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Active and spontaneous learning in a small group – a case of learning DC-circuit phenomena in the 3rd grade

Abstract

In this study, the learning of DC-circuit phenomena in a small group in the 3rd grade (9-year-olds) of a comprehensive school is scrutinised. The focus of the study is on the progressive nature of learning sciences, and especially on its active and spontaneous components. Learning in a small group is examined from the standpoint of pupil's talk. The article explores the small group's learning process for the basic components of DC-circuits, especially bulbs. This process is treated from the standpoint of developing the conception of "the brightness of the bulbs". In this study it is shown that even in the case of abstract subject matter, a small group can be a fruitful learning environment, where active and spontaneous learning can take place.

INTRODUCTION

If teachers are asked for the characteristics of a dream pupil in a class, the answer would probably describe a pupil who is keen to learn new things and participate actively in discussions during lessons. In practice, these kinds of activities are manifested for example by the questions the pupil asks during the lesson. According to Rop (2003), it is more common that pupils ask questions that are of practical importance to them, like; "do we have to know this for the test", whereas more thoughtful probing spontaneous questions like "what would happen if" are rarer. These "what would happen if" questions are more than welcome signs of so-called "active learning" that has been especially discussed in the social constructivist-oriented research literature. These questions are particularly important for pupils involved in learning abstract subject matter like a DC-circuit.

In this study one possible solution to promote and activate the learning involving DC-circuit phenomena is presented. As a teaching solution, learning is organised in small groups. This means that all phases of learning such as charting preconceptions, introducing the topic, experimenting and discussions about observations are realised in small groups. This teaching method is supposed to activate learning by giving pupils an opportunity to talk and think together as much as possible while doing experiments under the guidance of the teacher. Different tools for activating talk in small groups are used. In this study, teaching DC-circuits has been designed to highlight the pedagogical principles which *underpin pupils' active and observation-based learning as well as the wholeness of the DC-circuits.*

On the grounds of the research frame set the study seeks answers to questions concerning the developing conception, the brightness of the bulbs in the DC-circuits of the small group, and especially the active and spontaneous part of this process. The research questions are as follows:

1. What ideas do pupils use to account for, or to predict, the brightness of bulbs in DC-circuits?
2. How do their ideas develop through talking about a wider range of situations?
3. How does the active and spontaneous learning of the small group manifest itself in the learning process?

LEARNING PROBLEMS ASSOCIATED WITH DC-CIRCUIT PHENOMENA

According to the extensive research literature on learning DC-circuit phenomena, pupils in general have serious learning problems with understanding DC-circuit phenomena and distinguishing the main concepts from each another (Gunstone et al., 2009; McDermott & Shaffer, 1992; Shipstone et al., 1988; Duit & von Rhöneck, 1997; Millar & King, 1993). This study focuses on young pupils, whose learning of DC-circuit phenomena has not been studied to any great extent. The target group of this study, 9-10-year-olds, has not been of special interest (Georghiades, 2000). Science learning studies have generally concerned pupils of the upper level of comprehensive school, or older students. Also in the domain of DC-circuit phenomena, studies of learning difficulties have centred on pupils who have already finished the lower level of the comprehensive school. For example Shipstone's study (1984) examined 12-17-year-olds, in Cosgrove et al.'s (1985) study 10-18-year-olds, and Tsai et al. (2007) 13-16-year-olds were studied. Tiberghien's (1983) and Lee's (2007) studies are exceptions; in Tiberghien's study pupils in the age group 8-year-olds onwards, and in Lee's study 10-11-year-olds were scrutinised.

The learning problems associated with DC-circuit phenomena typically occur in the qualitative stage. Although pupils in high school can solve quantitative exercises, they do not understand how circuits function qualitatively nor can they apply the learnt concepts to a concrete circuit. Similar kinds of problems with understanding the function of circuits are also seen in younger pupils. Furthermore, there are many misconceptions associated with DC-circuit phenomena: it seems to be difficult for pupils to think about the effects of the circuit as a whole instead of those of its individual components. Typical examples of misunderstanding are considering the battery to be a source of constant current, and thinking that the current is used up by the circuit. The learning results of DC-circuit concepts tend to be weak and pupils' concrete observations of DC-circuit phenomena do not meet with their earlier conceptions (McDermott & Shaffer, 1992; Duit & Rhöneck, 1997).

However, the results reported are not unambiguous: for instance in one of our previous studies of 3rd, 6th and 9th graders in a comprehensive school (Kallunki & Lavonen, 2010) encouraging results were reported about pupils' qualitative understanding of the functioning of the DC-circuits. Our results revealed that although the theoretical explanations of DC-circuit phenomena, which have been obtained as results in typical mental model studies (e.g. Shipstone et al., 1988), might remain undeveloped, learning at the qualitative level of understanding could take place.

SOCIAL CONSTRUCTIVISM AND ACTIVE LEARNING

Learning together is one way to increase the activity of learning. Although learning must involve an individual's own process, discussing with others can make learning more effective. This philosophy belongs to the school of social constructivism that distinguishes between aspects of an individual's activity and a group's contribution in the learning process. This means that both an individual's own active learning process, and the group's interior discussion and negotiation of the meanings of concepts affect learning (Cobb & Yackel, 1996; McClain & Cobb, 2001). On the other hand, according to an extreme interpretation of social constructivism, it is not possible to differentiate between an individual's learning and the actions of a small group (Cobb & Bauersfeld, 1995). This kind of interpretation encourages using small group learning as a teaching approach.

Social constructivism, which has its roots in the work of Vygotsky and his followers, sees learning science as the process of learning the social language of science (Scott et al., 2007). From this viewpoint, for example, in small group learning talk and language are at the focus of learning, because they create meanings for the matter to be learnt. Vygotsky's salient concept, the zone of proximal development (ZPD) also includes an idea of learning as a social process, as it highlights the role of the mediation of a small group or a teacher (Shayer, 2003) in learning.

Social constructivist oriented perceptions about active learning also come out in Michael's (2006) summing up of the main research findings which underpin student-centred and active learning. The summary includes among others the following aspects: 1) learning involves the active construction of meaning by the learner, 2) individuals are likely to learn more when they learn with others than when they learn alone, 3) meaningful learning is facilitated by articulating explanations, whether to one's self, peers, or teachers. Furthermore, working in a group is said to activate learning because the group dialogue develops pupils' meta-awareness of their own understanding and learning process (Richardson, 2003). According to Lavonen (2002) discussing is especially important for familiarising pupils with a new domain of the natural sciences, when its role is to recognise phenomena and their properties. One other important stage in discussing is in making interpretations and conclusions on the basis of experiments. The purpose of discussions is particularly to guide pupils to conceptualise observations, and in this way to promote concept formation.

According to Collins and O'Brien (2003) in practice implementing active learning means paying attention to the educational methods used. This means for example applying activities that force pupils to reflect on new ideas, and to participate, think and solve open-ended problems. For example simulations and role-plays can be used. Also continuous assessment of the students' degree of understanding is important.

Small group learning has been advocated as one of a range of active learning strategies. In small group learning it is important that pupils in a group have positive interdependence on the other group members. They should understand that their own working helps other group members, and respectively they benefit from the work of others. In addition, it is important that everyone is responsible for their own work when a group's work is divided into personal tasks. The social skills of the group members and the inner-group processing of a task are essential for the successful completion of the task (Bennett et al., 2010; Bennett et al., 2004; Johnson & Johnson, 2002).

How can then active learning be identified? Is not every form of learning an active process? How is it possible to separate more active learning episodes from ones that are not so active? To answer the above-mentioned questions in this study, the activity of learning was evaluated by utilising Anderson & Krathwohl's (2001) thinking levels of pupils' talk. According to this line of thinking, particularly pupil's talk that manifests understanding, applying, analysing, evaluating, or creating, instead of purely remembering requires a higher level of thinking. In this study these higher-level thinking forms are paralleled with active learning. So, in this study the activity of learning is understood as something more than memorising that involves elements of processing the knowledge. Furthermore, in the classification of Anderson and Krathwohl (2001) there is one even higher level of thinking, i.e., the level of creativity. According to them creativity means reorganising learnt knowledge into a new pattern or structure. In this study we claim to see evidence of spontaneous learning when what is learnt is put to use in new kinds of ways or situations. In these situations the members of the small group independently made their own DC-based observations of, and conclusions about, phenomena that are not the primary interest of teaching at that moment utilizing the knowledge they have acquired during the instruction. Thus, the spontaneity of learning especially means pupil's unprompted expanding of the topic to be learnt.

PROMOTING ACTIVE LEARNING IN THIS STUDY

In this study learning was activated by constructing a small group learning environment, in which pupils talked, argued and negotiated about their conceptions of the topic while doing experiments, playing or solving problem tasks. Discussion was stimulated for instance with the aid of 1) special connection cards designed for this purpose, and 2) using different learning games like claim cards and a word explanation game. The aim was to encourage everyone to speak in order to promote learning and to get information about the pupils' different conceptions. Moreover, the goal of using a small group as a learning centre was to analyse the small group's learning during teaching. In these discussions the role of the teacher was to pull together and guide the discussion and thinking.

The connection cards that were used in this study are enlarged and laminated pictures of real elements of the electric circuit consisting of batteries and bulbs. The cards are used like real components of DC-circuit. They can be connected to form different kinds of circuits by adding or removing cards of bulbs or batteries. In this study, the pupils constructed different connections with the connection cards and discussed what kinds of DC-circuit phenomena would take place in the corresponding real connections. While most of the studies concentrate on experimenting with real connections (Borges & Gilbert, 1999), the interviews used in this study were done with the aid of connection cards. According to Kallunki (2008; 2009), using connection cards instead of real components is a new kind of situation for pupils, and really makes thinking more visible. Because the bulbs do not light in connections with the connection cards, nobody can be sure of the right answer – or at any rate, no one can demonstrate one's conception to be right – discussion is more democratic and more fragments of the topic to be learned are uncovered.

In this study the focus of learning was mainly on the social constructivist perspective, because the small group's learning was studied through the talk and discussions in the group, and the language used was analysed. However, the ultimate target of the analysis was to chart the developing processes of the small groups' conception, the brightness of the bulbs in the DC-circuit. The active and spontaneous parts of learning were especially focused on. This purpose fixes the focus on the conceptual development of understanding of DC-circuit phenomena taking place in the small group, where pupils are learning by sharing scientific ideas under the guidance of a teacher.

Figure 1. Connection cards used during the lessons.

Figure 2. Third-graders drawing hypotheses of an electric circuit. The hypotheses have been made with the aid of connection cards. In the figure electric circuits have been constructed with connection cards i.e. laminated pictures of bulbs and batteries. These cards have been connected with real conductors.

ANALYSING THE PROCESS OF LEARNING SCIENCE

The purpose of the analysis is to uncover the different embryos and more developed fragments of the conception, the brightness of the bulbs in the DC-circuits. In the analysis all the different *expressions describing the pupils' own empirical observations in which the observed phenomenon or property to be learned is identified, classified, compared or predicted qualitatively* are taken into account. In addition, also all *theoretical explanations of the observations* that pupils represent are ruled in the analysis.

The analysis frame is based on Gilbert's and Nersessian's model-related and Kurki-Suonios' empirical-based approaches to learning natural sciences (Gilbert et al., 2007; Nersessian, 2002; Kurki-Suonio, 2011). From Gilbert's model-related approach has been adopted the idea of models developing from pupil's lower level models to higher level scientific models (Gilbert, 2004; Gilbert & Boulter, 1998). Also Gilbert's idea of highlighting the meaning of talk to change originally individuals' private and personal cognitive representations to expressed representations (Gilbert et al., 2007) is utilized. Nersessian's model-related approach can be seen in the analysis in searching for spoken expressions of sorting out natural phenomena: "in categorizing experiences we sort phenomena, noting relationships, differences, and interconnections among them. A conceptual structure is a way of systematizing, of putting concepts in relation to one another in at least a semi – or locally – coherent manner" (Nersessian, 2008). Kurki-Suonios' empirical-approach, which is a "practical teaching philosophy" of teaching and learning physics (Kurki-Suonio, 2011) has been used as a source of concept categories used: terms of doing empirical observations and identifying, classifying, comparing or predicting that highlight the meaning of empirical observations in modelling come from Kurki-Suonio.

In this study, qualitative understanding and qualitative concept formation that are defined as different expressions describing pupils' own empirical observations are analysed. Thus, the focus is on the way the pupils express and describe these things in their own words. In the case of DC-circuit phenomena, qualitative concept formation can appear for instance in the form of comparing different brightness of bulbs after making changes to the circuits, identifying the components of lighting a bulb or observing the heating up of a battery.

METHODS

Studying pupils' learning processes of DC-circuit phenomena was realised as a teaching experiment. The teaching experiment consisted of interviews (3) and lessons (5) that dealt with DC-circuit phenomena in a talk-activating small group learning environment: 1) primary interview (PI), 2) lessons 1-3 (L1-3), 3) an intermediate interview (II), 4) lessons 4-5 (L4-5) and 5) a final interview (FI). The data was gathered from the lower stage grade (3), at a Finnish compulsory school in Helsinki. The pupils, who represented average pupils, worked in small, mixed four-person groups consisting of two boys and two girls. All the interviews and lessons were videotaped.

During the lessons and interviews analysed, the small group of third graders learnt by talking and negotiating while constructing DC-circuits with bulbs and batteries. In these sessions, real connections, picture cards, connection cards and open problem tasks were used as stimuli for small group learning. Teaching focused on experiments on the electric circuit and the electric current. In these experiments and discussions, the small group identified different parts of the electric circuit, lit a bulb with a single battery, puzzled over different ways of connecting a bulb and a battery, pondered on the lighting order of several bulbs, and connected more bulbs in series.

The working method in a small group was as follows: firstly hypotheses were made with the connection cards; secondly observations were made with real connections; and thirdly the observations were discussed with the teacher, the teacher then summarised the observations and emphasised the main

subject matter. During the third phase the teacher defined and named the new concepts based on information from the earlier phases.

In this study the analyses that have been done follow the general principles of content analysis (Patton, 2002; Tuomi & Sarajärvi, 2002), where the videos of interviews and lessons are used as data. The data consists of the discussions and negotiations in the small groups under the guidance of the teacher or the interviewer. In this study, analyses of the small groups of third graders (9-year-olds) will be presented. Table 1 is an example of content analysis. It includes some selected lines of the original talk in the first column. In the second column there are depicted reduced expressions after the content analysis. These reduced expressions represent the small group's stage of qualitative understanding of the subject matter. The third column includes results of the analysis and describes the final fragment of what the small group expressed in its talk.

RESULTS: BRIGHTNESS OF THE BULBS

In this analysis the focus is on the small group's learning process of "the brightness of the bulbs" in different phases of the teaching experiment. The development of the conception, "the brightness of the bulbs", in the first half of the teaching experiment (PI, L1, L2 and II) is analysed. In the analysis different expressions concerning the brightness of bulbs in different electric circuits are reviewed. By the development of the conception "the brightness of the bulbs" is meant in this case developing possible explanations of the observed brightness of bulbs in different situations.

First conceptions: Connections with the connection cards

In the preliminary interview different DC-circuits were constructed with the aid of connection cards. In the interviews, the interviewer did not tell to the small group whether the given DC-circuit would work or not, it was small group's task to describe freely their own conceptions about the different situations. So, in this first case, the interviewer asked the group to discuss different DC-circuits in series in order to chart pupils' understanding of the functioning of different circuits. The interview started with questions about the circuits of one bulb and one battery, and it continued questions about several bulbs in series. The questions were as follows: If the bulbs were lit, would the bulbs in this circuit (3 bulbs in series with one battery) light as brightly as that one (5 bulbs in series with one battery)? The reason for asking the questions in this way was to make sure that the teacher does not give any hints whether the bulbs light or not. In this way, the little different nuances in pupils' thinking were supposed to be uncovered. See Table 1 for a discussion of this episode.

According to the analysis in Table 1, the speculative discussion about the lighting of bulbs in different circuits uncovered interesting aspects about the small group's thinking. Firstly, Niko thought that bulbs would not light as brightly in the different circuits in question. Then, there existed a thought that the bulbs can wear down and this would affect their lighting. As Laura said, the bulbs would light differently if one of them is older. It is plausible that in this opinion the question was about mutual similarity of the brightness of the bulbs in one circuit. However, this answer includes a view that bulbs can be different and that lighting gradually wears them down. Finally, the small group expressed a conception that identical bulbs in series would light up in the same way. Although the small group concentrated on the question of the relative brightness of the bulbs in series of the same circuit instead of brightness in different circuits, the members however expressed opinions about possible differences between the bulbs and that these differences might affect the way they light. Furthermore, the small group logically guessed that if the bulbs were identical they would produce the same brightness of light. As it turns out the short episode utilising connection cards as tools for constructing electric circuits forced the small group to think instead of purely repeating some remembered facts. The group did not really know what would happen in this case so they were forced to try to explain and think actively.

Table 1. Brightness of the bulbs in the preliminary interview (PI).

ORIGINAL TALK	REDUCED EXPRESSION	FINAL FRAGMENT
<p>L: If the bulbs would light, would the bulbs in this circuit (3 bulbs in series with one battery) light as brightly as those (5 bulbs in series with one battery)?</p> <p>N: I guess no. Not necessarily.</p> <p>L: Perhaps not. If the bulbs are different, if the other one is older.</p>	<p><i>an old bulb does not light as brightly as a newer one</i></p>	<p>Similar bulbs in series would light similarly</p>
<p>L: What about supposing that they were exactly similar: batteries were similar and the bulbs similar?</p> <p>L: Well, in that case they (brightness of the bulbs) would be similar.</p> <p>M: Perhaps, perhaps or...</p>	<p><i>bulbs in series would light similarly</i></p>	

Second conceptions: Real connections with one bulb

During the first lesson the first real electric circuits were constructed. The purpose of these experiments was simply to get the bulbs to light. While learning this primary subject of the lesson, constructing electric circuits, the small group also made independent and spontaneous observations of other things like the brightness of the bulbs. So, in this phase the teacher did not ask or guide the pupils to compare the brightness of the bulbs, but the only task was to construct simple electric circuits where the bulb lights. In Table 2 the small group's talk during constructing simple electric circuits with one bulb, one battery and the necessary conducting wires are presented.

Table 2. Observations of the brightness of the bulbs (1st L).

ORIGINAL TALK	REDUCED EXPRESSION	FINAL FRAGMENT
<p>T: Let's give a new bulb to you also, so...</p> <p>L: ...so there will be a bright light.</p>	<p><i>the brightness of the bulb depends on its age</i></p>	<p>Brightness is a property of the bulb</p>
<p>L: This bulb gave a smaller light than the previous one. This one (light) also is very small. Look at this!</p> <p>N: Your light is brighter than ours.</p>	<p><i>bulbs differ in brightness</i></p>	
<p>L: Could we please get another bulb, because there isn't any light coming out from this one?</p> <p>T: Yes, there is!</p> <p>L: Yes, but it is just a tiny light.</p> <p>M: Why do these lights burn so badly?</p>	<p><i>dimness is a property of the bulb</i></p>	

During the episode represented in Table 2, the discussion of the small group was vivid and relaxed, which meant that pupils made lots of spontaneous and independent observations. For instance, Laura quickly completed the teacher's thought "Let's give a new bulb to you, so..." by her own idea "...so there will be a bright light". Laura's talk uncovered her way of thinking; the brightness of the bulb depends on its age. Similarly, in the next lines Niko, Laura and Matti all thought aloud about the brightness of the bulb being one of its properties. According to them, bulbs differ from each other

based on their characteristic brightness: the dimness of a bulb was described as “small light” or “tiny light”, furthermore questions were put about bulbs “burning badly”.

These lines of discussion uncovered a few aspects of the small group’s phase of understanding. The group’s learning progressed based on empirical observations; while they built simple electric circuits the small group simultaneously also made spontaneous observations and recognised the different brightness of the bulbs, classified the bulbs into bright and dim ones, and compared the brightness between the bulbs. Where this episode uncovered more than just active learning was in their proactive observations. These kinds of comparative observations were not supposed to be made yet in this phase, but later with the circuits of several bulbs. So, as discussed earlier, learning in small groups by negotiating can really increase the activity of learning. In this case the small group learnt more than was expected. It is noteworthy that already in this phase of learning, before doing any experiments with several bulbs in series these 9-year-olds had an intuitive curiosity about what would happen when they made observations of the brightness of the bulbs.

Third conceptions: Connections with several bulbs

At the beginning of the second lesson, the small group’s own hypothesis, “it is not possible to light more than one bulb with a battery” was tested with real connections. During these tests there was not any discussion about the brightness of the bulbs. Then the teacher stopped experimenting and there was a short discussion. The different connections were discussed with the aid of connection cards shown by teacher. The answers to teacher’s questions “What happens, if I connect two bulbs (in series) to this battery, and only one to this one?” and “Do they light as brightly or does some bulb look brighter than the others?” are shown in Table 3.

Table 3. Adding more bulbs in series (2nd L).

ORIGINAL TALK	REDUCED EXPRESSION	FINAL FRAGMENT
<p>T: What happens, if I connect two bulbs to this battery, and only one to this one? Do they light as brightly or does some bulb look brighter than the others?</p> <p>L: I know.</p> <p>N: I don’t know.</p> <p>Mi: I don’t know.</p> <p>L: If you have two (bulbs in series), they look worse. Because I saw a moment ago, when we switched on one bulb, it was bright. But when we switched on two bulbs, they were both pale.</p>	<p><i>two bulbs in series light more dimly than one bulb alone</i></p>	<p>Adding more bulbs dims all the bulbs</p>

As is apparent from the short discussion in Table 3 it was Laura (L) who had made her own observations independently that show active learning. Laura’s explanation was clear: “If you have two (bulbs in series), they look worse. Because I saw a moment ago, when we switched on one bulb, it was bright. But when we switched on two bulbs, they were both pale”. So, Laura used her own everyday language to describe her observations: “looking worse” means dimmer bulbs, similarly “pale bulbs” was an expression for dim bulbs. Thus, in this phase, before really being asked to compare the brightness of bulbs in series she had already made her own conclusions. Besides making spontaneous and active observations about the different brightness of the bulbs, the students had also recognised and classified two different electric circuits, compared the number of bulbs in the circuits, and compared the brightness of bulbs in these circuits. Laura’s understanding about the brightness of the bulbs can be distilled into an empirical based fragment, *adding more bulbs dims all the bulbs*.

Final conceptions of the brightness of the bulbs

Our last episode to be analysed was the intermediate interview of the small group. During the interview that was done after three lessons, different kinds of connections of DC-circuits were discussed by looking at situations presented in the picture cards. In addition, several experiments with real components were done. In these experiments different numbers of bulbs in series were used and different brightness of the bulbs were compared. The teachers' concluding teaching periods, which included determining and naming new concepts such as the electric circuit and the electric current, had also taken place. In these discussions the new concepts were closely been connected to the empirical observations. In this phase the learning of the brightness of the bulbs had reached the levels shown in Table 4.

Table 4. Explaining the brightness of the bulbs (II).

ORIGINAL TALK	REDUCED EXPRESSION	FINAL FRAGMENT
<p>T: Which of these two bulbs (A or B in different circuits) do you think burns brighter? (Two electric circuits with different number of bulbs in series).</p> <p>Mi: This one (shows the electric circuit of fewer bulbs in series)</p> <p>T: Why do think this way?</p> <p>Mi: In this (electric circuit) there are more (bulbs) than in the other.</p> <p>T: Do you agree Niko?</p> <p>N: Yes, I completely agree with her.</p>	<p><i>the more bulbs in an electric circuit the dimmer the bulbs</i></p>	<p>Adding more bulbs dims all the bulbs</p>
<p>T: Is it possible to find out, how strong an electric current there is in the electric circuit?</p> <p>N: Yes. You can test by bulbs.</p> <p>T: How do you test that?</p> <p>N: Well, you have to connect a battery and a bulb with conducting wires...and then...</p> <p>M: ... if they light there is current.</p> <p>T: Please, let Niko tell us.</p> <p>N: ... and the brighter (the bulb) the stronger the electric current.</p>	<p><i>the burning of bulbs as a sign of electric current in the electric circuit</i></p> <p><i>the brighter the bulb the stronger the electric current</i></p>	<p>Brightness of the bulb as a gauge (and a sign) of the electric current</p>

In this phase the whole small group seemed to have understood qualitatively the causal relations between the brightness of bulbs and the number of them in series. For instance Milja (Mi), who had been very uncertain at the beginning of the teaching experiment, clearly showed progress. According to her, a bulb that is in a circuit of fewer bulbs burns brighter than similar bulbs in circuits of more bulbs. Milja's explanation for the brightness of bulbs was simply the number of bulbs in series: the more bulbs in series the dimmer the bulbs.

In the other episode of Table 4 a more theoretical explanation was given for the brightness of bulbs. According to Niko, the electric current of a given electric circuit is able to be qualitatively measured by comparing the brightness of the bulbs: he had understood that it is possible to test or measure the strength of the electric current by comparing the brightness of bulbs: according to him the brightness of bulbs tells us about the strength of the electric current. Thus, in Niko's explanation, the quantity of the electric current got an observation-based meaning.

CONCLUSION

The article explored a small group's learning process of the basic components of DC-circuits, especially bulbs. The learning process of DC-circuit phenomena was treated from the standpoint of developing explanations of "the brightness of the bulbs". The study encourages giving room for the pupils' own thinking and talking in order to support the active learning process. As shown in the study, it is important to encourage pupils to make observations and discuss them with others. Talking about their own observations also develops the pupils' understanding of the topic giving them possibilities to improve their physics language skills. For example, the pupils' own expressions like, "pale bulbs" or "badly burning", used in this study acted as important promoters in the small group's active learning process. It seems that in this kind of environment and atmosphere, pupils listen carefully to others talk, which also activates their own learning process.

The analysed small group of 9-year-olds was very keen to describe their own empirical observations by identifying, classifying, comparing or by making qualitative predictions of the observed phenomena or property. During the teaching period analysed, the pupils' knowledge in the small group progressed by developing their ideas on the grounds of empirical observations. The small group also showed independent progress. This independent progress appeared in a proactive way when pupils made certain observations ahead of time. For instance, the small group started independently to compare the brightness of the bulb, already in the phase of constructing the first circuits with one bulb. According to the teacher's lesson plan these kinds of comparisons would have been in turn but not until the circuits of several bulbs. These comparisons can be understood as signs of spontaneous learning that is in this study used to highlight the pupils' will to expand unprompted the topic to be learnt. In this study, the small group that was analysed did not only settle for actively discussing and processing the topic the teacher gave, but it also extended its interest in phenomena that were not in the core of the teacher's plan in that phase.

As for the content of the learning process, it can be concluded that gradation and progression were distinguished in the small group's learning during the period analysed. In the active and even spontaneous learning process, first more local and then more comprehensive aspects can be differentiated: In the beginning of learning (Table 1), there exists no clear comprehensive conception of the brightness of the bulbs, but the light of a single bulb is understood as its property: "Similar bulbs in series would light similarly". This local understanding goes on in the next phase (Table 2). The brightness of a single bulb is its own property: "Brightness is a property of the bulb". In the second phase, the focus has already extended to a more comprehensive observation and recognition of the circuit: "Adding more bulbs dims all the bulbs" (Table 3 and Table 4). In the final phase analysed, the small group has learnt to compare the phenomenon; the final conception "Brightness of the bulb as a gauge (and a sign) of the electric current" (Table 4) tells us about comprehensive understanding of the DC-circuit phenomena, whereas at the beginning of learning (Table 2) the corresponding fragment "Brightness is a property of the bulb" had concentrated on the brightness of a single bulb.

The learning results underpin the earlier presented Gilbert's idea of developing pupils' lower level models towards more developed scientific models. In this study, the pupils' conceptions "Similar bulbs in series would light similarly", "Brightness is a property of the bulb", "Adding more bulbs dims all the bulbs" and "Brightness of the bulb as a gauge (and a sign) of the electric current" represent these gradually developing models by pupils. Pupils' learning process also fits with Nersessian's idea of modelling through categorizing and sorting phenomena, and noting relationships, differences, and interconnections among them. For example, expressions such as "pale bulbs", "badly burning" or "tiny light" include pupils' modelling process that clearly sorts different brightness of the bulbs to different categories. Furthermore, Kurki-Suonio's terms of "doing empirical observations" and "identifying", "classifying", "comparing or predicting" that highlight the meaning of empirical observations in modelling facilitated by doing the analysis of small group's learning process and specially forced to take into account the qualitative level of concept formation.

REFERENCES

- Anderson, L. W. & Krathwohl, D. R. (Eds.) (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives*. New York: Longman.
- Bennett, J., Hogarth, S., Lubben, F., Campbell, B. & Robinson, A. (2010). Talking Science: The research evidence on the use of small group discussions in science teaching. *International Journal of Science Education*, 32(1), 69–95.
- Bennett, J., Lubben, F., Hogarth, S. & Campbell, B. (2004). *A systematic review of the use of small-group discussions in science teaching with students aged 11-18, and their effects on students' understanding in science or attitude to science*. Research Evidence in Education Library. London: EPPI-Centre, Social Science Research Unit, Institute of Education. Web site: http://eppi.ioe.ac.uk/EPPIWeb/home.aspx?page=/reel/review_groups/science/review_one.htm
- Borges, T. A. & Gilbert, J. K. (1999). Mental models of electricity. *International Journal of Science Education*, 21(1), 95–117.
- Cobb, P. & Bauersfeld, H. (Eds.) (1995). *The emergence of mathematical meaning*. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
- Cobb, P. & Yackel, E. (1996). Constructivist, emergent, and sociocultural perspectives in the context of developmental research. *Educational Psychologist*, 31(3/4), 175–190.
- Collins, J.W. & O'Brien, N.P. (Eds.) (2003). *The Greenwood Dictionary of Education*. Westport, CT: Greenwood.
- Cosgrove, M., Osborne, R. & Carr, M. (1985). Children's intuitive ideas on electric current and the modification of those ideas, 247–256. In R. Duit, W. Jung and C. von Rhöneck (Eds.) *Aspects of understanding electricity: Proceedings of an international workshop*. Kiel: IPN.
- Duit, R. & von Rhöneck, C. (1997). Learning and understanding key concepts of electricity. In A. Tiberghien, E. L. Jossem & J. Barojas (Eds.) *Connecting research in physics education with teacher education*. The International Commission on Physics Education. Web site: <http://www.physics.ohio-state.edu/~jossem/ICPE/TOC.html>
- Georghiades, P. (2000). Beyond conceptual change learning in science education: focusing on transfer, durability and metacognition. *Educational Research*, 42(2), 119–139.
- Gilbert, J. K. (2004). Models and modelling: Routes to more authentic scientific education. *International Journal of Science and Mathematics Education*, 2, 115–130.
- Gilbert, J. K. (2004). Models and modelling: routes to more authentic scientific education. *International Journal of Science and Mathematics Education*, 2, 115–130.
- Gilbert, J. K., Justi, R. & Ferreira, P. (2007). Modelling, visualization, and the development of an understanding of the levels of representation in chemical education. Paper presented in ESERA 2007 Conference August 21 - 25 at Malmö University, Malmö Sweden. Web site: <http://195.178.227.107/esera/Files/153.doc>
- Gilbert, J. K. & Boulter, C. J. (1998). Learning science through models and modelling. In B.J. Fraser & K. G. Tobin (Eds.) *International handbook of science education*, 53–66. Great Britain: Kluwer Academic Publishers.
- Gunstone, R., Mulhall, P. & McKittrick, B. (2009). Physics teachers' perceptions of the difficulty of teaching electricity. *Research in Science Education*, 39(4), 515–538.
- Johnson, D. W. & Johnson, R. T. (2002). Yhdessä oppiminen. In P. Sahlberg & S. Sharan (Eds.) *Yhteistoiminnallisen oppimisen käsikirja*, 101–118. Helsinki: WSOY.
- Kallunki, V. (2008). Using connection cards to uncover children's internal representations of DC-circuit phenomena. In R. Jurdana-Šepić, V. Labinac, M. Zuvic-Butorac and A. Susac (Eds.) *Frontiers of physics education, selected contributions*, 398–404. GIREP-EPEC Conference, 26–31 August 2007, Opatija, Croatia.
- Kallunki, V. (2009). *A Historical Approach to Children's Physics Education: Modelling of DC-circuit Phenomena in a Small Group*. Report Series in Physics HU-P-D164. Helsinki: Helsinki University Print.

- Kallunki, V. & Lavonen, J. (2010). Understanding of DC-circuit phenomena in different ages. In B. Lazar, R. Reinhardt (Eds.), *Proceedings of the XIV IOSTE Symposium*, June 13-18 2010, Bled, Slovenia: Sociocultural and Human values in Science and Technology Education, 587–593. Ljubljana: IRI UL, Institute for Innovation and Development of University of Ljubljana.
- Kurki-Suonio, K. (2011). Principles Supporting the Perceptual Teaching of Physics: A “Practical Teaching Philosophy”. *Science & Education*, 20(3-4), 211-243.
- Lavonen, J. (2002). Luonnontieteitä yhteistoiminnallisesti. In P. Sahlberg & S. Sharan (Eds.) *Yhteistoiminnallisen oppimisen käsikirja*, 221-244. Helsinki: WSOY.
- Lee, S.-J. (2007). Exploring students’ understanding concerning batteries – Theories and practices. *International Journal of Science Education*, 29(4), 497–516.
- McClain K. & Cobb P. (2001). Supporting students’ ability to reason about data. *Educational Studies in Mathematics*, 45(1-3), 103-129.
- McDermott, L.C. & Shaffer, P. S. (1992). Research as a guide for curriculum development: An example from introductory electricity, Part I: Investigation of student understanding. *American Journal of Physics*, 60, 994-1003.
- Michael, J. (2006). Where’s the evidence that active learning works? *Advances in Physiology Education*, 30,159-167.
- Millar, R. & King, T. (1993). Students’ understanding of voltage in simple series electric circuits. *International Journal of Science Education*, 15(3), 339-349.
- Nersessian, N. J. (2002). Maxwell and “the method of physical analogy”: Model-based reasoning, generic abstraction, and conceptual change. In D. B. Malament (Ed.) *Reading natural philosophy. Essays in the history and philosophy of science and mathematics*, 129-160. Chicago and La Salle: Open Court.
- Nersessian, N. J. (2008). Mental Modeling in Conceptual Change. In S. Vosniadou (Ed.) *International handbook of research on conceptual change*, 391-416. New York: Routledge.
- Patton, M. Q. (2002). *Qualitative research & evaluation methods*. Thousand Oaks: Sage.
- Richardson, V. (2003). Constructivist pedagogy. *Teachers College Record*, 105(9), 1623–40.
- Rop, J. (2003). Spontaneous inquiry questions in high school chemistry classrooms: perceptions of a group of motivated learners. *International Journal of Science Education*, 25(1), 13–33.
- Scott, P., Asoko, H. & Leach, J. (2007). Student conceptions and conceptual learning in science. In S. K. Abell & N. G. Lederman (Eds.) *Handbook of research on science education*, 31-56. London: Lawrence Erlbaum Associates, Publishers.
- Shayer, M. (2003). Not just Piaget; not just Vygotsky, and certainly not Vygotsky as alternative to Piaget. *Learning and Instruction*, 13, 465-485.
- Shipstone, D. M. (1984). A study of children’s understanding of electricity in simple DC circuits. *European journal of science education*, 6(2), 185-198.
- Shipstone, D. M., von Rhöneck, C., Jung, W., Kärrqvist, C., Dupin, J. -J., Johsua, S. & Licht, P. (1988). A study of students’ understanding of electricity in five European countries. *International Journal of Science Education*, 10(3), 303-316.
- Tiberghien, A. (1983). *Critical review on the research aimed at elucidating the sense that the notions of electric circuits have for students aged 8 to 20 years*. In International summer workshop: research on physics education, La Londe les Maures. Paris: Arman Colin.
- Tsai, C.-H., Chen, H.-Y., Chou C.-Y. & Lain, K.-D. (2007). Current as the key concept of Taiwanese students’ understandings of electric circuits. *International Journal of Science Education*, 29(4), 497–516.
- Tuomi, J. & Sarajärvi, A. (2002). *Laadullinen tutkimus ja sisällönanalyysi*. Helsinki: Kustannusosakeyhtiö Tammi.