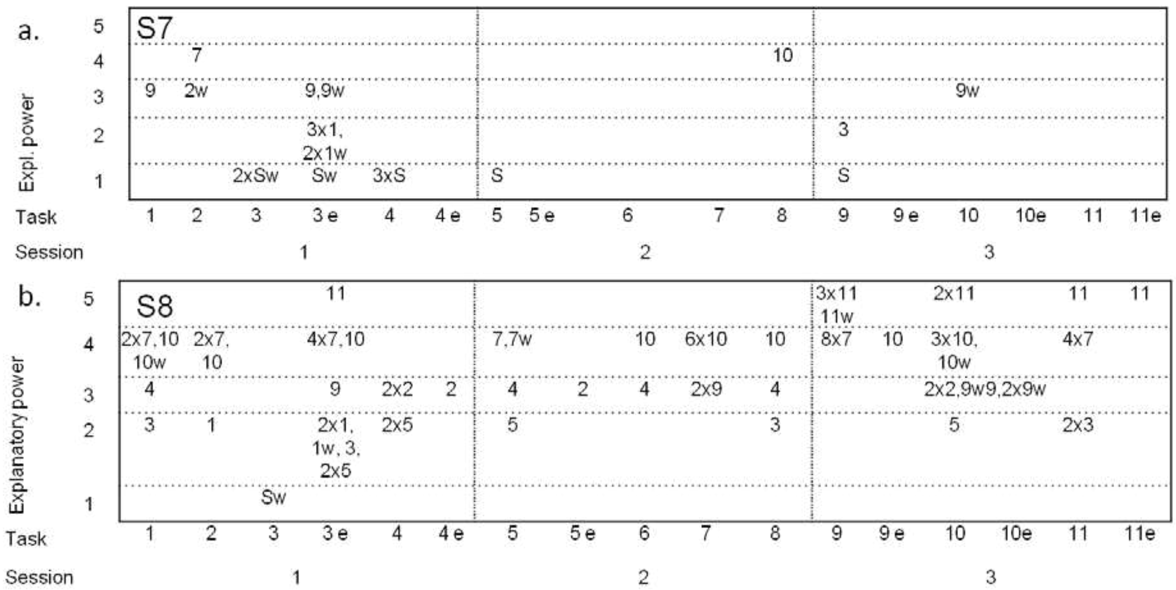

Figure 1. Students S7's (a.) and S8's (b.) explanations (S, 1-11) during the DC-tasks categorized by their explanatory power. w refers to false prediction or explanation. Few examples of explanations were given in Table 1 (S, 1, 2, 7 and 11).

There were three different categories of conceptual patterns of changes students' explanations according to the explanatory power and their schematic features are presented in Figure 2. The categories are:

1. *No development* (3 students). Although the explanations vary in different tasks, they are at the same level of explanatory power (1-3). The explanations are (rather) simple. Therefore, no conceptual development occurs. The students were not able to apply the relational knowledge to their explanations. An example of this is student S7 presented in Figure 1a.
2. *Conceptual development* (5 students). The explanatory power of students' explanations increases when they solve gradually more challenging tasks. The explanations become more complex and scientific, students learn to apply relational knowledge to their explanations and conceptual development occurs.

3. *Conceptual mastery* (2 students). Students use explanations with varying levels of explanatory power already from the first tasks. The pattern reveals the flexibility to adjust the explanations: sometimes it is easier to use simpler explanation instead of more complex and scientific explanation. This is seen as a sign of cognitive utility and thereby, it is concluded that these students already master the topic. An example of this is student S8 presented in Figure 1b.

The explaining and understanding the given tasks requires use of relational knowledge. However, the students in first category are still in the early stage of learning to use the relational knowledge. The students in second category are learning during the tasks to apply the relational knowledge, nevertheless, they are still in the stage of learning compared to the conceptual pattern of students who already master the topic.

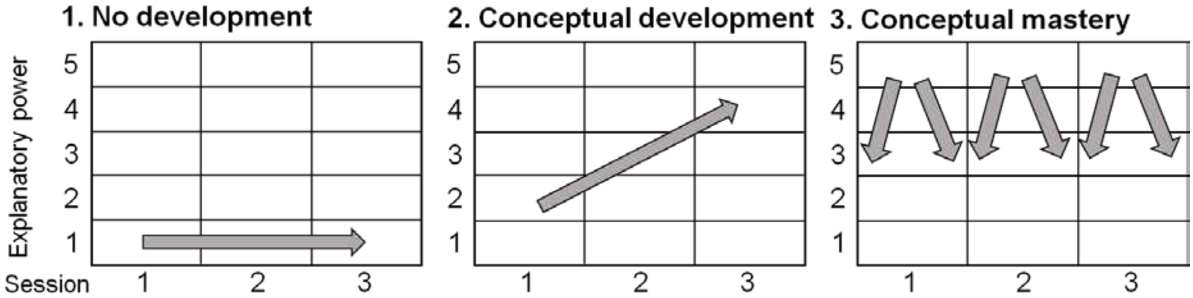

Figure 2. Schematic features of conceptual patterns of changes in students' explanations.

Conclusions

At the advanced level of learning, the key issue is to learn to use relational knowledge, which means the use of scientific concepts relations with each other in form of models, laws and more broadly theories. The findings show, that the gradually more challenging DC-circuit tasks can help students to develop their theoretical understanding. At the level of mastering the use of relational knowledge, new phenomena, such as cognitive utility emerge and there is flexibility of providing explanations at different levels of complexity. The initial findings of this study suggest that more effort should be put in the role of relational knowledge in the advanced level of learning. However, the research is still in progress and further data analysis is still ongoing. There could be cases, were students only uses simpler explanations although they master more scientific explanations. One challenge in analysis is that some students are rather inactive during the group sessions and the analysis relies on students' discussion.

References

Andersen, H., Barker, P., & Chen, X. (2006). *The cognitive structure of scientific revolutions*. New York: Cambridge University Press.

Gentner, D. (2005). The development of relational category knowledge. In L.Gershgoff-Stowe, & D. Rakison (Eds.), Building object categories in developmental time (pp. 245-275). Hillsdale, NJ: Lawrence Erlbaum.

Goldwater, M. B., & Schalk, L. (2016). Relational categories as a bridge between cognitive and educational research. Psychological Bulletin, 142(7), 729-757.

Halford, G. S., Wilson, W. H., & Phillips, S. (2010). Relational knowledge: The foundation of higher cognition. Trends in Cognitive Sciences, 14(11), 497-505.

Hoyningen-Huene, P. (1993). *Reconstructing scientific revolutions: Thomas S. Kuhn's philosophy of science*. Chicago: The University of Chigago Press.

Kokkonen, T. (2017). Models as Relational Categories. Science & Education. doi: 10.1007/s11191-017-9928-9

Kokkonen, T., & Mäntylä, T. (2017). Changes in University Students' Explanation Models of DC Circuits. *Research in Science Education*. doi: 10.1007/s11165-016-9586-y

Ohlsson, S. (2009). Resubsumption: A possible Mechanism for Conceptual Change and Belief Revision. *Educational Psychologist*, 44(1), 20-40.

Perkins, D. N., & Grotzer, T. A. (2005). Dimensions of causal understanding: The role of complex causal models in students' understanding of science. Studies in Science Education, 41(1), 117-165.

Acknowledgments

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