COLLABORATIVE CONCEPT LEARNING

Collaborative learning tasks, student interaction
and the learning of physics concepts

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SAMENWERKEND BEGRIPPEN LEREN

Samenwerkingstaken, interactie tussen leerlingen
en het leren van natuurkundige begrippen

(met een Nederlandse samenvatting)

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Co-promotor: dr. J.L. van der Linden, Faculteit Sociale Wetenschappen, Universiteit Utrecht

Woord vooraf

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Carla van Boxtel Gemert, maart 2000

CONTENTS

1 General Introduction

The objective of the research that is reported in this thesis is to study the complex interplay between features of collaborative learning tasks, the quality of student interaction and the learning of physics concepts. The central questions concern how features of collaborative learning tasks affect the quality of student interaction and the types of student interaction that contribute to the learning of physics concepts. More specifically, the thesis deals with the interaction between students from higher classes of secondary education working together face-to-face in dyads on a collaborative learning task that aims at improving their understanding of electricity concepts. The learning of concepts, the potential contribution of student interaction to learning, and the role of task characteristics are themes that are considered to be important in both educational research and in educational practice.

The learning of concepts is one of the most essential learning activities inside, as well as outside of school. Concepts can be considered cultural products that are used to think, communicate and act. An important aim of instruction in schools is that the students get acquainted with the concepts that are used within specific domains, and that they improve their ability to use these concepts in their mutually agreed upon 'scientific' meaning. However, previous research showed that most students experience difficulties learning to use physics concepts in their scientific meaning (Chi, Slotta & de Leeuw, 1994; Vosniadou, 1994; Perkins & Unger, 1994; Caravita & Halldén, 1994; Chinn & Brewer, 1993; Eylon & Linn, 1988; Driver, Guesne & Tiberghien, 1985). Several authors suggest that the use of concepts in spoken communication (talking about and 'with' concepts) contributes to the learning of these concepts (Duit & Treagust, 1998; Lijnse, 1994; Palincsar, Anderson & David, 1993; Lemke, 1990; Van Oers, 1987). From this point of view collaborative learning has a high potential to contribute to the learning of concepts, since it can provide students with the opportunity to talk about the concepts and to use them to describe and explain phenomena.

In both educational practice and educational research, there is an increasing interest in collaborative learning. In educational practice, the interest in collaborative learning coincides with the shift to more student-centered learning environments in which the students can take more responsibility for their learning. In the Netherlands the heightened interest in group work is reflected in the publication of a growing amount of literature on this topic (Van der Linden & Roelofs, 2000; Haenen & Haitink, 1998; Hoek, 1998; Kanselaar, van der Linden & Erkens, 1997; Ebbens, Ettekoven & van Rooijen, 1997; Ros, 1994; Vedder, 1985). In educational research, the interest in how and under which conditions student interaction facilitates learning resulted in a large body of literature (Cowie, van der Aalsvoort & Mercer, in press; Van der Linden, Erkens, Schmidt & Renshaw, in press; Dillenbourg, 1999; O'Donnell & King, 1999; Rogoff, 1998; Webb & Sullivan Palincsar, 1996; Cohen, 1994; Hertz-Lazarowitz & Miller, 1992). Next to the composition of the group, the group size, the reward structure and the preparation for group work, the task is often discussed as one of the main factors that affects the quality of the student interaction and consequently the learning outcomes (Webb & Sullivan Palincsar, 1996). There have been many studies of the effects of different group tasks, but mostly these studies focused on outcomes and less on the processes that take place during group work. Other studies did focus on these processes, but primarily dealt with cooperative learning tasks and studied the scripting of interaction through a task division, the assignment of roles, the development of cooperative norms and training to improve questioning and argumentation. Less is known about the role of task characteristics in collaborative peer workgroups in which the students work on a common product and share both activities and materials. Recently, Derry (1999) concluded that there is still no theory of task characteristics related to the topic of collaborative learning. More insight is needed into the nature and content of student interactions on various tasks and domains, and in the way tasks inhibit or foster a productive interaction.

The goal of this thesis is twofold. First, it aims to contribute to a theory about how features of collaborative learning tasks affect the quality of the student interaction. Second, it strives to make a contribution to the issue of the relationship between student interaction and learning. More specifically, this research tries to answer the question of what kind of student interaction contributes to the learning of *physics* concepts. I try to build on (socio)constructivist, socio-cultural and more domain-specific perspectives on concept learning and the relationship between student interaction and learning. I start from the idea that the complex interplay of task characteristics, student interaction and the learning of domain related concepts can be more adequately addressed from different theoretical positions that emphasize different aspects of learning (see also Salomon & Perkins, 1998; Duit & Treagust, 1998; Schnotz & Preuß, 1997; Phillips, 1995). This research approach is reflected in the methods that are used to measure the learning of concepts and to analyze the quality of the student interaction. Although the main purpose of the present thesis is to make a scientific contribution, I consider the results of the research also relevant for the design of collaborative learning tasks in educational practice.

This thesis contains three empirical studies. Before these studies are presented, Chapter 2 gives an outline of the relevant theories and empirical studies that are related to the subject of collaborative concept learning. After a description of the theoretical framework underlying the research, the research questions and the method of the research are presented in Chapter 3. The three empirical studies are presented and discussed in Chapters 4 through 6. Finally, Chapter 7 contains a summarization and a general discussion of the main results of the three studies, and concludes with some recommendations for future research and educational practice.

Parts of the results of the studies are already published or will be published as articles in international journals or as chapters in books. However, this thesis is written as a book and is not a collection of separate articles. In this book the results of the studies are described in more detail and communalities are discussed. A list of publications related to the research is included in the Appendix.

2 Theoretical Framework

The aim of this chapter is to provide a description of the relevant theories and empirical studies which are used as a theoretical framework for the current research project. Section 2.1 starts with a description of the domain and the problematic aspects of the learning of physics concepts. Section 2.2 contains a brief overview of the ways the learning of concepts can be described, and concludes with the definition of concept learning that will be used in this thesis. Section 2.3 discusses two lines of research on the relation between peer interaction and learning, and concludes with a provisional answer to the question regarding the types of peer talk which can contribute to the learning of physics concepts. Section 2.4 examines how collaborative learning tasks may affect the quality of peer talk.

2.1 Concept Learning within the Domain of Physics

Physics, as it is taught in schools, is related to an academic discipline. Although academic disciplines make use of the same national language (e.g. in the Netherlands, the language is Dutch) each discipline also has its own 'language' or discourse genres. Academic disciplines are characterized by discipline-bound concepts and ways of reasoning, sometimes referred to as professional jargon. In physics, scientists try to interpret and predict physical phenomena and to induce theories that can explain particular observations. Physicists then try to generate theoretical or object models. Within this discipline, concepts are used as "tools" to think about, describe, explain and manipulate physical phenomena.

A concept has a label or term, for example *current strength* or *force*. In the discourse these terms can function as meanings (De Groot & Medendorp, 1986). Within the physics community, the terms that are used refer to a more or less mutually agreed upon meaning. However, students' understanding of concepts and phenomena, as well as their reasoning, often differ from the generally accepted understanding and reasoning that is used within the academic discipline (Chi, Slotta & de Leeuw, 1994; Driver, Guesne & Tiberghien, 1985). Despite educational lessons involving the appropriate meaning and usage of scientific terms, students frequently do not use the physics terms appropriately, or do not use them at all. This is problematic for several reasons for which I provide a brief outline below. The following outline discusses domain specific problems that focus on electricity as it is taught in secondary schools. The examples given are related to this topic. The problematic aspects of learning physics concepts are clearly present within the sub domain of electricity.

2.1.1 Problematic aspects of learning physics concepts

2.1.1.1 Conceptions and ways of reasoning in everyday life and in the context of physics

A person's ideas about natural phenomena are influenced by years of everyday experiences, perceptions and physical sensations. However, since these ideas are primarily based upon (unreflective) interaction with a natural environment that does not inform us about the underlying mechanisms of phenomena, they are often incomplete, incoherent and incorrect from a scientific point of view (Eylon & Linn, 1988; Di

Sessa, 1993). For example, many people are able to use electrical appliances without a real understanding of how or why they work, and although we can experience static electricity, this experience does not give us many clues to scientifically explain it. Scientists, on the other hand, not only use concepts to describe and order experience, but also give a theoretical reconstruction of that experience.

Scientific terms that are used within the discipline, yet overlap with terms that are used in everyday life, give rise to particular problems. For example, the everyday usage of the term *current* includes the idea of current consumption (Osborne, 1983) as illustrated in everyday language where it is often said that electrical appliances ”consume” or ”use up” current. In everyday life this conception is satisfactory, but not when trying to learn and understand fundamental ideas in science. When confronted with an electric circuit with a bulb between two ammeters, students often predict that the ammeter behind the bulb will read a smaller current strength than the ammeter before the bulb (Driver, Squires, Rushworth & Wood-Robinson, 1994; Osborne, 1983). However, this is scientifically incorrect since the bulb only transforms the energy that is provided by the current, thus allowing the current strength to stay the same throughout the entire circuit. Joshua and Dupin (1987) argue that the idea of current consumption is also related to the everyday knowledge that a battery wears out. They suggest that when students are provided with a plausible alternative theory for the wearing out of the battery, they have less reason to resist the idea that current is consistent throughout a serial circuit. Introducing a plausible alternative theory that is intelligible and of high quality is one of the instructional strategies suggested by Chinn and Brewer (1993) to avoid the ignorance, rejection, exclusion or reinterpretation of data that is contradictory to the students’ own conceptions.

The cause-and-effect reasoning which is functional in everyday life can also be problematic in describing and explaining phenomena in a more scientific manner. Many students use sequential reasoning when considering electric circuits. They do not perceive the circuit as a system and subsequently believe that a change in the circuit will affect only the section after the point of change and not before (McDermott & Van Zee, 1985; Psillos & Koumaros, 1993). Von Rhöneck and Grob (1987) state that instruction may even enhance this sequential reasoning by introducing the idea of the direction of a current.

The fact that students have difficulties with the use of concepts in their scientific meaning is also explained by the existence of ontological presuppositions (Vosniadou, 1994; Chi et al., 1994). These presuppositions involve ideas about fundamental features of various phenomena in which students assign concepts to the wrong ontological categories. Everyday language can be viewed as a “thing-language” (Lijnse, 1994; Van Parreren, 1971). The idea of electricity is often seen as “matter” or a “thing” instead of as a process that is constraint-based and has no causal agents (Chi et al., 1994). This false categorization may explain statements such as “Current can be used up,” and ”Current is stored in the battery.” According to Psillos and Koumaros (1993) materialistic reasoning in electrical phenomena is a dominant form of reasoning by students of all ages and in all contexts.

2.1.1.2 “Unknown” phenomena and terms

In contrast to terms that are used by both the community of physicists *and* the general population, there are also physics concepts that are constructs of phenomena that can not be observed or experienced, and therefore are not used in everyday life by the general population. Scientific theories and concepts are formulated to explain these microscopic phenomena that are outside of the realm of everyday life. For example, explaining electrical phenomena requires the imagination of something that is not directly perceptible: the flow of electrons. It is difficult to describe in words how to formulate the idea of electrons or energy. Textbooks and teachers often use analogies to make such concepts more understandable. A model or a process is often compared with a model or a process that the students are already familiar with (Duit, 1991; Clement, 1993; Mason, 1994). For example, the flow of electricity can be compared with the flow of water or with the motion of a crowd of objects. In these situations, everyday conceptions do not hinder the learning of the scientific meanings but foster their understanding. It must be taken into account, however, that students must understand the analogy itself and that most analogies break down at some point because of dissimilarities between the systems that are compared.

2.1.1.3 Textual, mathematical and graphical forms of representation

Another problematic aspect of learning physics concepts is the interrelated use of multiple forms of representation: textual, mathematical, and graphical. The physics language has a multilingual character. Students have to “read” concepts and understand their interrelations from language, symbols, diagrams and formulas in order to associate these different forms of representation with each other (Alexander & Kulikowich, 1994; Perkins & Unger, 1994). Relations can be formulated at different levels of precision: a qualitative level (for example, there is no current without voltage), a semi-qualitative level (for example, current strength increases when the voltage increases), and a quantitative level (for example, $I = V/R$). Using the language of physics also implies using these mathematical forms of representation. In everyday life we rarely use the quantitative way of describing and reasoning. Formulas have stripped down and abstract characters that make it difficult to understand what is actually represented by the formula (Perkins & Unger, 1994). It is also difficult to relate formulas to what actually can be observed. In schools, it frequently appears that the students can reproduce and use a formula, but are unable to relate the quantitative results of their algebraic manipulations to the described phenomena (McDermott & Van Zee, 1985, Van Aalst, 1985). Quantitative relations are easily manipulated without a true understanding of what they represent. This implies that students are often conjuring tricks with formulas which they do not understand. Härtel (1985, pg. 344) argues that formulas should only be introduced after students have gained some qualitative understanding:

“The definition and the presentation of a physical term as the result of a measurement like $R = V/I$ is a method to demonstrate the elegance of the physical method, its exactness and clearness. Such a method is, however, a shortcut of the historical development of these terms within the development of science. It suppresses the qualitative relationships of these terms, thereby blocking or hindering real understanding.”

2.1.2 Conclusion

In sum, different explanations are provided to explain why students have problems learning to use physics concepts in their *scientific* meaning. Some of these explanations draw on the idea of a difference between the everyday use of concepts and ways of reasoning when compared with more scientific ones. Others focus on the ontological presuppositions and the unfamiliarity with some of the terms and forms of representation that are used within the discipline. I conclude that the learning of physics concepts in schools specifically implies that students have to understand concepts in their scientific meaning (see also

Lijnse & De Vos, 1990). This requires an understanding of the *theory* in which the concepts are used to describe and explain phenomena (Caravita & Halldén, 1994), as well as the ability to understand and use mathematical forms of representation.

2.2 What does it mean to Learn Concepts?

In schools, it is preferred that the students use physics terms in their scientific meaning. Consequently, the meanings that students use are often described as misconceptions, everyday conceptions, naïve conceptions or alternative frameworks. As described by Strike and Posner (1982), many researchers in the domain of science education describe concept learning as a process of conceptual change: the transformation of naïve or everyday conceptions and mental representations to more scientific ones. This idea is currently considered too simple by numerous other researchers. The following sections present various ways in which the learning of concepts can be described. For many years theories of concept learning were based on a cognitive constructivist perspective on learning. More recently, however, situational and socio-cultural approaches shed another light on the process of concept learning. I will try to show how these different perspectives on learning both contribute to a description of concept learning within the domain of physics. I will conclude by giving a definition of concept learning that will be used in this thesis.

2.2.1 Constructivist perspective

Since the 1950s, the dominant cognitive perspective on learning has described knowledge as a product of information processing. Cognitive structures are assumed to be at work in the process of problem solving and the learning of concepts and skills. In the last decade, many authors have come to share the idea that these cognitive structures are individually constructed. Knowledge is not “found”, transmitted or passively received, but *actively constructed* (Brown, Collins & Duguid, 1989; Duffy & Jonassen, 1992). In other words, an individual constructs knowledge on the basis of previously acquired knowledge and through the processing of new information (Alexander, Schallert & Hare, 1991). New information is believed to be processed, stored and integrated with previously stored knowledge in long-term memory. The knowledge in long-term memory can be activated or retrieved and then applied in other situations (Anderson, 1990; Mayer, 1989). From this constructivist perspective, conceptual change or conceptual growth requires certain cognitive processes in order to construct a change in mental representations, structures or schemata. Most researchers describe conceptual learning as a process of enrichment, increased coherence, reorganization and refinement of conceptual ideas (Chinn & Brewer, 1993; Vosniadou, 1994). The extension, restructuring, organization, refinement and differentiation of conceptual knowledge is the result of cognitive processing of new information and the use of conceptual knowledge during the accomplishment of tasks. An important claim that is made in most literature about the learning of scientific concepts, is that it requires deep processing or elaborative activities (e.g. Elshout-Mohr & Van Hout-Wolters, 1995; De Jong & Ferguson-Hessler, 1993). From a constructivist point of view, elaboration contributes to the construction of a more integrated conceptual framework. Several strategies that are described below as deep processing strategies include the active use of prior knowledge, the recognition and acknowledgement of problems and attempts to look for meaningful relationships.

The active use of prior knowledge is considered an important condition for the construction of conceptual knowledge. Prior knowledge is often described as the knowledge that a student has when entering a new learning situation. When prior knowledge is activated, it affects the processing of new information. Many authors state that becoming aware of our own preconceptions is an important condition for conceptual change because it may result in a cognitive conflict. The students must then experience that their conceptions are not adequate in explaining or manipulating certain phenomena (Schmidt, De Volder, De Grave, Moust & Patel, 1989; Eylon & Linn, 1988; Joshua & Dupin, 1987; Pintrich, Marx & Boyle, 1993). This cognitive conflict may arise from laboratory work, computer simulations, teacher demonstrations or discussions. Chinn and Brewer (1993) advocate explicit comparison of preconceptions with new information because students are often not aware of the inconsistencies and in most cases, they do not readily abandon their preconceptions. Different instruction models stress the importance of a phase of prior knowledge activation to achieve conceptual change. Licht (1990), for example, designed a learning environment in which students initially had to formulate expectations on the sole basis of their preconceptions and intuition. Afterwards, students were confronted with conflicting evidence through hypothesis testing or demonstration. The strategy focussed on four problem areas: the idea of current consumption, the idea of a constant current, local/sequential reasoning and a lack of discrimination between voltage and current. A significant improvement was reported for the first two problem areas. Biemans (1997) designed a strategy for students working in a computer environment stimulating the activation of relevant prior knowledge and the validation of this knowledge through explicit comparison with new information. This strategy resulted in a significant improvement of the learning results.

Krapp, Hidi and Renninger (1996) describe problem recognition and the attempt to solve these problems as an important deep processing strategy. Two types of problems are important when considering conceptual learning. First, students can experience knowledge gaps or a lack of understanding. When they are confronted with this problem, educators would like them to make the problem explicit through the formulation of a question. Despite this desire, students in classroom settings rarely ask (high level) questions. Interestingly, question asking is claimed to be at the heart of active learning and deep comprehension (Graesser, Person & Huber, 1993). Since questioning can often elicit elaboration, some instructional models focus on stimulating and improving this occurrence (Brown & Palincsar, 1989; King, 1990; Webb, 1989). Another problem that students can experience is being confronted with information that conflicts with their own understanding. Chinn and Brewer (1993) stress that students need to be motivated to understand conflicting information and alternative theories. They view this as an important condition for reaching an adequate understanding of science concepts since it is well known that many students incorporate new information in their own theories.

A third important deep processing strategy is the attempt to look for meaningful relationships (Krapp et al., 1996; Novak, 1990). Within the domain of physics, three types of relations can be distinguished. First, students should be able to relate different concepts as is done in the domain specific theories. For example, they have to understand how current strength is related to resistance and voltage. Second, students must be able to use physics concepts to describe and explain concrete phenomena. Within the sub domain of electricity, for example, a bulb has to be considered as a resistor and a battery as a voltage source. Finally, within physics, students must also be able to associate concepts and the relationships between them with different forms of representation, such as magnitudes, formulas or diagrams. Some instructional sequences on introductory electricity explicitly focus on these different types of relations. Both Härtel (1985) and White and Fredriksen (1987) argue that a qualitative understanding of the relationships between the physical quantities should precede the introduction of formulas. White and Fredriksen suggest using an instructional model that is characterized by levels of increasing complexity. At the first qualitative level, the students learn to deal with basic elements of electric circuits, such as the necessity of a voltage source and a closed circuit. At the second qualitative level, the students explore relations between voltage and current strength and between resistance and current strength. At this level the relations are described in terms of *increases* and *decreases*. Finally, the relations are described at a quantitative level and Ohm's formula is used to calculate the exact values of the quantities. Psillos and Koumaras (1993) suggest a course about electricity that starts with the phenomenological technical level in which students can become familiar with batteries, bulbs and circuits. Then, the phenomena that can be observed and measured in the electric circuits are described at the macroscopic level of quantities such as voltage, current, resistance and energy and their interrelationships. The function of the battery, the current strength, the resistance and their interrelationships are then explained through the underlying mechanisms at the microscopic level of moving electrons. Finally, the relations between the physical quantities on the macroscopic and microscopic level are described with formulas.

Constructivist theorists have become increasingly aware that cognitive processes and structures are influenced by the social and cultural settings in which they occur (Palincsar, 1998; Vosniadou, 1996; Pintrich et al., 1993; Azmitia & Perlmutter, 1989; Solomon, 1987). Duit and Treagust (1998) state that in constructivism in science education, there was a tendency to neglect social aspects of the construction processes. Cognitive activities do not take place in a social vacuum, but are influenced by motivational, emotional and social factors such as confidence, interest, status differences, authority, evaluation structures and verbal interaction. Within this socio-constructivist perspective individual cognitive development is increasingly studied in relation to the social context in which it appears. It is increasingly acknowledged that knowledge and learning have significant social aspects. However, the situative and socio-cultural approaches often criticize the socio-constructivist or the social 'influence' conceptualizations because of the idea of a distinction between the social context and the cognitive activities that are located in the minds of individuals. The next section gives an outline of these perspectives.

2.2.2 Situational and socio-cultural perspectives

The situative and socio-cultural approaches that have recently emerged as a new school of thought on learning and instruction suggest that learning must not be understood as a process that is solely in the mind of the learner. Situative and socio-cultural theorists direct our attention to the way in which knowledge is constructed through interaction with others and to the ways that knowledge construction is mediated by language and cultural tools. Although most of the situated and socio-cultural approaches are grounded in the writings of Vygotsky, Leont'ev and Bakhtin (see Wertsch, 1991) the perspective is not a single view.

The perspective includes the ideas of learning as a situated process, as a process of changing participation, as mediated by cultural tools and as the joint construction of knowledge.

Wertsch (1991) argued that it is not possible to study thinking and cognition independently of the social, interpersonal, cultural, institutional, and historical settings in which they occur. The physical and social environments are considered integral to the cognitive activity and not just as contexts for it. Situations co-produce knowledge and thus part of the meaning of concepts will always be inherited from the context of use (Brown et al., 1989).

Vygotsky (1978) argued that individuals can internalize the community's tools for thinking. He believed that higher mental functions originate in social interactions. Due to the transformational nature of internalization, the mental functions must not be viewed as mere copies. Vygotsky stated that higher mental functions in particular can be developed through participation in social activities under the guidance of a more capable adult or peer. Some socio-cultural authors try to avoid distinguishing between 'internal' and 'external' processes. Rogoff (1990, 1995 pg 687), for example, prefers a description in which learning is not described as a change in cognitive structures in the mind but as a transformation of participation in socio-cultural activities.

"Individuals develop as they participate with others in shared endeavors that both constitute and are derived from community traditions."

Some researchers who studied mother-child interaction adopted this idea. Wertsch (1985) described cognitive change as a process in which the child becomes able to *use* certain concepts in the conversation with the adult. Hoogsteder (1995) studied the communication between young children and their caregivers in informal learning situations and developed an instrument to make the children's participation visible. Adopting the use of these more sociological and anthropological perspectives, the learning of science concepts can be described as a change of the student's participation within a particular kind of discourse, as a process of socializing students into a community of physicists, or as an enculturation process in which a learner becomes a member of a discourse community and can act according to the norms and conventions of this community (see also Cobern & Aikenhead, 1998; Lave & Wenger, 1991). There still are not many empirical studies related to the learning of science concepts in which the concept of participation is adopted.

Another theme in the writings of Vygotsky is that thinking and acting are mediated. In other words, there is always some socio-cultural dimension that shapes the way people think and act. Thinking and acting are mediated by the psychological tools (such as spoken and written language, algebraic symbol systems, images, gestures) and the technical tools (such as computers and calculators) that are socially constructed in a particular culture (Wertsch, 1991; Säljö, 1995). Using another tool may also change the form and character of an activity. The tools are cultural products and include the wisdom and assumptions that went into their creation. Through the mastery of communicative and technical tools we appropriate the ways of understanding that are developed within particular discursive practices (Säljö, 1995). Students gradually move from using tools under guidance to using them on their own and in their own way. From this perspective, conceptual learning can be described as the mastery of cultural tools which results in a move from being a peripheral participant to a full participant of a discourse community.

Finally, the socio-cultural and situative approaches state that learning and cognition are distributed over the entire social and physical environment of an individual and not just within the individual himself (Cole & Engestrom, 1993). Knowledge is jointly constructed. Mercer (1995, 1996) describes speech as a social mode of thinking because it is not only a means for sharing thoughts but also a tool for the joint construction of thinking. From this perspective, the learning and understanding of concepts is distributed over persons and tools whereas the meanings of concepts are jointly constructed through communication.

2.2.3 Concept learning as defined in this thesis

An in depth discussion of the two perspectives on cognition and learning and an attempt to resolve the contradictory points of view is beyond the scope of this thesis. The present research builds on both constructivist and socio-cultural perspectives on learning. Although the different perspectives have contradictory points of view on the epistemological level of describing the nature of knowledge and the process of learning, I started from the idea that they can give a complimentary contribution to the description of concept learning, the analysis of peer talk and the determination of patterns of talk that contribute to concept learning. I find myself in agreement with Schnotz and Preuß (1997) and with Salomon and Perkins (1998), who suggested that considering the different perspectives is more promising than contrasting or simply disregarding one of them.

How can the different perspectives contribute to a description of concept learning within the domain of physics? Recent constructivist and socio-cultural perspectives on learning both draw upon the idea that knowledge is actively constructed. This activity, however, can be described in terms of individual cognition or in terms of social processes (Phillips, 1995). Whereas the constructivist perspective merely focuses on individual cognitive activities and development, the socio-cultural perspective views the socio-cultural activity as the basic unit of analysis and provides us with an understanding of learning and thinking as social and situated processes. In this thesis I try to broaden the idea suggested by Phillips (1995) that the construction of knowledge may be described in terms of *both* individual cognition *and* social processes.

My description of concept learning does not involve a change of an individual's stored possession of meanings or a replacement of naïve ideas by scientific ideas. I prefer to define concept learning in physics as a change in the way a person participates in situations that require the use of scientific meanings and forms of reasoning. With the word 'participation', I mean the way a student *uses* physics concepts in these situations. The scientific meaning of physics concepts and the situations in which it is appropriate to use these meanings are 'defined' by the community of physicists in the academic discipline and in schools (although, it must taken into account that the agreed upon definitions are also subject to change). In schools, students are stimulated to describe and explain both familiar and unfamiliar phenomena in terms of scientific concepts and theories. The problems that students have in this process of learning concepts primarily deals with gaining access to the discourses and practices of the community and with differentiating between the everyday contexts and the scientific contexts of interpretation. Various conceptions can co-exist (Caravita & Halldén, 1994; Schnotz & Preuß, 1997). Conceptions that are not pursued in education may be used in everyday situations, whereas more scientific conceptions are used in school. In sum, becoming a full participant of the discourse and practice of physics implies the growing ability to think, speak and act with the concepts that originate in the community of practitioners.

Rogoff (1995) also described learning as a process of changing participation. However, she suggested that the socio-cultural perspective on learning does not require a storage model of past events. She stated that acting on the basis of previous experiences should not be described as a retrieval and use of memories because prior and upcoming events are involved in the ongoing present event. I agree that the understanding of a concept may not be stored in or activated from long-term memory, but can be considered as a construction that is situated and embedded in a social activity. Nevertheless, in this focus on the situated activity and the social construction of meaning I do not want to lose sight of the existence of an individual cognitive system. Schnotz and Preuß (1997), for example, used the functioning of the individual cognitive system to give a plausible explanation for the frequently made observation that students hold on to the use of everyday or 'naïve' conceptions. They suggest that the conceptions that students use often have the structure of their previous conceptions since frequently used schema configurations in our memory have a higher likelihood of guiding the construction of meaning in a similar situation, or one that is perceived to be similar. In line with the previously discussed idea that cognition occurs both in and between individuals, I hold on to the idea that our memory is at work in the process of establishing meaning. Thus, together with situated and social forces, schema configurations in the memory are at work in the formation of a student's participation in an activity and in the co-construction of knowledge (see also Damon, 1991). I agree with Salomon and Perkins (1998) and with Damon (1991) that in the joint and situated construction of knowledge, individual activities and reflections still play a critical role, and that each agent in a socio-cultural activity retains its separate identity and contributes in its own way to the joint construction of knowledge.

Another comment that I would like to add is that, although all learning is social in some sense because it is mediated by social interaction and cultural tools, the degree of active social mediation may vary from situation to situation. Social interaction can refer to interaction between different kinds of agents such as teachers, peers, learning materials and physical tools. For example, when a student reads a textbook, the learning that takes place can be described as socially mediated because a) the information that is presented in the textbook can be considered a product of a specific discourse community, b) the author of the textbook tries to communicate his understandings to the reader, c) the student may read the textbook to prepare for an oral examination or another social activity, and d) studying a textbook is an activity that belongs to a certain culturally and historically shaped setting, namely school. However, in this situation the degree of *interactivity* is very low. Interactivity can be described as the extent to which the different agents in a certain situation can influence each other through action and reaction (Erkens, 1997). Learning that is mediated by social interaction occurs in a situation in which agents shape each other's actions through communication. This communication can be verbal, nonverbal, face-to-face, computer-mediated, can occur through spoken or written language, and can be synchronous or asynchronous. The next section explicitly examines a specific form of socially mediated learning. It gives a brief overview of the research on the relation between learning and face-to-face *peer interaction*.

2.3 The Potential of Peer Interaction

In the discussion on how to enhance the learning of physics concepts, many researchers advocate the participation in social interaction. Lemke (1990) believes that it is the specific *use* of the physics concepts in communication such as the discussion of hypotheses, essay writing, reporting experimental results and asking questions that is most important. He states that students need to 'talk science'. In line with this assumption, Palincsar, Anderson and David (1993) suggest that "scientific literacy" can only be promoted through participation in science activities and in the use of the language of science. According to Lijnse (1994) conceptual learning is a process of joint construction of meanings. Students and teachers have to talk about physical phenomena in order to negotiate and co-construct the scientific meanings. Lijnse argues that this process can only start at the everyday life level because at this level there is enough commonality in language and experiences to make a discourse possible.

Although the use and negotiation of physics concepts is frequently advocated, we know little about *which* patterns of speech, or "talk" contribute to the learning of physics concepts, or how to explain this contribution. The literature on peer interaction may help us in the formulation of a provisional answer. The section below reviews two relevant lines of inquiry concerned with peer interaction. This review is confined to the question of how social interaction between *peers* can facilitate learning. With peers, I refer to classmates of similar age. The first line of research that will be discussed holds the idea that the language production that is asked for in collaborative learning situations leads to elaborative cognitive processing. The second line of research is based upon the idea that in social interaction, knowledge is co-constructed and that mediational tools play an important role in the negotiation and co-construction of meanings.

2.3.1 Peer interaction stimulates elaboration

One of the most important explanations of the positive results of collaborative learning may be the notion that peer interaction stimulates elaboration of conceptual knowledge. In a collaborative learning situation, students must negotiate goals, represent problems, and understand the meaning of concepts and procedures. Collaborating students have to make their thoughts explicit. Teasley (1995) found that students working in dyads on a micro-world task generated more elaborative "talk" than students who worked individually and were asked to speak aloud. She also found a significant positive correlation between the proportion of interpretative utterances and final hypothesis scores. Teasley suggests that talking to someone else becomes more elaborate because communication implies that you want to be understood by the other, which results in more coherent explanations. Due to the need to communicate coherent explanations, the students can gain a greater conceptual clarity for themselves (Damon & Phelps, 1989). The burden of explanation pushes students to evaluate, integrate and elaborate knowledge in new ways. The mechanism that is believed to explain the relation between elaborative talk and individual learning outcomes is the idea that elaborative talk results in reflection on and the (re)organization, differentiation, refinement and extension of conceptions.

The researchers that suggest a relationship between elaborative talk and conceptual learning focus particularly on the asking and answering of questions as well as the elaboration of controversy by providing justifications and argumentation. Through verbalization, students can become aware of their knowledge gaps and lack of understanding thus resulting in the asking of questions to verify the other's understanding, or in asking for explanations. Webb (1989, 1991) found a relationship between giving elaborated help and learning outcomes. She argued that elaborated help stimulates the awareness of knowledge gaps, inconsistent reasoning, and reorganization. Giving elaborated help results in more elaborated concepts because students create new relations by giving examples, using analogies, reformulating or by referring to school or everyday experiences. In teacher-led discussions, questioning and explaining in "everyday language" may be discouraged. King (1990) found that higher order questions in particular elicit elaborative answers. Although the giving of explanations is specifically believed to contribute to learning, receiving explanations is also thought to contribute to the filling in of knowledge gaps and the correction of misconceptions (Webb & Sullivan Palincsar, 1996). Hertz-Lazarowitz (1992) states that explanation and help are especially effective for the receiver when they are elaborated, understood and used.

Verbalization also makes it possible for ideas to be questioned or criticized by another student (Cohen, 1986; Carter & Gail Jones, 1994). Damon (1984) suggests that peers are more likely to challenge one another than to challenge an adult. The partner can point to inconsistent or incorrect reasoning. Part of the research on conflict has been conducted in a Piagetian framework and has focused on the role of socio-cognitive conflict in the promotion of individual cognitive restructuring (Doise & Mugny, 1984). Socio-cognitive conflicts are situations in which students experience that interpretations or strategies of others are different from their own interpretations and strategies. A cognitive conflict results from this social situation and then leads to the questioning of the student's own understanding and their subsequent pursuit of new ideas. The majority of studies on socio-cognitive conflict have focused on younger children as they work on a conservation task. However, this research did not give us much insight into how *verbal interaction* in conflict situations can contribute to individual progress. Brown and Palincsar (1989) and Dillenbourg, Baker, Blay and O'Malley (1995) explain the important role of conflict and controversy by the fact that it can generate explanations, justifications, reflection and a search for new information. Not only is the cognitive conflict "inside" a person (which elicits reflection) considered important, but also the verbal interaction that is meant to resolve the "social" conflict. From this perspective, a conflict is valuable for learning when it is acknowledged and verbalized, when it does not have its origins in social-affective tensions, and when students are willing and able to resolve the conflict through argumentation. Webb (1995) states that avoiding conflict, because of the domination of a group member or from social pressure not to challenge others, will prevent individuals from recognizing and exploring different perspectives, beliefs and strategies. Light, Littleton, Messer and Joiner (1994) studied the verbal interaction of 11-year-old students who worked in pairs on a computer route planning task. Negotiation was one of the verbal interaction categories that were distinguished in the coding scheme. During negotiation a given move or strategy is discussed, a proposal from one child is met by opposition or a counter-proposal and this is then followed by one or more further utterances in which the children try to overcome the contradiction. Negotiation turned out to be one of the significant predictors of increased pair performance and subsequent higher individual outcomes.

2.3.2 Peer interaction implies the co-construction of meanings

In another line of research on peer interaction, researchers do not focus on the behavior of individuals in social interaction, but on the social dynamics and the co-constructed features of peer talk. “Mutual understanding”, “shared thinking” and “negotiation” are terms that are frequently used within this line of research. When peers work on a common task, mutual understanding must be created and sustained continuously (Roschelle, 1992). To coordinate activities and to achieve a common product, the collaborating students need to create a shared meaning of the task, the concepts, procedures and strategies that are used.

Can we distinguish between types of peer talk in which meanings are co-constructed in varying degrees? Few researchers make a distinction between categories of talk that reflect different degrees and different types of co-construction. Mercer (1995) distinguished between disputational, cumulative and exploratory talk. In disputational talk students show little interest in achieving a shared understanding. However, in both cumulative and exploratory talk, students co-construct understanding. Cumulative talk is described as the accumulation and integration of ideas without critical challenges. In exploratory talk students engage critically but constructively with each other’s ideas. Mercer considered exploratory talk more valuable for learning because there is no automatic consensus (as with cumulative talk) or unproductive dispute (as with disputational talk), but rather productive argument, questioning and exploration. Wegerif (1996) found that the appearance of exploratory talk between students working on a computer task improved the problem solving of the group in addition to the individual scores on a post-test. Crook (1998) used the term “collaborative engagement” to describe situations in which collaborating students are actively engaged in each other’s ideas and reasoning and try to reach a shared understanding. Baker and Bielaczyc (1995) described a situation in which students do not join in when their partner is engaged in higher level elaboration as a missed opportunity.

What enhances and what hinders the creation and maintenance of a mutual understanding? The mechanism that leads to a mutual understanding is frequently described as negotiation (Baker, 1994). It is constituted by asking verification questions (see also Graesser et al., 1993; Erkens, 1997), giving explanations, arguing when in conflict (Baker, 1994), and by gesturing and using facial expressions (Schegloff, 1991). Baker and Bielaczyc (1995) suggest that missed opportunities to co-construct may occur when there is a spontaneous task division, when students are at a different phase of problem solving and fail to maintain a shared focus, or when students are focused on reaching agreement without adopting a critical attitude. Clark and Brennan (1991) state that the possibilities to reach a common ground are also shaped by the medium of communication. In face to face communication where participants share the same physical environment, it is easier to reach and maintain a common ground. Delayed communication, as evidenced in written letters, email and phone communication, imposes certain constraints on the grounding process. Clark and Brennan also show how a shared past can facilitate the grounding process. When collaborating persons know that they share some experiences, less effort has to be made to check if meanings are shared. A shared past makes it also possible to refer explicitly to particular experiences that may help in creating and repairing a mutual understanding. Next to the use of language, shared objects and tools can also play an important role in the negotiation and co-construction of meaning during communication. Crook (1998) states that most analyses of student talk in the context of collaborative learning neglect the importance of how a collaborative learning situation is resourced. He argues that collaborating students will benefit from referential anchors because they can support the construction of a shared understanding: *"The more abstract the terms of the problem, the more helpful it may prove to have external representations that resource the construction of a shared understanding"* (pp. 241). Finally, Crook argues that a certain commitment between the collaborating persons is necessary. The collaborating persons must be *willing* to make an effort to reach mutual understanding. In line with this assumption, Azmitia and Perlmutter (1989) report that the appearance of mutuality is more likely when the students who collaborate are friends. Friends are more likely to share resources, resolve conflicts, give explanations of their actions and try to change each other's opinion.

2.3.3 Conclusion

The different lines of research on peer interaction consider *the need, the willingness and the possibility to negotiate meaning* as important aspects of peer interaction that facilitate learning and understanding. However, the process of negotiation is described differently. The first line of research that was discussed above stresses that the need to negotiate triggers the verbalization of understanding and thinking and stimulates the awareness of knowledge gaps and the giving of explanations and justifications. Many of these studies tried to relate elaborative utterances of individual students to individual task performance measures. This research is in line with the constructivist perspective, in which elaboration is seen as a strong concept to explain the appearance or lack of conceptual understanding. The features of social interaction are believed to affect the cognitive processes within the individual. Several studies gave some empirical proof for the suggestion that elaborative talk contributes to the use of more elaborate conceptions in subsequent situations. Section 2.3.1 described different types of elaborative talk, such as reasoning, giving elaborated answers and arguing to resolve a conflict. These types of talk are elaborative because they include the active use of preconceptions, the construction of meaningful relations and the explicit comparison of different conceptions (enhanced by the asking of questions and the appearance of controversy).

In socio-cultural studies we rarely come across the term elaboration. This is probably because elaboration is usually described as an "individualistic" learning activity or strategy. From a socio-cultural perspective, learning and cognition are distributed over the whole social and physical environment and the socio-cultural activity is used as the basic unit of analysis. Peer talk is not considered to be an independent variable that affects an individual's understanding of meaning. Meanings are produced in the course of the social activity and have a co-constructed nature. Some of the research on peer interaction and learning especially focus on the way meaning is negotiated and co-constructed in the dynamics of the social interaction. These studies describe negotiation less as a process of verbalization and elaboration, but as a process of achieving a shared meaning. Common ground allows for joint thinking and the co-construction of meanings which can then be appropriated by the individual.

Both lines of research also suggest factors that shape the need, the willingness and the possibility to negotiate meaning. (Socio)constructivists, for example, stress the role of prior knowledge, the personal motivation to understand, the skills to resolve controversy and the equality of the group members. Socio-cultural researchers suggest that a face to face situation, the availability of shared objects and tools, shared experiences, an amicable relation and a willingness to reach mutual understanding can facilitate the process of co-construction.

In sum, trying to learn from the results of both lines of research and from the different perspectives on the relation between social interaction and learning (see also Van der Linden et al., in press), I suggest a provisional answer to the question of what kind of peer talk can contribute to the learning of concepts. I hypothesize that peer talk that is specifically characterized by talk about the concepts, elaborative contributions of the participants and a continuous attempt to achieve a shared understanding of the concepts while making maximum use of the available mediational means, contributes to the learning of concepts.

2.4 The Role of the Collaborative Learning Task

How can we stimulate the appearance of peer interaction which achieves understanding through elaboration and negotiation? Besides prior knowledge, personal motivation and the composition of the group, the task design is another important factor that can shape the need, the willingness and the possibility for students to negotiate meaning. In school settings peer interaction is typically organized in cooperative or collaborative peer workgroups. This thesis is confined to collaborative learning tasks that are performed in a face-to-face interaction. First I shall explain why I choose to work with collaborative learning tasks. Second I will describe different characteristics of collaborative learning tasks that may affect the quality of the student interaction.

2.4.1 Collaborative learning tasks

Designs for collaborative learning tasks share two important features: a) the participants are supposed to share goals, tools and activities and b) the participants are supposed to have an equal opportunity to contribute and participate in the discourse. Collaborative learning needs to be distinguished from cooperative learning and peer tutoring. Examples of cooperative learning groups are those in which students help each other while still maintaining their *own* worksheet, and groups in which each student does a different part of the group task. In contrast to cooperative learning groups, in collaborative peer workgroup students try to reach a common goal and share both tools and activities (Webb & Sullivan Palincsar, 1996). When students are simultaneously involved in the execution of the same task and must achieve a common goal, there is a need to talk, to share ideas, to coordinate and to negotiate meaning. Shared goals enhance a positive interdependency between the collaborating students (Cohen, 1986; Johnson & Johnson, 1992). A positive interdependency exists when the participants of the group perceive that they cannot succeed unless the others do, and that they must coordinate their efforts with the efforts of the others to complete the task. (Johnson & Johnson, 1992). In collaborative peer workgroups, however, a positive interdependence is commanded by neither a division of labor nor a division of necessary resources.

Further, in contrast to peer tutoring, in collaborative peer workgroups the participants have comparable knowledge, capacities and status. Peers may more easily adapt to each other's level of understanding and, when the peers are classmates, the shared experiences in class may facilitate the negotiation of meaning. Collaborative learning tasks aim at a symmetrical participation in the interaction. The participants must have an equal opportunity to contribute.

I started from the idea that collaborative learning has a strong potential to engage students in activities that are valuable in the process of concept learning, such as verbalization of their understanding of the concepts, (collaborative) reasoning with the scientific meanings of concepts, the asking and answering of questions, the elaboration of conflicts and the generation, comparison and evaluation of explanations. When no task division is imposed, the peers can collaborate face-to-face and when the collaborating peers share the same sort of prior instruction in the domain, there is a good basis for negotiation and co-construction. Participation in peer "talk" gives students the opportunity to use, negotiate and co-construct the meanings of physics concepts. However, it is not guaranteed that a high quality discourse will always occur in collaborative peer workgroups. Simply providing a collaborative learning task does not guarantee that the students will engage in collaboration and elaboration. Student talk in collaborative learning groups can also be characterized by competition, asymmetrical participation and a narrow focus on finishing the task instead of actually understanding the concepts. A task division may occur spontaneously during collaborative learning, although it is not imposed or stimulated by the instruction or the task structure (Erkens, 1997). Shared goals may be imposed by the task but also have to be negotiated and settled during the process of collaboration.

It is of interest to know how desired patterns of peer talk can be promoted. Kumpulainen (1996) and Bennett and Dunne (1991) found that the quality of students' talk was closely linked with the nature of the task design. O'Donnell and Dansereau (1992) and Cohen (1994) state that task characteristics will influence the type and amount of processing and will consequently affect the outcomes of collaborative learning. Although collaborative learning tasks share the two features that are described at the start of this section, collaborative learning tasks can differ from each other on several points. In the following section I consider important characteristics of collaborative learning tasks and the way they can influence the quality of student talk.

2.4.2 Task characteristics

In this thesis I consider task characteristics apart from the domain, the learning goals, the reward structure and the training in, for example, specific discourse or collaboration skills. Collaborative learning tasks can differ from each other in their design through the kind of product that is asked for, the tools or resources that are available, and the script that is given which may impose a sequence of particular activities or which may structure the interaction and the use of the resources that are available. Below I will briefly discuss these characteristics of task designs and how they may influence the quality of peer interaction.

2.4.2.1 The group product that is asked for

Group products can be material or verbal, can require concrete or abstract activities, and can be divergent or convergent. Students can be asked, for example, to reach agreement about a statement that serves as input in a class discussion. In this case, the group product is verbal. Material products, such as posters, written reports or objects, facilitate interaction because students can refer to parts of the product that they are constructing (Roth & Roychoudhury, 1993). The products provide a joint working space on which the results of joint thinking can be made visible. However, making a concrete product can also hinder a more conceptually oriented discourse. When numerous concrete actions are needed to construct the product, utterances related to these actions can dominate student talk at the cost of abstract talk (Bennett & Dunne, 1991). Carter and Gail Jones (1994) conclude that when groups are engaged in experiments, this group work may lead to “hands-on-science” without “minds-on-science.” Furthermore, tasks may differ from each other in the degree to which they are “open”. Cohen (1994) suggests that products with answers not fully predetermined (open tasks) and with multiple acceptable solutions are more suitable for collaborative learning. According to Baker (1994) a collaborative learning task must create the “room” and the necessity for negotiation. Attempts to understand may be discouraged when only one correct answer is emphasized. In that case, the students may trust too much on the participants that seem to have more understanding and on authorities, such as textbooks or a teacher.

2.4.2.2 The tools that are available

Wertsch (1991) describes the study of learning as the study of people in action using tools. Säljö (1995) suggests that learning is also the growing ability to use a particular set of tools in productive ways and for particular purposes. Artifacts that are the residue of cultural behavior can enable, constrain and shape ways of thinking and acting. Concrete tools, such as textbooks, simulation programs or materials to perform an experiment, can offer students exploration and manipulation possibilities, but they can also structure and sustain communication.

The way tools represent information (in words, graphs, pictures or animation), and the way this information is organized can affect the discourse of students. Roschelle (1992) showed, for example, that diagrams can be social tools for achieving convergence of meaning in a discourse, because they can support individual reasoning and facilitate negotiation of meaning. Sometimes researchers provide specific tools because they are believed to result in more elaborative talk. King (1992), for example, trained students to use question-stems on cards which could assist them in asking higher level questions about the materials. She reported positive learning outcomes. Roth and Roychoudhury (1993) showed that students who co-construct a relation between two physics concepts not only use verbal and non-verbal mediation but also use diagrams, pictures, texts and experimental materials to reach agreement. Diagrams were used to ascertain that they were talking about the same thing. Sometimes passages in a textbook sustained students in explaining their understanding of a concept during controversy, or functioned as an extra source of feedback.

A textbook is an artifact that is both material and conceptual at the same time. Conceptual constructions are incorporated in the text and figures printed on paper. Although the role of textbooks is changing (due to a shift to learning environments in which students actively construct their own knowledge) they are still an integral component of education. A textbook is often a method that scripts a certain sequence of learning activities, but a textbook can also be one of the tools available to a group to support communication and negotiation in order to complete a group task. Although there is a growing amount of research on the use of information and communication technology in collaborative learning situations, there is little research that gives insight into the way more traditional resources such as textbooks are used during collaborative learning tasks and in how this use affects the content and patterns of student talk and the learning outcomes. Answering these questions may add to our understanding of the way certain resources have a role in shaping peer collaboration and learning. It may also help us with the design of adequate support of the use of resources in collaborative learning environments.

2.4.2.3 Scripting student activities and interaction

A script can describe the nature and sequence of activities that a group has to be engaged in as well as specifying the roles played by the group members (O'Donnell & Dansereau, 1992). A script can force the students to follow a desired pattern of verbal interaction whereas scripting roles can include the specification of management roles, such as question commander, materials coordinator, reflector and encourager (Kagan, 1992). The assignment of such procedural roles is especially applicable in groups of three or more students. Scripted cooperation and reciprocal teaching are examples of scripting student interaction through the assignment of roles that force the students to engage in certain activities, such as summarizing, questioning or elaborating (both discussed in King, 1999). These procedures appeared to be effective for the learning of factual material and remembering prose. Structuring interaction through a role division can stimulate positive interdependency and can result in higher learning outcomes (Yager, Johnson & Johnson, 1985; O'Donnell & Dansereau, 1992). However, Cohen (1994) and Salomon and Globerson (1989) indicate that when conceptual learning is the goal, interaction should not be heavily structured. A free exchange of ideas, hypotheses and strategies is needed in order to stimulate conceptual understanding and a task or role division may hinder such a conceptually oriented interaction.

Some research focuses on forms of collaborative learning in which no roles are assigned but a desired discourse pattern is stimulated by training students to ask thought-provoking questions (King, 1989, 1992), generate explanations or use certain social norms (Palincsar et al., 1993). In the collaborative problem solving program that was conducted and researched by Palincsar et al. (1993) small groups had to generate a solution to a science problem related to matter and molecules. As part of the scripting of the sequential activities, students were asked to individually generate their own solutions to the problem before meeting in small groups. This procedure was meant to activate prior knowledge, but also stressed the expectation that each student would then contribute to the group work. Although imposing such an individual preparation phase can be considered another form of scripting the student interaction, in this study the effects on the asymmetry in student participation and the appearance of co-construction and argumentation were not investigated. Another form of scripting that to my knowledge, has also not previously been investigated, is in the use of resources such as textbooks or experimental materials, during collaborative work. A script might promote the use of such resources in a way that supports and promotes the elaboration, negotiation and co-construction of conceptual understanding.

2.4.3 Conclusion

Characteristics of the task design are important because they may constrain or facilitate a productive peer interaction. Collaborative learning tasks must be carefully designed if optimal features of peer interaction are meant to occur. Of course, task characteristics may interact with: characteristics of the classroom setting in which students collaborate, previous experiences with comparable tasks, previous experiences with collaborative learning and with the composition of the group. However, these aspects of the collaborative learning situation are not a focus of this research. The research project that is reported on in this thesis focuses only on collaborative learning tasks in relation to patterns of peer talk and outcomes.

In the 1980s there was a considerable amount of research done on the effects of different group tasks and cooperative structures (Johnson & Johnson, 1990; Slavin, 1983). Most of these studies focused on the outcomes of peer workgroups and not on the processes that appeared in them. Recent studies on the relation between tasks and patterns of peer talk deal mostly with cooperative learning tasks and often focus on the way interaction is scripted through a task division or the assignment of roles. Much less is known about how task characteristics shape the peer interaction in collaborative learning settings. This especially holds for the product that is asked for and the tools that are available. What type of group product, and what kind of tools in collaborative peer workgroups can support both individual and collaborative reasoning with concepts and the construction of a mutual understanding? Few attempts have been made to investigate which tasks can contribute to both elaborative talk *and* to the process of co-construction in order to achieve a mutual understanding. Further, we cannot simply generalize earlier findings about the relationships between task characteristics, the quality of peer interaction, and learning results to situations in which our goal is learning *physics concepts*. Therefore, we need to study the more specific question of what kind of collaborative learning tasks can contribute to a peer interaction which enhances the learning of physics concepts, and how this contribution can be explained.

3 The Studies in this Thesis

In the previous chapter an outline was given of the theories and studies related to the learning of physics concepts, the potential of student interaction, and the role of the task design. Figure 1 gives a visual representation of the theoretical framework that constituted my research on collaborative concept learning. The framework that is presented in Figure 1 shall be discussed in more detail below. I will conclude this part by presenting the main research questions. The second section describes the method of the three empirical studies.

3.1 Research Questions

Figure 1 is based upon the idea that the student interaction during a collaborative learning task is shaped by the participation of the students, their participation in previous but also subsequent situations (because the task functions as a preparation for these situations), the features of the task and the broader setting. I prefer the term ‘shaped’ because it better reflects the idea that what is in the outer circles of Figure 1, can be considered planes of the collaborative learning activity. I consider them to be independent factors that influence each other for the sole purpose of analysis. The figure also reflects a focus on both the individual activity and the collaborative activity as a unit of analysis.

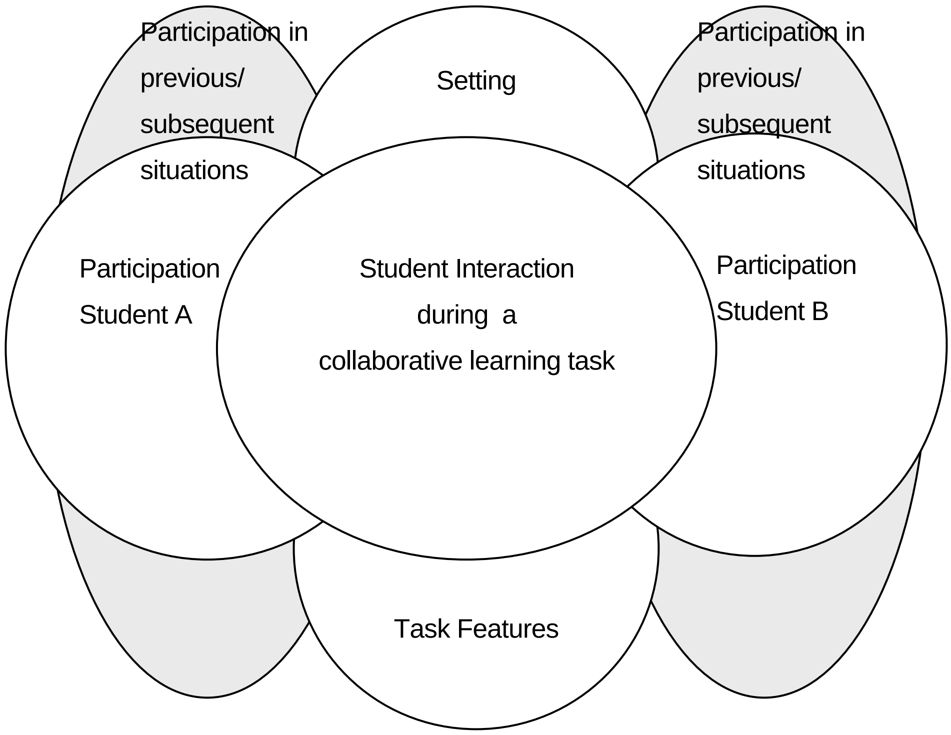

Figure 3.1 Theoretical framework of the research

In section 2.2.3, the learning of physics concepts was described as the changing way a person participates in situations that require the use of scientific conceptions and forms of reasoning. More specifically, it was described as the growing ability to think, speak and act with physics concepts in their scientific meaning. The participation of a student in situations that precede the collaborative work, the participation in the interaction during the collaborative learning task, and the participation in subsequent situations can be related to each other. I prefer the term participation, because it better reflects that the behavior of individual students is situated and social: it is shaped by the setting, the task, the participation of the partner, the dynamics of the interaction and previous experiences.

The discussion of the existing literature on student interaction (section 2.3.3) was concluded with the hypothesis that a student interaction that is characterized by talk about the concepts, elaborative contributions from the participants, a continuous attempt to achieve a shared understanding of the concepts making maximum use of the mediational means that are available, contributes to concept learning. The studies that are discussed in this thesis are meant to test this hypothesis.

Does the verbalization of the understanding of the concepts, elaborative talk and co-construction of the meaning of and the reasoning with the physics concepts contribute to the learning of these concepts? Does student talk which reflects collaborative engagement and a continuous attempt to achieve a mutual understanding contributes to the learning of concepts? In sum, how do the features of the interaction, and the way an individual student contributes to this interaction (his or her participation in the interaction), relate to the performance of individual students in subsequent situations in which they are asked to use these same physics concepts?

It was stated in section 2.4.3, that the features of collaborative learning tasks, which include the kind of group product that is asked for, the instruction or script that is given to structure interaction and the use of the tools that are available, affect the quality of the student interaction. The features of the task are defined in the design of the task, but are also shaped in the collaborative learning activity itself. Several important questions regarding the features of the task can be investigated. What kinds of collaborative learning tasks are suitable to enhance a student interaction that contributes to the learning of physics concepts? How do features of the task influence the appearance of elaboration and co-construction of meanings in the student interaction? Can we trace the features of student interaction to the characteristics of the task design?

Aside from and partly independent of task characteristics, also student characteristics, such as prior knowledge and interest, and the broader setting in which the task takes place will affect the quality of the learning processes during the group work. A focus on understanding, which often goes together with interest in and some initial understanding of a domain, is believed to influence the amount of engagement and persistence the students show (Alexander & Kulikowich, 1994; Hidi, 1990; Krapp et al., 1996; Pintrich et al., 1993; Tobias, 1994). However, there is hardly any research that studied this assumption in the context of collaborative learning. It is likely that what a student ‘brings’ to the collaborative learning session due to previous experiences within the domain and with collaborative learning tasks, is also at work in the shaping of the student’s participation in the discourse. A student who is interested in the domain and has a lot of experience in using the domain-specific concepts may produce more (elaborative) talk than a student with less interest and prior knowledge. The question regarding the relationship between the participation of

the students in the interaction and student characteristics, shall be addressed in the empirical studies of the present research project, although it is not a main research question.
The broader setting in which students work on a collaborative learning task will also shape the collaborative learning processes. Values, practices and communication patterns in Dutch schools and in the Western culture will be different from goals, tools and patterns in other school systems and cultures. The quality of the learning climate in classrooms will affect student activities. Although I recognize the importance of this cultural dimension, it is not a subject of the research.

The current research project attempts to answer the following main questions:

1 How do features of the collaborative learning task affect the student interaction?
2 What kind of student interaction contributes to the learning of physics concepts?

3.2 Method

3.2.1 Subjects and collaborative learning tasks

Subjects of the studies are between 15 and 16 years old students from physics classes in intermediate general secondary education (in Dutch: 4 HAVO). The subjects work together in dyads on a collaborative learning task which functions as the introduction to a new course about electricity. In the upper level of secondary schools the students are expected to have developed some initial understanding of concepts such as energy, voltage, current and resistance. Throughout this new course about electricity, the students are expected to use the electricity concepts to improve their understanding of the concepts and to use the concepts to solve problems, and to describe and explain phenomena. Students from the *higher* classes of secondary education are chosen as subjects because these students are already familiar with electrical concepts and terms. A fruitful discussion and negotiation about the meaning and the use of concepts requires that the participants are at least familiar with the terms and have some initial understanding of the concepts and their interrelationships. A second argument for using the more advanced students is that these students have more experience with collaborative learning, so it is less likely that a lack of collaborative skills will put a severe constrain on the peer collaboration. Further, these particular students have voluntarily chosen to undergo an examination in physics (even though in the last two classes of intermediate general secondary education physics is not a compulsory subject), so that it is less likely that a complete lack of motivation to understand physics will constrain active participation.
I decided to work with collaborative *dyads* because I expect that this form is most likely to create maximum opportunities for all students to communicate about the concepts. The constructivist perspective on learning stresses the need of active participation in valuable learning activities. A larger group may encourage asymmetric participation or may lead to cognitive overload.
The choice to work with tasks that function as the *introduction* of a new course about electricity is based upon two considerations. First, throughout the course the students will be confronted with the use of electricity concepts by the authors of the textbooks and by the teacher. The students will also be asked to

use the concepts themselves in several problem solving questions, laboratory work and class discussions. I believe that a collaborative learning task may prepare the students for using the physics concepts during the course, as well as in future situations. Different authors (see section 2.2.1) advocate the verbalization of conceptual understanding to enhance an explicit comparison between these conceptions and those that are used in textbooks and by teachers. Driver et al. (1994) describe several group tasks that are meant to give students the opportunity to make their ideas and understanding explicit and available for reflection and checking before starting a new curriculum unit. Driver suggests that an elicitation phase in which students can generate and discuss their own concepts should be followed by a phase in which students can explore and use new concepts and then can compare them with their previous ideas in order to achieve organization and restructuring (1994, 1988). Further, as was discussed in section 2.1.1.3 about the learning of concepts within the domain of physics, it is considered important that the students gain some qualitative understanding of the concepts before they engage in algebraic manipulations with formulas. A starting task can focus on the exchange and negotiation of such qualitative understandings. Second, the verbalization and negotiation of the meaning of the physics concepts may promote that the students become aware of a lack of understanding and of the existence of different perspectives. It is likely that the students are more eager to search for answers or test hypotheses during the rest of the course when they themselves have posed the questions and the hypotheses are also based on differences of opinion they have experienced themselves. Besides, the group product may be an extra tool for the teacher to diagnose the way the students use the electricity concepts and which problems they have in using the concepts in their scientific meaning. In sum, there are good reasons to assume that a collaborative learning task may be especially useful to *start* a new curriculum unit. Although it is of interest to know how the collaborative learning tasks affect activities and conceptual understanding during the rest of the course about electricity, this question is not addressed in this research project.

3.2.2 Design

To answer the research questions, an intervention study is chosen for the following reasons. First, in order to investigate whether elaborative talk and talk in which students co-construct meanings are related to the learning of concepts, we need to promote the chance that this kind of student interaction actually occurs. The task is an important instrument to promote certain kinds of talk. I try to design collaborative learning tasks that can elicit the desired patterns of student interaction. Second, a systematic manipulation of the features of the task design makes it possible to study more systematically the way task designs shape the patterns of discourse.

Concept learning is a long-term process that is shaped within a broad range of activities. The situations in which these activities take place can be more or less interactive. It is assumed that participation in a collaborative learning task would contribute to the improvement of conceptual understanding. Damon (1991) states that from a developmental point of view it is important to know what individuals bring with them to the interactive setting and what they take away in a lasting sense from such settings. Salomon and Perkins (1998) suggest that from a constructivist perspective there exists a spiral of reciprocal relations between socially distributed understandings and individual cognitive ones. They made a distinction between the effects with and the effects of social interaction in peer workgroups. The *effects with* are to be found in the process while students are engaged in collaboration. The *effects of* are the cognitive, social, metacognitive and affective “residues” of these activities that will affect learning and behavior in new situations, either of individual students or of the group. In the context of a collaborative learning environment which is meant to contribute to concept learning, elaborative activities and activities which reflect collaborative engagement can be considered as the desired ”effects with,” and improvement of conceptual understanding reflected by a change in the way students use certain physics concepts in new situations as the desired “effect of.” To study how participation in peer interaction changes the way a student uses the physics concepts, a pre-test post-test design is chosen. In this study the individual learning outcomes will not only be related to the individual participation of the students in the interaction (how much the student talks and what the character of that talk is) but also to the features of the interaction that can only be described on the group level (for example, the appearance of co-construction). The method that is used to analyze student talk at these two levels will be described in the following section.

3.2.3 Analyses of student interaction

Although within the socio-cultural line of research the methods are still developing, most socio-cultural researchers use the social activity as the unit of analysis and analyze how in the dynamics of social interaction the individual, interpersonal and cultural aspects are simultaneously at work. Rogoff (1995) suggests that in the study of social activities the institutional, interpersonal and individual processes cannot be separated, but that the researcher may focus on one plane without losing sight of the other planes in the background. She uses the term “planes” to stress that the processes do not exist as separate entities but are only analytic distinctions. The same idea underlies the theoretical framework of this research, as was presented in Figure 1 (section 3.1). Interpreting the behavior of the individual requires some attention to the broader situation in which this behavior occurs. In this study I foreground both the individual plane and the interpersonal plane of the discourse. The study does not focus on the institutional plane which includes, for example, the culture of the class, the school and the educational system in which these schools participate.

Many studies into collaborative learning focus only on the level of individual utterances and acts, or only on the group level that reflects the co-construction and negotiation of meaning. The unit of analysis is of course related to the perspective on learning and the research questions. Recently, Kumpulainen (1997) argued that an analysis method that pays attention to different levels and aspects may unite some features from cognitive, socio-constructivist and socio-cultural perspectives to learning. Coding the protocols only on the utterance level, that can give a description of the participation of a student, does not give a description of the dynamics of the student interaction, for example of the way students construct reasoning or resolve a conflict. The contingencies of the actions of both partners also need to be categorized (Grossen, 1994). The coding scheme that is designed in the present study is based on the hypothesis that verbalization of conceptual understanding, elaboration of conflict, co-construction and the asking and answering of questions are important aspects of student interaction that can contribute to concept learning. The categories of the coding scheme had to “grasp” the verbalization of one’s own understanding, elaborative talk, co-construction and the use of available tools. The method that is used in this study consists of a two-level and a two-dimensional analysis. It focuses on both utterances and meaningful episodes and on both the communicative dimension and the content dimension. An extensive and refined category system is considered necessary to describe the complex dynamics and co-constructed nature of student interaction. The levels and dimensions must be considered as analytical tools and not as separate entities that exist in reality.

I do not want to confine the analyses of the student talk to only a few transcripts. Detailed and comprehensive analyses are very useful to show how the student interaction is shaped by several elements, such as the cultural setting, the tools that are used and previous experiences. However, to make a systematic comparison of the quality of talk between dyads working on different tasks and to relate features of verbal interaction to the outcomes of the collaborative activity, in this study all transcripts are analyzed in a quantitative way. A possible drawback of such an analysis is that significant correlations between the incidence of some kinds of talk and outcomes do not *explain how* such behavior contributes to learning (Wegerif & Mercer, 1997). In the presentation of the results, this criticism is partly obviated by not only presenting the results of the statistical operations but by also including transcribed extracts of talk with comments. These examples also give the reader an opportunity to check the interpretations of the researcher.

3.2.4 The three experimental studies

This thesis reports on three experimental studies. The three experimental studies all examine whether the collaboration on the task results in an improvement of the individual use of the physics concepts (as measured by the comparison of scores on the pre- and post-test) and in all studies individual learning outcomes are related to the features of the verbal interaction. In each study I manipulate the task design and compare the student interaction that emerges in the different task conditions. The first experiment focuses on how the nature of the group product that is asked for affects the quality of peer talk. A concept mapping task is compared with a poster task. This experiment also investigates the influence of scripting a phase of individual preparation before starting collaborative activities. The results of this first study and the new questions that it generated lay the foundation of the design of the second experimental study. In the second study a more comprehensive concept mapping task, in which characteristics of the poster task are also included, is used. However, this study is not only meant to investigate the effects of this new group product that is asked for, but specifically focuses on the way textbooks are used as an extra tool during the collaborative accomplishment of the task. A comparison is made between student interaction and learning outcomes in conditions with and without the availability of textbooks. Based upon the results of this study a third study is designed to investigate the effects of two scripts that were meant to elicit a productive use of a textbook during collaborative concept mapping.

The following chapters describe in more detail the research questions as well as the methods of the three experimental studies.

4 The First Study

This chapter presents the results of the first experimental study that was carried out in the context of this research project. The first section presents the results of a search for suitable tasks which would engage students in elaborative talk about electricity concepts, and which therefore could function as the introduction of a new unit about electricity. The research questions and hypotheses are given in the second section. The third section describes the experimental tasks, the subjects, the procedure and the tests and questionnaires that were used. This section also presents the coding scheme that was developed to analyze the communicative functions and propositional content of utterances, as well as the elaborative episodes in student talk. In section 4 the results of the study are presented and illustrated with examples of student talk. Finally, the chapter concludes with a summary and a discussion of the main results. This section also includes some *new* questions that resulted from the study.

4.1 Collaborative Learning Tasks for Concept Learning

Which tasks encourage students to co-construct conceptual meanings through active participation in a discourse? Which tasks facilitate collaboration and engage students in elaborative activities? Two types of collaborative learning tasks described in the literature seem to be suitable for collaborative learning that contributes to the improvement of conceptual understanding. These tasks may elicit elaborative talk about physics concepts and therefore function as a good introduction to a new curriculum unit about electricity. In the following two sections, the selection of a concept mapping and poster task is explained. I describe the potentials of these tasks as well as their possible drawbacks. In the third section, the choice to also investigate the effects of a phase of individual preparation before starting the collaborative work is clarified.

4.1.1 Concept Mapping

Concept mapping originated in the study of changes in students' understanding of science concepts (Novak & Musonda, 1991), but soon became an instructional tool to promote conceptual understanding. Concept maps are diagrams indicating interrelationships among concepts and representing conceptual frameworks within a specific domain of knowledge (Novak, 1990). A concept map represents the main concepts and relations within a domain. It is a network in which the nodes represent concepts, the lines linking the nodes represent relations and the labels on the lines represent the nature of the relations. Within the domain of physics the propositions describing the relationships between concepts mostly reflect physical laws. For example, within the domain of electricity the concepts voltage, current strength and resistance can be related to each other. A possible proposition to describe the relationships between these concepts is "*if the voltage increases, then the current strength increases, provided that the resistance does not change*." This regularity is a qualitative description of Ohm's law ($I = V/R$) which accounts for the observation that current strength is proportional to the amount of voltage.

Several studies have shown that concept mapping results in meaningful learning. A meta-analysis of Horton, McConny, Gallo, Woods and Hamelin (1993) reports a moderate positive effect on student achievement and a large positive effect on student attitudes. Making a concept map helps learners become aware of and reflect on their own (mis)understanding. It helps students take charge of their own meaning making (Novak, 1990a). Further, it contributes to the development of an integrated conceptual framework. Roth and Roychoudhury (1993, 1994) argue that concept mapping as a *collaborative* activity promotes communication and negotiation about meaning. Concept mapping engages students in talk about meaningful conceptual relationships. The requested group product forces students to pay attention to key principles in the domain, and thus stimulates “abstract talk”. Because it is an open task with no predetermined or fixed answers, collaborative concept mapping elicits negotiation. The product serves as a visible representation that can facilitate communication about abstract concepts and relationships. Students can refer to the concept labels and the propositions of the emerging map while verbalizing their ideas and negotiating meaning.

In most research on concept mapping, students constructed a concept map after they had completed a unit of laboratory work, lectures and other assignments. Roth and Roychoudhury (1993) report that a negative outcome of such concept mapping tasks is that scientifically incorrect notions sometimes become ingrained or go unchallenged. When a concept mapping task is used as the introduction of a curriculum unit, this may be considered less of a problem because the subsequent student activities and instruction can be focused on an explicit comparison of new information with the conceptions that are expressed in the concept maps. Novak (1990a) suggests that a concept map can be an important tool for teachers to diagnose the use of meanings and relations of concepts that are scientifically incorrect. This implies that students who co-construct a concept map will also verbalize and negotiate partly unscientific conceptions. Such verbalization and negotiation may also be a functional start to a new curriculum unit.

Another important drawback of concept mapping is that it tends to focus on theoretical relationships. Concept mapping frequently elicits talk about the meaning of electricity concepts and their interrelationships. It does not however, focus on the way the concepts and their relationships are used to describe and explain concrete phenomena, yet this is where problems tend to arise for many students (see chapter 2). Learning to use these physics concepts to describe or explain a certain phenomenon can be considered an important part of concept learning. Trying to explain a concrete phenomenon may be a stronger task to elicit such talk.

4.1.2 Explaining a concrete phenomenon

At the phenomenological technical level electricity can be associated with electrical appliances, batteries, bulbs and wires. Phenomena such as the shining of a bulb or the working of an electric heater can be described and explained in terms of electricity concepts. There have been some empirical studies in which the subjects had to collaborate on an explanation task which functioned as a first task of a curriculum unit.

Schmidt et al. (1989) found that a small group discussion in which the participants try to explain a phenomenon in terms of underlying principles or mechanisms can organize and reorganize prior knowledge while facilitating the comprehension of new information. In their study the students, who had not studied osmosis for nearly two years, were asked to discuss why a red blood cell shrinks when it is put into a salt-water solution, whereas a red blood cell that is put into pure water swells and bursts. After discussing the ‘blood cell problem’ in a small group, the students were then asked to read a text about osmosis and diffusion. Finally, a free recall test was administered without time limits. Compared with the students in a control condition in which the students could not discuss the problem, the students who discussed the blood cell problem before reading the text recalled significantly more explanatory propositions. The researchers suggest that the discussion about the underlying processes of the phenomenon induced the subjects to pick up explanatory information from the text. During the discussion the students became aware that their conceptual models had only limited explanatory power. And although sometimes the explanations that the students gave were incorrect from a scientific point of view, generating and formulating such explanations was helpful in mastering new information.

The group product that was asked for in the study by Schmidt et al. was strictly a verbal product. Driver (1988) and Driver et al. (1994) describe a group task in which the students not only had to discuss a possible explanation, but were also asked to present it on a poster. Driver considers such a poster task to be a suitable group task in the phase of generating ideas. For example, in the context of a course on the structure of matter, the students begin by providing their own explanation of 'how a smell reaches you'. At the end of the course students revisit their posters and reflect on the changes in their explanations. As with the concept mapping task, a poster task also has the advantage of facilitating interaction within the group through the group product. The students can refer to the explanatory model that emerges on the poster while verbalizing their ideas and negotiating meaning. When the students are also provided with some physics concepts, these concepts may function as additional tools to help generate and negotiate scientific explanations.

4.1.3 Individual preparation

A collaborative learning task implies a common task on which all group participants work simultaneously. Therefore a task division was not scripted in this study. A role division would be artificial and probably less necessary in the case of dyadic learning. However, without a task or role division it becomes more important that the requested group product, the tools that are available and the instruction that is given stimulate a symmetric participation, elaboration and shared ideas. Besides scripting a task or role division it is also possible to script the sequence of activities. When a group task functions as the start of a new unit, it may be useful to allow the students to prepare individually before starting collaborative activities because it has been some time since they have previously worked with the physics concepts in prior school years. Palincsar and others (1993) used such a sequenced script with a collaborative problem solving task. They developed a group task for collaborative problem solving in the domain of physics. Students were asked to write down their own solution before they met in groups. This procedure was meant to not only activate relevant prior knowledge, but also to stress that each student was expected to contribute to the group work. However, the effects on student interaction and learning outcomes were not investigated (see also chapter 2).

Individual preparation may increase questioning (because students become aware of knowledge gaps or misunderstanding during individual preparation) and conflict (because students want to defend their own ideas when they are sure about them). Second, individual preparation may also result in a more symmetric participation in the interaction. The request to prepare individually stresses that each student is expected to contribute to the group product. When students are very insecure about their knowledge, individual preparation may help them to participate in the discourse. It is likely that a student will verbalize his ideas better after he has explicitly written them down on paper. Finally, it is possible that students who prepare individually for a collaborative learning task experience a clear difference between what they can do and understand on their own and what they can do in collaboration with another student. This may result in a more positive evaluation of the collaborative work.

4.1.4 Conclusion

A concept mapping task and a poster task were chosen for this study because they have a strong potential for engaging students in elaborative talk about and 'with' physics concepts, and also because the tasks are suitable for collaborative work. Both the concept mapping and poster tasks are open-ended tasks in which students work on a concrete product. A concept mapping task focuses specifically on conceptual meanings and relationships, and may therefore be less powerful in provoking talk in which physics concepts are used to explain concrete phenomena. A poster task may have more potential to elicit such talk, especially when students are *asked* to use certain physics concepts in their explanation. Making a poster may also have some drawbacks. First, making a poster requires writing and drawing activities which may result in less intensive talk about the concepts. Second, a poster task may elicit less talk about the theoretical relations between the concepts. Most concept mapping and poster tasks do not *require* students to include different forms of representations. However, both in a concept mapping and a poster task students can be *asked* to include different forms of representations, such as text, formulas, diagrams, models and symbols.

Individual preparation for a collaborative task may have positive effects on student interaction. Because a collaborative learning task design does not *ensure* that all participants must contribute, an extra tool to stimulate equal participation might be useful. Individual preparation can also stimulate elaborative activities, due to more questioning and controversy, and may result in a more positive evaluation of collaboration on the task.

4.2 Research Questions and Hypotheses

The main questions of this research project are: how do characteristics of the collaborative learning task affect the features of peer talk and which of these features contribute to the learning of physics concepts? In an attempt to answer these questions in this first experimental study, I decided to focus on the nature of the group product that is asked for as well as the effects of a phase of individual preparation. Even though both concept mapping and poster tasks have the potential to engage students in elaborative talk and co-construction, there are still some differences between them that may affect the content and patterns of peer talk. Considering these assumptions and the main questions of this research project, the first study aimed at answering the questions and testing the hypotheses that are presented below. Section 4.3 describes the experimental design and the instruments that were used to answer the research questions and to test the hypotheses.

1 Features of student interaction

a) *Do the concept mapping and the poster task elicit elaborative talk about physics concepts and if so, what is the nature of this elaboration?*

b) *Do the concept mapping and the poster task elicit the verbalization of scientifically incorrect conceptions that are common within the domain of electricity?*

The collaborative tasks that were used in this study were expected to elicit elaborative talk and also to promote a symmetric participation in this talk and the appearance of co-construction. Further, the collaborative tasks were expected to elicit the verbalization of scientifically incorrect conceptions about electricity concepts, such as the idea of current consumption, nonrecursive current and the lack of differentiation between current strength and voltage. During the collaborative learning sessions the students can be confronted with other interpretations and part of the scientifically incorrect statements about the electricity concepts can be discussed and possibly even corrected.

2 The effects of task characteristics on the student interaction

a) *What effect does the product that is asked for (concept map or poster) have on the features of the student interaction?*

b) *What effect does the preparation for the collaborative task (individual preparation or no individual preparation) have on the features of the student interaction?*

One of the main research questions concerns the effects of task characteristics on the quality of student interaction. Although both the poster and concept mapping tasks were hypothesized to elicit elaborative talk, the propositional content of this elaboration was expected to be different. In contrast to the concept mapping task, the poster task was assumed to elicit more talk about relations between electricity concepts and concrete phenomena and less talk about their theoretical relationships. Further, there is a possibility that drawing and writing activities during the poster task constrain talk about the concepts.

The individual preparation was hypothesized to result in more questions and conflicts within the dyads. Further, the individual preparation was expected to result in a more symmetric participation of students in the discourse.

3 Improvement of conceptual understanding

a) *Do the collaborative tasks result in an improvement of conceptual understanding?*

b) *Does the kind of product that is asked for (concept map or poster) affect the individual learning outcomes?*

c) *Does the preparation for the task (individual preparation or no individual preparation) affect the individual learning outcomes?*

It was expected that active participation in the collaborative concept mapping or poster task would improve the students' understanding of the electricity concepts. Such an improvement was considered to be

reflected in the growing ability to use the electricity concepts adequately in situations that ask for the use of scientific conceptions and in an independent test situation void of group interaction.
Because the poster task was assumed to elicit more talk in which the electricity concepts are related to concrete phenomena, it was expected that the students who worked on a poster would specifically improve their use of the electricity concepts to describe and explain a concrete phenomenon.
Starting from the assumption that individual preparation results in more questioning, argumentative talk and a more symmetric participation in interaction, individual preparation was supposed to result in a greater improvement of conceptual understanding.

4 Features of student interaction related to student characteristics and outcomes

a) *Is the participation of students in the interaction related to their prior knowledge and attitude towards physics?*
b) *Are individual learning outcomes related to the amount of elaborative talk (on the group level) that appears in the student interaction?*
c) *Are individual learning outcomes related to the amount of participation of the student in the interaction?*

The first question is of interest because student characteristics such as prior knowledge and interest, may affect the quality of learning processes and outcomes aside from and partly independent of task characteristics. A student who is interested in the domain and has a lot of experience in using the domain-specific concepts may produce more (elaborative) talk than a student with less interest and prior knowledge.
Elaborative talk about the electricity concepts (on the group level) and the contribution that a student makes to such talk (the individual level) were assumed to be positively related to the understanding of the electricity concepts that the students show after their participation in the group work.

5 Student evaluations

How do the students experience the task, their learning and the collaboration with their peer?
This question was specifically intended to verify whether findings related to the differences between the poster and concept mapping tasks, as well as the usefulness of individual preparation and the elements of student interaction which promote learning, are also shared by the students themselves. It was expected that the students would give a positive evaluation of the task, their learning and their collaboration with a peer. It was also assumed that the students who prepared individually would give a more positive evaluation of the usefulness of collaboration on the task.

4.3 Method

This section begins with a description of the experimental tasks that were used, the subjects that participated in the study and the procedure that was followed. Secondly, a description is given of the instruments that were used: the pre-test and the post-test, the Attitude Towards Physics questionnaire, the Student Evaluation questionnaire, and the coding scheme with which the transcripts were analyzed.

4.3.1 Experimental tasks

A pilot study (Van Boxtel, 1997) was set up to evaluate the concept mapping and poster tasks and the phase of individual preparation. Four students from the Educational Sciences department of Utrecht University participated in this pilot study. One dyad made a concept map and one dyad made a poster. On the basis of the results of this pilot study some minor changes in the instruction for the tasks were made. For example, the number of concepts that had to be used and the time that students were given to complete the task were reduced.

The Appendix (Ia) contains the instructions that were used in the concept mapping task from this experimental study. Students had to make a network on a large paper (A2) using ten given electricity concepts, such as current strength, voltage and resistance. Related concepts had to be connected and the links that represent the relations between concepts had to be labelled precisely. The students were asked to also map the symbols, formulas and graphs that they associate with the concepts and the relations, thus integrating multiple representations. Because the task was meant to stimulate the students to talk about their own understanding of the concepts, no additional tools other than paper, pencils and the post-it notes labelled with the electricity concepts were provided. No textbook or teacher was available. The fact that students could only use each other as a source of information and feedback was also assumed to contribute to a positive interdependency. The use of a large paper made it difficult for the students to divide the task into parts and thus was also meant to strengthen interdependency and negotiation between the collaborating students.

In the poster task the working of an electric torch had to be explained using given concepts such as current strength and resistance (the same concepts that were used in the concept mapping task). A simple drawing of an electric torch was already provided on the poster. Students could draw an electric circuit inside the electric torch and could link the electricity concepts to parts of this circuit. They had to focus on principles underlying the working of the electric torch. As in the concept mapping task, the students were also asked to integrate multiple representations in their poster. A full description of the instructions for the poster task is given in Appendix Ib.

Individual preparation consisted of making a design for the concept map or poster (see Appendix Ia and Ib). The students were asked to make such a design with the electricity concepts given on the paper. These ten concepts corresponded with the concepts that had to be used in the collaborative learning task.

4.3.2 Subjects and design

Forty students (of 15 or 16 years of age) from two physics classes in intermediate general secondary education, each in a different school, participated. In Dutch secondary schools the number of girls that choose the subject physics in their examination programme is much lower than the number of boys (Jorg, 1994). Some empirical studies showed that boys tend to dominate interaction in mixed-gender groups (Webb, 1984; Lindow, Wilkinson & Peterson, 1985; Lockhead & Harris, 1984). In her research about co-operative learning in Dutch schools Ros (1994) found more verbal interaction in same-sex groups than in mixed-gender groups. Since this study was not designed to investigate the influence of group composition, a possible negative influence of sex-heterogeneity had to be precluded. Within each participating class the students were randomly assigned to same-sex dyads. Four girl-girl dyads, fifteen boy-boy dyads and one mixed-gender dyad participated in the study. The students were accustomed to working in small groups. The design of the study is shown in Table 4.1.

Table 4.1 Number of dyads in the conditions

	Concept Map	Poster	Total
Individual preparation	5	5	10
No individual preparation	5	5	10
Total	10	10	20

A factorial design with two between-subject factors (the kind of product that was asked for and the individual preparation for the task) was used. Within each class the same number of dyads was randomly assigned to one of the four conditions: (1) concept map with individual preparation; (2) concept map without individual preparation; (3) poster with individual preparation and (4) poster without individual preparation. Five dyads participated in each condition.

4.3.3 Setting and procedure

The procedure of the experiment is shown in Table 4.2. Five weeks before students worked together in dyads, they took the pre-test that was meant to measure prior knowledge on the domain of electricity. They were also asked to fill in the questionnaire *Attitude towards Physics*. One week before the collaboration session the students received instructions about making a concept map and a poster. This training was related to the topic of phase changes and was given by the researcher. The experiment was carried out in a room in school under the guidance of the experimenter (the researcher or a graduate student). During the accomplishment of the collaborative task the students were recorded on video. The video recorder was placed on a tripod and was focused on the product and not on the students' faces. The students were informed about this and were told that the experimenter was interested in how they would make the product. They were not informed about the exact research questions. During the instructions one week before the collaboration session the students were informed about the goal of the collaborative task in the context of the new course about electricity, and that they would not gain a mark for the group product. The experimenter sat at some distance from the students. After the instruction, he or she did not look at the students through the camera or otherwise, but simply read a book or some articles. The session lasted for a maximum of 45 minutes, depending on the time students needed to complete the task. In the conditions with individual preparation, students worked five minutes individually on the design for the concept map or poster and had 40 minutes to complete the collaborative task. In the other conditions, dyads were given 45 minutes to finish the task. Immediately after the students finished the group task they were asked to answer the questionnaire about the task. The post-test was administered in the next physics lesson (one week later).

Table 4.2 Procedure of the task

Activity	Time in minutes
Pre-test	40
Attitude towards Physics Questionnaire	10
Training	40
Individual preparation	5
Collaborative work in a dyad	45 (max.)
Student Evaluation Questionnaire	5
Post-test	40

4.3.4 Measurement of concept learning

Concept learning was described as the changing way a student uses the physics concepts in situations that ask for the use of scientific conceptions and ways of reasoning (see section 2.2.3). A pre-test and a post-test were constructed to measure such a change in the domain of electricity. The tests consisted of three units (see Appendix II). The *Concept definition Unit* aimed at testing the ability of students to communicate the scientific meaning of six electricity concepts. The students were asked to give a definition in their own words of the meaning of the concepts, to give important magnitudes, units and formulas and to make a drawing to make the meaning of the concept clearer. The *Problem-solving Unit* was constructed to test the understanding of the relations between the concepts and the application of these relationships to specific circuits. Students had to decide, for example, which circuit current strength was higher (more examples are included in the Appendix). The *Essay Question* was meant to test the ability to use the electricity concepts interrelatedly in the description and explanation of a concrete phenomenon. In the pre-test the students had to explain the working of an electric torch and in the post-test they had to explain the working of a flat iron. The problem-solving items and the essay questions of the pre-test and the post-test were designed as parallel items. The Concept definition Unit of the post-test contained the same concepts and had the same format as the Concept definition Unit of the pre-test.

The tests were constructed in consultation with two physics teachers and a teacher educator to achieve representative coverage of the content of the construct domain and to check student familiarity with the types of test items that were used. In a pilot study, the test units were administered in five classes (103 students) to assess their difficulty, reliability, parallel character and time needed to complete. On the basis of the results of this pilot study, one of the problem-solving items was replaced because it was too difficult. Some items, on the other hand, were simply reformulated to make them easier to understand. In the pilot study the item homogeneity (Cronbach's alpha) of the Problem-solving Units turned out to be acceptable (.73 for pre-test and .53 for the post-test). The Cronbach's alphas of the Concept definition Units were .66 (pre-test) and .70 (post-test). In the Problem-solving Unit some of the items that were designed as parallel items had unequal mean scores and low correlation. In order to increase the parallel character of the Problem-solving Unit in the actual pre-test and post-test, three of the problem-solving items from the pre-test were also used in the post-test.

Table 4.3 contains some descriptive information for each of the three units of the pre-test and the post-test that were used in the first study. The scores of the pre-test and the post-test were normally distributed

(Kolmogorov-Smirnov test). One of the six concepts from the Concept definition Unit had to be excluded (electric circuit) for statistical operations because apparently many students confused it with a switch. In Dutch, the two terms are almost the identical. To get an indication of the difficulty of the test the p'-values were calculated by dividing the mean scores through the maximum scores. The pre-test can be considered as a moderately difficult test (.43), whereas the post-test has a desirable p'-value of .51. The p'-value of the Essay Question in the post-test (the flat iron question) was lower than in the pre-test (the electric torch question).

Table 4.3 Descriptives of the pre-test and the post-test

Unit	Number of items	Maximum score	Response Format	Cronbach's alpha	
				pre-test	post-test
Concept definition[1]	5	20	definition, magnitude/formula and drawing	.69	.73
Problem-solving	6	12	multiple choice with justification of answers	.32	.20
Essay Question	1	8	essay	-	-
Total	12	40		.64	.66

[1] The item 'electric circuit' was excluded to gain an acceptable reliability.

The score on the pre-test was used as covariate in the analyses of variance that were conducted to investigate the effects of the type of product (concept map or poster) and preparation (individual preparation or no preparation) on scores of the post-test. The pre-test scores were also used in the calculation of partial correlations between frequencies of student talk categories and post-test scores. Due to the low item homogeneity of the Problem-solving Unit, no separate analyses of variance and correlational analyses were conducted with this unit. Although all items of the Problem-solving Unit in the pre-test and the post-test were meant to measure the understanding of the relations between the concepts and the application of these relationships to explaining phenomena in specific circuits, most of the problem-solving items had low or even negative intercorrelations. The students did not perform consistently across the problem-solving items. This may be due to the fact that each item focused on a different relationship (for example on the relationship between voltage and current strength or on the relationship between sort of material and resistance) and that some items asked for the 'reading' of electric circuits while others did not.

4.3.5 Scoring of the tests

An answer key to score the tests was constructed in consultation with two physics teachers. The Concept definition Unit was scored on the quality of the given definitions and the correctness of the associated magnitudes, formulas, symbols and drawings. For the Concept definition Unit of the tests, concordance

between two judges on ten randomly chosen tests (each containing 5 items) reached .81 (Cohen's Kappa).
The Problem-solving Unit was scored on the number of correctly chosen alternatives and on the quality of the accompanying explanations. The inter-rater reliability between two judges on ten randomly chosen Problem-solving Units was .80 (Cohen's Kappa). The answers on the Essay Question were determined by the number of adequately used electricity concepts and by the completeness of the explanation when compared with the answer key (the two scores were summerized). Inter-rater agreement between two judges on ten randomly chosen answers reached .61 (Cohen's Kappa) for the number of adequately used electricity concepts and .70 for the completeness of the explanation.

4.3.6 Measurement of attitude towards physics

To explore the influence of affective factors, the *Attitude towards Physics Questionnaire* was administered (see Appendix III). This five point Likert-scale questionnaire was an adaptation of a questionnaire on mathematics (Cito, 1987). The items focused on interest in physics, the amount of pleasure taken in working within the domain of physics and the perceived relevance and difficulty of physics. A higher score on the questionnaire reflected a more positive attitude towards physics. The Cronbach's alpha reliability was .92.

4.3.7 Measurement of student evaluations

To measure students' experiences with the concept mapping task, the poster task, individual preparation and the collaboration with a peer, a Likert-scale questionnaire was constructed. This questionnaire had a six-point continuum ranging from 'completely agree' to 'completely disagree' and contained three units: the perceived contribution of the collaborative task to concept learning, the evaluation of the task and the evaluation of the collaboration with their peer. Some of the items were based on a questionnaire of Roth (1994) that was used to investigate student views of concept mapping. The items of the questionnaire ae included in the result section.

4.3.8 Coding of verbal interaction

Transcripts of the video recordings were used to categorically describe the nature of the students' verbal interactions. The transcripts included all talk and relevant non-verbal actions, such as pointing, pasting the post-it cards with the concepts on it, gesturing and writing. The transcripts were analyzed on both the utterance and episodic levels. The coding on the utterance level (3781 utterances) was done with WinMax Pro '96 (Kuckartz, 1996), a computer-programme for qualitative data. To identify contingencies reflecting elaboration and co-construction, the transcripts were analyzed on an episodic level by making use of the utterance level coding. On the episodic level the analysis focused on questioning, conflict and reasoning episodes and on the content dimension on reactions to incorrect propositions. The categories that were distinguished in the coding scheme are described in more detail below. The coding scheme is also included in Appendix IV.

4.3.8.1 The utterance level: communicative functions

Utterances of students who are collaborating on a task can be interpreted with respect to their content and communicative intentions. In an utterance, students can express their intentions and beliefs. A coding scheme to identify communicative functions of utterances was developed in a study by Erkens (1997) and was based on the methods of Barnes and Todd (1977), Burton (1981), Schiffrin (1987) and Lehnert (1978). Some adjustments to this category system were made on the basis of a pilot study (Van Boxtel, 1997) in which transcripts of two students who worked on the poster and the concept mapping task were coded. In the coding scheme an utterance was considered an individual message unit that is distinguished from another utterance through a 'perceptible' pause, comma or period. The communicative functions were identified on the basis of the illocutionary force and the functional meaning of the utterance, whereby not only its linguistic form but more specifically, its retrospective and prospective effect on the discourse guided the coding. A question, for example, can be asked in order to acquire information or explanation, but can also be used to acquire acceptance or approval. The functional meaning of the utterance is always related to the way a student interprets the situation at a particular moment. To facilitate a reliable coding, in the coding scheme each category was operationalized in terms of discourse markers, such as 'thus' and 'or'.

The coding scheme contained the following mutually exclusive and exhaustive categories: statements, arguments, evaluations, questions, requests, proposals, confirmations, negations, repeats, orders and off-task utterances. Some of these categories were divided into subcategories which are described in more detail in the Appendix (IVa). For example, a distinction was made between different types of questions and arguments. Arguments are logical extensions of what is previously said and thus reflect reasoning. The formulation of arguments was a specific indicator of elaborative talk by the students. At the group level the number of arguments in student talk were an indicator of elaborative talk in the group. Since the transcripts specify to which student an utterance belongs, the coding on the utterance level can give an indication of the amount and the nature of the participation of each student in the interaction and the possible asymmetry in participation.

In contrast to the category-system developed by Erkens (1997), answers were excluded from the responsive category. The pilot showed that in several cases, answers to questions consisted of more than one utterance and included arguments or critical questions which would imply that an utterance could be coded as both an answer and an argument. To keep mutually exclusive categories, a response to a question (other than a confirmation, acceptance, negation or repeat) was coded on the utterance level as a statement when it did not belong to the evaluative or elicitative categories. Question-answer sequences were coded at the episodic level and could include several utterances. Inter-rater agreement (Cohen's Kappa) between two judges for the communicative functions categories reached .89 (353 utterances from a randomly chosen transcript).

4.3.8.2 The utterance level: propositions

The participation of students in the interaction can be operationalized as the number of utterances a student formulates, but considering the goal of the task, utterances in which the students say something about the meaning or the relations of electricity concepts were considered especially valuable for the improvement of conceptual understanding. A different coding scheme (included in Appendix IVb) focused on the content of the utterances. A proposition was defined as an utterance in which the student makes a statement about the meaning or a relation of an electricity concept. Such talk about concepts can be explicit by using the labels of the concepts, but can also be implicit by the use of words such as ‘this’ and ‘it’. In the second chapter the attempt to look for meaningful relationships within the domain was described as an elaborative activity. In line with the types of relationships that can be distinguished within the domain, four proposition categories were distinguished to code talk about electricity concepts: propositions in which a statement is made about a single concept, propositions in which a concept is related to another concept, propositions in which a concept is related to a concrete phenomenon and propositions in which a concept is related to another form of representation (such as a magnitude or a drawing). Inter-rater agreement for the content categories reached .83 (Cohen’s Kappa).

Further, the scientific correctness of each proposition was coded. This was done to understand the amount to which the students verbalized their unscientific interpretations of and reasoning with the electricity concepts. Imprecise propositions were coded as correct. For example, when a student says *‘voltage belongs to resistance’* we do not know exactly what the student means by this statement. When he or she means that a resistor consumes voltage, it can be identified as being incorrect from a scientific point of view. Only when such an explicit incorrect proposition was given was it actually coded as incorrect. A total of 302 propositions (from two transcripts chosen at random) was judged by a second person to identify incorrect propositions. Inter-rater agreement reached .87 (Cohen’s Kappa).

4.3.8.3 Episodic level: question, conflict and reasoning episodes

The coding scheme on the episodic level (Appendix IVc) was based on the wish to identify and differentiate various modes of elaborative talk. Since elaboration is likely to occur in questioning, conflict and reasoning episodes (see 2.3.3), these three types of episodes were distinguished.

Question Episodes: Content-related question episodes were identified through a selection of the utterances which were coded on the utterance level as both a question (disjunctive, verification and open) and a proposition. To avoid overlapping categories, critical questions that are the beginning of conflict episodes, and verification questions that are part of a conflict or reasoning episode were excluded. For example, when the conclusion of a reasoning has the form of a question: *‘Thus current strength depends on resistance?’*, this question was considered part of the reasoning episode and not as the start of a question episode. A distinction was made between no answer, short answer and elaborated answer. A short answer is ‘yes’ or ‘no’ or an alternative. Elaborated answers were defined as answers that contain more information than just yes, no or an alternative, and could consist of one or several utterances.

Conflict Episodes: Conflict episodes were identified on the basis of negations, counter-arguments (reacting to an utterance of the other student) and critical questions. Only the conflicts that involved the meaning or relations of the electricity concepts were selected. A conflict was considered elaborated when one student explains or justifies his or her statement (individual elaboration) or when both students contribute to the resolution of the conflict through argumentation about the solution (collaborative elaboration). Resolution of a conflict can also be reached without elaboration when, for example, a student immediately accepts the statement or counterargument of his or her partner. Lack of elaboration of a conflict can also appear when students ignore the conflict and move on to another part of the task. Of course all elaborative talk in a collaborative learning situation can be considered ‘collaborative’ in some sense because what a student brings in is meant to communicate something to the partner and perhaps be confirmed by the partner. However, when one student justifies his or her view through arguments and the other student only accepts this reasoning without contributing counter arguments, complementary arguments or critical questions, the degree of co-construction is lower. The appearance of *collaborative* elaboration of conflicts was considered to be an indicator of co-construction because both students develop ideas together and contribute to the elaboration and solution of the conflict by trying to reach a shared understanding.

Reasoning Episodes: A reasoning episode was defined as a sequence of utterances in which definitions, observations or hypotheses about electricity concepts (propositions) are related to each other. A reasoning episode contains at least one utterance that is coded as an argument. Reasoning that appears in the answering of a question or the elaboration of a conflict was not identified as a reasoning episode. A distinction was made between individual reasoning and collaborative reasoning. An individually constructed reasoning is a reasoning that contains arguments of only one student. In collaborative reasoning the reasoning is co-constructed by contributions from both participants.

Four transcripts chosen at random were coded on the episodic level by two independent coders for reliability (a total of 1553 utterances). The proportion of agreement was 79%.

4.3.8.4 Episodic level: response to incorrect propositions

At the utterance level, incorrect propositions were identified. The tasks that were used in the study had primarily the function to stimulate students to verbalize, negotiate and elaborate their understanding of the electricity concepts and not to correct all unscientific notions. One task would not be strong enough to induce such a change. The tasks function as the start of a new course in which there will be enough time to let students compare their own ideas with other interpretations. However, the verbalization and negotiation of unscientific conceptions was considered to be a first step in the process of learning to use the concepts appropriately in their scientific meaning. During the group work the students can already be confronted with other interpretations. It was thought of interest to investigate to what extent incorrect propositions are corrected during the accomplishment of the task. Therefore three response categories were distinguished in the coding scheme (see also Appendix IVc). First, an incorrect proposition can be corrected. In that case the incorrect proposition in the discourse is ‘replaced’ by a correct proposition. ‘Corrected’ is used here to indicate that an incorrect proposition is responded to with an interpretation of the same concept or relation that does not conflict with the scientific meaning of the concept. It is considered to be an effect found in the process of students engaged in collaboration (see also section 3.2.2). It was not considered a measurement of the extent to which ‘misconceptions’ are no longer used by the student in subsequent situations. The correction can take place immediately after the verbalization of the incorrect proposition, but also later on in the discourse. Second, an incorrect proposition can be confirmed (for example with a ‘yes’ or a ‘mm mm’) or included in a reasoning. Finally, a third category was defined for cases in which an incorrect proposition is not explicitly confirmed but also not corrected. For example, when a student simply does not respond to the incorrect proposition or when he or she reacts with *‘I don’t know’*.

All transcripts were judged by a second person to identify reactions to incorrect propositions. Inter-rater agreement reached .87 (Cohen's Kappa).

4.3.8.5 The use of individual designs

In the conditions with individual preparation, students had to make a design for the concept map or the poster. A category system to describe the use of the individual designs as an extra tool during the collaborative work was not developed in advance, but was extracted from the protocols. The use of the individual designs will be described in the Results section.

4.4 Results

First, this section presents the results of the analyses of the student talk, illustrated by examples. The fragments that are included were translated from Dutch into English and the names of the students were changed. Relevant non-verbal actions are included within parentheses. Second, this section reports the differences in student talk between the concept map and poster conditions and between the conditions with and without individual preparation. Finally, the post-test scores and the relationships between the post-test scores and the amount and type of elaboration in student interaction are presented. Each section will repeat the hypotheses that were formulated in section 4.2. However, here the *operationalized* hypotheses will be presented together with a description of the statistical operations that were used to test the hypotheses.

4.4.1 Features of the student interaction

It was assumed that the concept mapping and poster tasks would elicit elaborative talk about the electricity concepts and the verbalization of scientifically incorrect conceptions that are common within the domain. The amount of elaborative talk about the electricity concepts at the utterance level was operationalized as the number of propositions and arguments. The number of incorrect propositions was believed to indicate the extent to which scientifically incorrect conceptions and ways of reasoning appeared. In the first sections the nature of the student talk will be described with frequencies and percentage distributions of communicative functions and proposition categories. The number of propositions and arguments a student formulates was also used to describe the amount and nature of student participation in the interaction. Asymmetry in student participation will be calculated for the number of utterances, arguments, and propositions. At the episodic level the giving of elaborated answers to questions, the elaboration of conflicts and reasoning were considered valuable patterns of peer interaction. These episodes reflect elaboration and a certain degree of co-construction. Section 4.4.1.5 presents the frequencies with which each type of episode occurred in the discourse.

4.4.1.1 Communicative functions

The mean time students worked on the collaborative task was 25.95 minutes (sd = 11.89). On the average the protocols contained 245.63 utterances (sd = 170.64). Table 4.4 shows the mean percentages of the communicative functions categories. The results refer to the student interaction in only nineteen of the twenty dyads because of videotape failure in one of the dyads.

Interaction was mostly characterized by statements, arguments (especially continuation and counter arguments) and questions. The students primarily asked verification questions. An example of such a verification question is: *'an electron transports energy, doesn't it?'* These questions are important in monitoring common ground (Graesser, et al., 1993; Erkens, 1997) and are used to construct the shared meaning needed to accomplish the collaborative tasks. The proportion of verification questions may also be high due to the fact that in order to complete the task, students could only use their own and each others' knowledge because no other information sources were available. The standard deviations show that the dyads differed moderately in the distribution of the interaction categories. From Table 4.4 it can also be seen that there was almost no off-task talk.

Table 4.4 Mean percentages and standard deviations of communicative functions categories (n = 19[1])

Category	Percentage		Category	Percentage	
	Mean	Sd		Mean	Sd
Statements	28.39%	11.47%	Questions	10.86%	3.94%
Arguments	23.40%	8.51%	-disjunctive	.37%	.44%
-continuation	10.38%	5.10%	-verification	5.65%	2.66%
-reason	1.87%	1.33%	-critical	.82%	.80%
-condition	1.39%	1.60%	-open	4.01%	2.50%
-consequent/conclusion	3.31%	2.65%	Request for evaluation	.66%	.86%
-disjunctive	.43%	.51%	Request	1.45%	1.80%
-counter	6.02%	3.33%	Proposal	8.29%	3.98%
Evaluation	5.36%	2.52%	Confirmation	10.18%	3.47%
Order	.54%	1.03%	Acceptance	2.44%	2.45%
Off-task	.94%	2.30%	Negation	2.08%	1.71%
			Repeat	5.42%	3.87%

[1] Interaction of one dyad was not videotaped, thus utterances could not be coded

4.4.1.2 Propositional content

In this section the results of the content analysis on the utterance level are reported. The students were assumed to communicate their understanding of the electricity concepts and to talk about meaningful relations. On the average the transcripts contained 79.32 propositions (sd = 46.21). The average intensity of talk about concepts was approximately three propositions per minute. Table 4.5 shows the character of the talk about the electricity concepts.

Most conversation about the electricity concepts was about relations between concepts. A further examination of these propositions revealed that a portion was characterized by imprecise language. Usually, the formulation of relations became more precise and specific during the accomplishment of the task. *'Resistance and current strength are related'* is an example of a proposition with low specification. A proposition with high specification is '*if resistance is small, the current strength is large'*. The proposition categories did not distinguish between descriptive and explanatory propositions about relations. However, the list of the propositions that we could generate with the computer programme gave the impression that the students did not talk much about the underlying microscopic mechanisms: the level of moving electrons. For example, many students stated that a higher voltage results in a higher current strength, but most students did not talk about how this relation could be explained. Students rarely formulated propositions about a single concept without relating it to another concept, a concrete phenomenon or another form of representation. Both products that were asked for focused in particular on relationships.

Table 4.5 Mean percentages and standard deviations of proposition categories (n = 19)

Category	Percentage	
	Mean	Sd
Single Concept	6.98%	7.90%
Relation	36.97%	26.15%
Concrete	30.72%	23.27%
Representation	25.34%	17.54%
Incorrect[1]	11.62%	5.02%

[1] Mean percentage of total number of propositions formulated in the dyad

The following example illustrates talk about the relations between voltage, electrons and current strength. It starts with an erroneous proposition and ends with its correction. Relevant codings of the propositional content of the utterances are given in the last column.

Example 4.1 Talk about relations of concepts

Ken:	voltage, voltage is the number of electrons per second	*proposition relation*
Ken:	that is voltage	
Dylan:	voltage	
Ken:	the number of electrons that move per second, or is that the current strength?	*proposition relation*
Dylan:	that is the current strength	*proposition relation*
Ken:	yes	
Ken:	then I write that down	
Dylan:	the voltage is the power with which the electrons move forward	*proposition relation*

Condition: poster with individual preparation

This example shows the differentiation of concepts through talk about how concepts are related to each other. The definition of voltage given by Ken is, from a scientific point of view, a more appropriate definition of current strength. Through the verbalization of his understanding Ken becomes aware of a possible confusion of the two concepts. Dylan confirms that the movement of electrons per second has to be related to current strength and continues to explain how voltage is related to the movement of electrons. In their attempt to define and negotiate a shared meaning of the concept voltage, the students relate several electricity concepts to each other.

In this example, Ken asks a verification question that is related to the meaning of the concepts voltage and current strength. The protocols showed several examples of questions that reflect the elicitation of a motivation to really understand a concept or its relations. Questions such as *'what is voltage?'*, *'why is a voltage resource needed in an electric circuit?'*; *'but what actually is a molecule?'* , *'aren't current strength and voltage the same?*' and *'how do they precisely relate?'* made an opening to the appropriation of the theoretical framework of electricity concepts as it is used by scientists. The fact that the questions are posed by the students themselves seems to make them eager to search for an answer.

Sometimes the remembrance of an analogy helped the students use the electricity concepts to describe what was happening in an electric circuit. Example 4.2 illustrates the use of such an analogy. The students' physics teacher had explained the behaviour of electrons in an electric circuit through an analogy with trucks that load and unload their goods. After Daniëlle initially uses the word 'trucks' instead of 'electrons', Isabel continues the use of the truck-analogy. Apparently she understands the analogy Daniëlle is referring to and shares the memory of its use by the teacher. This shared experience in the classroom supports the students in the co-construction of a shared meaning of what is happening in the electric torch. The analogy helps Isabel and Daniëlle in explaining the shining of the electric torch. This fragment shows talk in which electricity concepts are used to describe and explain a concrete phenomenon. Isabel relates the shining of the bulb to the existence and the transportation of energy.

Example 4.2 Making use of an analogy to describe a concrete phenomenon

Isabel:	the energy, the energy that, that belongs to the electrons (points), they contain the energy, don't they?	*proposition relation*
Isabel:	from the battery, so that the bulb can shine?	*proposition concrete*
Daniëlle:	(…) but that is here (points), here the trucks are	
Isabel:	yes the bulb, the trucks give, they have energy inside so that they can pass through the current to the bulb	*proposition concrete*
Isabel:	so that they can pass through the energy to the bulb and the bulb can use that energy	*proposition concrete*
Isabel:	to let the bulb shine	*proposition concrete*

Condition: poster with individual preparation

Table 4.5 shows that on the average a quarter of all talk about the electricity concepts was talk in which the students related the electricity concepts to other forms of representation. Most propositions in which the students used other forms of representations were about magnitudes (such as V, I, R and J), drawings (for example, an electron, a battery, a bulb or a resistor) and formulas (mostly, $V = I$xR). There was no talk about how regularities could be represented in a graph and none of the group products contained a graph in which the relation between two quantities was represented.

4.4.1.3 Incorrect propositions and reactions to incorrect propositions

As shown in Table 4.5, an average of 11.62% of the propositions that were formulated in the dyad consisted of incorrect propositions. Sometimes students gave incorrect formulas or made errors in linking magnitudes to the concepts. For example, *R* (resistance) was described as a multiplication of *V* (voltage) and *I* (current strength) instead of as a division, and voltage was mistakenly linked with ampere. In both the concept mapping and the poster conditions, most incorrect propositions reflected the confusion between the concepts of voltage and current strength. Several times voltage was described as something that 'goes round' in the circuit and is hindered by the resistance. Some students considered voltage and energy to be the same concept.

In Example 4.3, Bram describes voltage as something that is stored in a battery and runs through the wires of the electric circuit.

Example 4.3 Incorrect proposition that is confirmed.

Bram:	batteries consist of voltage, that is running through the wires to the resistor	*proposition concrete*
Ron:	yes the resistor gets the voltage	*proposition concrete*
Ron:	yes (writes)	
Bram:	this goes through the wires of the circuit to the bulb	*proposition concrete*

Condition: poster without individual preparation

Particularly in the concept mapping conditions, there were also many students who gave an incorrect description of the relation between the cross-section area of a wire or a resistor and the resistance. For example: *"cross-section area (points), the thicker the more resistance (points)"*. The protocols contained only one example of the verbalization of the idea of current consumption. In this case, one of the students stated that part of the current would be lost when the electrons have to cover a long distance.

Approximately a third (37.4%) of all incorrect propositions (163) was corrected during the discourse. Example 4.1 contains a correction of an incorrect description of the meaning of voltage. A third (33.7%) of all incorrect propositions was explicitly confirmed or included in a reasoning. Example 4.3 shows a confirmation of an incorrect proposition. Many corrections were focused on incorrect magnitudes and formulas such as current strength being measured in ampere instead of voltage. The next fragment is an example of an incorrect proposition about voltage that is not reacted to. The fact that Arthur is not reacting to the statement of Daniel is related to the way the students are working on the task at the specific moment. Daniel is making his statement while Arthur is writing on another part of the poster. The whole protocol of the talk between Daniel and Arthur shows several examples of a sort of task division during which the students do not negotiate or co-construct reasoning. Daniel includes the incorrect proposition in the group product without a verbal confirmation of his partner.

Example 4.4 Incorrect proposition that is not reacted to

Daniel: the voltage circulates	*incorrect proposition*
Arthur: (writes)	
Daniel: (writes near to electric circuit)	

Condition: poster with individual preparation

4.4.1.4 Asymmetry in participation

The tasks were assumed to stimulate an equal participation of the students in the discourse. As expected, asymmetry was low for all dyads. The mean proportional distribution of utterances was 55.5%-44.5% with a standard deviation of 9%. This means that an average of 55.5% of all utterances was formulated by one of the students while 44.5% was formulated by the other student. The asymmetry of arguments was 56%-44% whereas the asymmetry in questioning was somewhat larger at 64%-36%. The mean proportional distribution of propositions was 58%-42%.

4.4.1.5 Elaborative episodes

The results of the analyses on the episodic level are presented in Table 4.6.

Table 4.6 Sums, percentages, mean frequencies and standard deviations of episodic categories (n = 19)

Categories	Sum	%	Frequency	
			Mean	Sd
Question Episodes	241	100%	12.68	7.67
Answered questions	181	75%	9.53	6.04
- elaborated answer	62	26%	3.26	2.68
- short answer	119	49%	6.26	4.01
Not answered	60	25%	3.16	2.50
Conflict Episodes	89	100%	4.68	3.59
Elaborated conflicts	64	72%	3.37	2.69
- collaborative elaboration	33	37%	1.74	1.79
- individual elaboration	31	35%	1.63	1.54
No elaboration	26	29%	1.37	1.34
Reasoning Episodes	98	100%	5.16	4.17
- collaborative reasoning	64	65%	3.37	2.63
- individual reasoning	34	35%	1.79	1.93
Total Elaborative Episodes[1]	224		11.79	7.79

[1] Total Elaborative Episodes = Elaborated answers + Elaborated conflicts + Reasoning Episodes

Question Episodes: From Table 4.6 it can be seen that question episodes appeared more than twice as often as either conflict or reasoning episodes. However, most questions did not lead to elaboration. The fact that short answers were more frequent than elaborated answers is probably due to the high proportion of verification questions (59% of all questions).

The next fragment contains an example of a question episode about the relation between resistance and the cross-section area of a resistor. An open question is followed by an elaborated answer. Wendy gives an example of the cross-section area of a resistor and the way it is related to other processes in an electric circuit. She also explains this relation by referring to a theory about molecules. The same problem is discussed for a second time a couple of minutes later. This suggests that Sonja does not completely understand what Wendy means or just does not yet agree with it. Apparently she is motivated to understand the relation. In the attempt to explain the statement about resistance, Wendy first refers to her earlier stated theory about molecules and then to the results of a shared experiment they had conducted a year ago. This is comparable to the way Isabel and Daniëlle made use of the remembrance of an analogy (see Example 4.2): recalling prior knowledge. In explaining the abstract theory about molecules, Wendy also makes use of gestures. The explanation of the relation between resistance and the cross-section area is not a simple verbalization of something that is stored in the memory, but is constructed and therefore situated in the present social activity. However, this example shows how the elaboration and co-construction of meanings may be related to previous activities that are remembered and brought into the discourse.

The participation of Wendy in this episode is greater and more elaborate than the participation of Sonja. Wendy formulates more propositions and more arguments. However, the elaborated answer that is given in response to Sonja's question also contains propositional contributions of Sonja herself. Sonja is not only actively engaged in the reasoning that Wendy gives, but also contributes to this reasoning with the last argument that is added ('and then it shined less'). This reflects a certain degree of co-construction.

Example 4.5 Elaborated answer

Wendy:	we can use this one, cross-section area of a resistor	*proposal*
Wendy:	but I don't know what to write about it	*statement*
Sonja:	of a resistor, but how do you mean that?	*open question*
Sonja:	I didn't understand it	*evaluation*
Wendy:	look, there is a resistor	*statement*
Wendy:	if the resistance is high, then U is …	*argument conditional*
Wendy:	then something is smaller, but I don't know what it is	*argument consequent*
Wendy:	it is something like this, resistance, when you compress it (gesticulates) then it is more dense, and has more molecules	*argument consequent*
Wendy:	when you expand it, the molecules are further away from each other and the current can go through it easier	*argument consequent*
Wendy:	it's something like that	*statement*

Sonja:	oh, oh yes	*confirmation*
…		
Wendy:	for example, sometimes you use such a block, okay?	*verification question*
Sonja:	yes, that is a resistor	*argument continuation*
Wendy:	and I don't know if you made that experiment, but we used another kind of material, it was smaller	*statement*
Sonja:	and then it shined less	*argument consequent*
Sonja:	oh yes, like that	*confirmation*
Sonja:	yes, that is possible	*acceptance*

Condition: poster with individual preparation

Conflict Episodes: As shown in Table 4.6, collaborative elaboration of conflict occurred as frequently as individual elaboration, but neither occurred very often. Example 4.6 shows a conflict that is elaborated. These students not only try to understand the given concepts, but also each other's interpretations. Tom and Mike have different points of view and elaborate on both perspectives trying to re-establish common understanding. They disagree about the question of whether a wire is a resistor or a conductor. The conflict starts with a negation of Tom. Then *both* Mike and Tom formulate a number of arguments and (critical) questions, although it can be seen that Mike formulates somewhat more arguments. It appears that Mike understands that both perspectives can be considered correct, but in the end Tom is still not convinced. The conflict is resolved by the proposal of Tom to choose his partner's perspective and see if it is correct. As a matter of fact Tom and Mike co-constructed a relation that they both agree on and that can be included in the group product, although there is no real shared understanding of the relations.

Example 4.6 Elaboration of a conflict

Tom:	look current strength has to do with the sort of material (points) with length (points), cross-section of the wire	*statement*
Tom:	I'm sure	*evaluation*
Mike:	the length of what? (points)	*open question*
Tom:	the length of the sort of material (points)	*statement*
Mike:	yes	*confirmation*
Tom:	of the wire	*statement*
Mike:	yes, a wire is also a resistor	*argument continuation*
Tom:	a wire is not a resistor, a copper	*negation*
Mike:	because it goes through it	*argument reason*
Tom:	a copper wire is not a resistor	*negation*
Mike:	of course it is	*negation*
Mike:	copper is resistance	*statement*
Mike:	it has to go through it, doesn't it?	*verification question*
Tom:	copper is not a resistor, it is a conductor	*counter argument*

Mike: a conductor is also	*counter argument*
Mike: when I put two wires through a plate of copper, what is it then?	*verification question*
Tom: a conductor	*statement*
Mike: a resistor, current has to go through it and it has difficulty with that, even if it conducts	*counter argument*
Tom: to go through copper?	*critical question*
Mike: yes, because some matters conduct better than others because when I have iron, for example, I don't know maybe it conducts better than copper, then it is easier for the current to go through it and there is less resistance	*argument reason*
Tom: yes (indignant)	*evaluation*
Mike: resistance, that is, that makes it difficult for current to go through	*statement*
Mike: that is only what resistance means	*statement*
Mike: thus, actually a wire too	*argument consequent*
Tom: but you can also say it the other way round	*counter argument*
Tom: there are conductors, there are conductors of different current strength	*statement*
Tom: there are conductors that conduct well, there are conductors that conduct moderately, there are conductors that conduct badly	*argument continuation*
Mike: but there is only current strength when you connect two wires to a battery or something like that	*counter argument*
Mike: otherwise you have got no current strength	*argument reason*
Mike: it depends a little, by means of resistance	*argument consequent*
Tom: do it first your way (erases lines)	*proposal*
Mike: yes, that's okay	*confirmation*
Tom: we will see if it's correct	*statement*

Condition: concept map without individual preparation

Reasoning Episodes: Table 4.6 shows that elaboration of conceptual knowledge was somewhat more frequent in the form of reasoning episodes than in the form of elaborated answers and elaborated conflicts. Collaborative reasoning was, overall, twice as frequent as individual reasoning. The following example illustrates the process of co-constructing a reasoning wherein both students contribute to the reasoning. After Haiko stated that an electric circuit has a voltage source (which is confirmed by Andy) he (finishing the proposition that Andy started) states that a voltage source gives voltage. Then, Andy continues in relating the voltage source to energy, and to current strength. Finally, Haiko relates the concept of current to the concept of energy.

Example 4.7 Collaborative reasoning in the concept mapping task

Haiko:	an electric circuit has a voltage source too, hasn't it?	*verification question*
Andy:	yes, actually it has	*confirmation*
Andy:	(draws)	
Andy:	and it consists of (writes)	*statement*
Andy:	the voltage source has, gives, gives	*statement*
Haiko:	the voltage source gives voltage	*statement*
Andy:	and energy	*argument continuation*
Haiko:	yes also	*confirmation*
Andy:	and current isn't it?	*verification question*
Andy:	the voltage source also gives current	*argument continuation*
Haiko:	and due to this current, there is energy	*argument consequent*

Condition: concept map without individual preparation

The students of the previous example construct a reasoning about the relations between several electricity concepts apart from a particular concrete electric circuit. In the poster task, students reasoned about the 'behaviour' of electrons in the electric circuit of the electric torch. In Example 4.1 Ken and Dylan discussed the meaning of voltage and current strength in a rather abstract way. Example 4.8 shows how they tried to use the concepts of energy, electrons, voltage and resistance in their description of what happens in the electric torch when the electric circuit is closed. They frequently pointed to the electric circuit while co-constructing the reasoning. The electric circuit that they drew 'inside' the electric torch helped them in explaining the working of the electric torch with a theoretical framework of scientific concepts. However, the transcripts did not show many examples of reasoning in which students tried to use several electricity concepts *interrelatedly* to explain the working of the electric torch.

Example 4.8 Collaborative reasoning in the poster task

Dylan:	thus here energy, here are the electrons that move from plus to minus (points)	*statement*
Ken:	shall we, what we actually have to write is that	*statement*
Ken:	the voltage source pushes these electrons through the wire (points)	*argument continuation*
Ken:	let's do it apart, you know	*proposal*
Ken:	and then, for example, it pushes further (points)	*argument continuation*
Ken:	and when it goes through the resistance of the bulb	*argument continuation*
Ken:	that is much much thinner	*argument continuation*
Ken:	and that's why a lot of them are pushed through it which causes it to glow and shine	*argument consequent*

Dylan: yes, because it is a wire of wolfram	*argument reason*
Dylan: it becomes very hot	*statement*
Ken: because of the friction	*argument reason*

Condition: poster without individual preparation

Although the student interactions were characterized by an average of almost 12 elaborative episodes, in some dyads there was little elaboration and co-construction. In one particular dyad, one student took the task very seriously and tried to formulate his ideas about the working of the electric torch whereas his partner did not. This student did not use the opportunity to test his ideas. He confirmed almost everything his partner said and sidestepped disagreement and problems by saying *'invent something'* or *'okay have it all your own way'*. He was more concerned with the product itself: *'I think we have to make a fair copy of it, because now it's not very beautiful'*. The participation of the students seemed to be also shaped by their attitude. The scores on the questionnaire that measured students' attitude towards physics revealed that the student who rarely contributed to the discourse had a negative attitude towards physics.

The next fragment from students working on a concept map shows an episode in which the students do not really justify their statements in case of disagreement (lines 25 and 29), barely elaborate on each other's ideas (lines 32 and 34), and rarely answer important questions (lines 2 and 45: *'more resistance means less voltage, that's right isn't it?* and *'does voltage circulate?'*). A spontaneous task division and little talk characterized the group work of these students. Frequently these students wrote a short text near the concepts that were on their own side of the paper. Even though these students read each other's texts, they really did not comment on them.

Example 4.9 Non-elaborative talk

1 Rick: here (writes)	*statement*
2 Rick: more resistance means less voltage, that's right isn't it?	*verification question*
3 Mario: (draws)	
4 Mario: cross-sectional area, the smaller	*statement*
5 Rick: I have that (looks at own design)	*statement*
…	
23 Rick: electrical voltage and voltage source	*statement*
24 Mario: yes that is	*confirmation*
25 Rick: also has to be the other way round	*statement*
26 Mario: yes otherwise	*confirmation*
27 Rick: no, because then this does not fit anymore	*counter argument*
28 Mario: don't mind, then we also place an arrow next to that	*proposal*
29 Rick: no it has to be the other way round	*negation*
30 Mario: the greater	*statement*
31 Mario: resistance and (points)	*statement*
32 Rick: just like this	*statement*

33 Rick:	voltage comes from voltage source (writes)	*statement*
34 Mario:	(writes)	
35 Rick:	isn't it?	*verification question*
36 Rick:	(…)[1]	
37 Mario:	the electrons flow (writes)	*statement*
38 Rick:	why is there a voltage source in an electric circuit?	*open question*
39 Mario:	because the voltage source sends the current	*argument reason*
40 Mario:	that's right	*confirmation*
41 Rick:	a piece of good luck	*evaluation*
42 Mario:	voltage source makes	*statement*
43 Rick:	(writes)	
44 Mario:	(writes)	
45 Rick:	does voltage circulate?	*open question*
46 Rick:	the less voltage, electric circuit	*statement*
47 Mario:	yes (indignant)	*evaluation*
48 Rick:	what rubbish	*evaluation*
49 Mario:	yes	*confirmation*

Condition: concept map with individual preparation

[1] unintelligible

4.4.2 Effects of task characteristics on student interaction

4.4.2.1 The kind of product that is asked for: Concept Map versus Poster

The group product that was asked for was assumed to affect the propositional content of the student talk. It was expected that the concept mapping conditions would generate more talk about relations between concepts, whereas the poster conditions would generate more talk in which electricity concepts are related to concrete phenomena. Further, I suggested the possibility that drawing and writing activities in the poster conditions would constrain talk about the electricity concepts. This would imply that during the poster task less propositions are formulated than during the concept mapping task.

Table 4.7 shows the differences between the concept mapping and the poster conditions for the proposition categories. Since the dyads differed in the time that they worked on the task, this table contains frequencies of categories divided by the time students worked on the group task (ratios). Differences between the conditions were tested with analyses of variance for each category with the product that was asked for and the preparation for the task as independent variables. First an ANOVA was conducted with the total number of propositions as a dependent variable. Then a MANOVA was conducted with the four proposition categories as dependent variables. The last column of Table 4.7 contains the significance level of the univariate F-tests that reflect the main effect of the factor 'product that was asked for' (concept map or poster).

Table 4.7 Mean ratios[1] and standard deviations of proposition and episodic categories in the Concept mapping and the Poster conditions and the p-values of the ANOVA's

Categories	Concept Map (n = 10)		Poster (n = 9)		p
	Ratio	Sd	Ratio	Sd	
Propositions	3.81	1.27	2.38	1.22	.02*
- single	.18	.14	.20	.16	.71
- relation	2.19	1.15	.49	.48	.00*
- concrete	.39	.41	1.24	.76	.01*
- representation	1.06	.70	.45	.32	.03*
Question Episodes	.62	.37	.46	.27	.24
Answered questions	.46	.25	.34	.21	.28
- elaborated answer	.11	.09	.14	.09	.55
- short answer	.34	.24	.20	.12	.12
Not answered	.16	.16	.11	.10	.35
Conflict Episodes	.26	.19	.11	.08	.06
Elaborated conflicts	.16	.09	.08	.07	.06
- collaborative elaboration	.09	.06	.03	.04	.03*
- individual elaboration	.07	.07	.05	.05	.46
No elaboration	.10	.12	.03	.05	.10
Reasoning Episodes	.28	.16	.14	.14	.04*
- collaborative reasoning	.18	.09	.10	.11	.09
- individual reasoning	.10	.10	.04	.04	.06
Total Elaborative Episodes[2]	.55	.23	.36	.22	.06

* p < .05

[1] Ratio: frequency divided by the time the students worked at the group task in minutes

[2] Total Elaborative Episodes = Elaborated answers + Elaborated conflicts + Reasoning Episodes

As suggested, it appeared that students who made a concept map talked more *intensely* about concepts (all proposition categories taken together) than the students who made a poster. A closer examination of the transcripts revealed that working on a poster resulted in more and longer phases in which students were writing or drawing. Some dyads spent considerable time drawing an electrical circuit inside the electric torch, whereas the concept map only required short sentences describing the relations between the concepts. As expected, students who made the concept map talked more about relations between the electricity concepts, whereas students who made the poster talked more about relations of the concepts with concrete phenomena.

However, the analysis also revealed some other (unexpected) effects of the product. Students who made a concept map talked more about relations of concepts with other forms of representation, such as formulas or magnitudes. A product effect was also found on the ratio of incorrect propositions (F (1,15) =

8.90, p = .01). In dyads that made a concept map, students more frequently formulated incorrect propositions than students who made a poster (not shown in the table).

Second, a MANOVA was conducted using the episodic categories as dependent variables. At the episodic level there also appeared to be an unexpected product effect. Although there was no multivariate effect of the product on the episodic categories, univariate F-tests showed that the interaction of dyads who made a concept map contained more collaboratively elaborated conflicts. The product also had an effect on the amount of reasoning. In dyads that made a concept map students more frequently constructed a reasoning (collaborative and individual reasoning taken together).

4.4.2.2 Individual preparation versus no individual preparation

It was hypothesized that individual preparation would result in more question asking and conflict. The analyses of variance revealed no significant effect of the preparation on the number of conflicts (F (1,15) = .64, p = .44). Perhaps the individual preparation time (5 minutes) was too short. The designs were very incomplete and did not explicitly show differences in understanding. Many students had no time to label the links in their design, and most conflicts were about the exact formulation of the relationships between the concepts. A MANOVA was conducted with the preparation for the group work and the kind of product that was asked for as independent variables and the different question categories (verification questions, critical questions, disjunctive questions and open questions) as dependent variables. The product that was asked for had an effect on the number of questions (F(1,15) = 3.53, p =.04). Dyads in which students prepared individually produced significantly more questions. The effect was mainly due to the difference in the number of verification questions.

Analyses of variance for the proposition and episode categories supported the hypothesis that there would be no significant differences.

The individual preparation was assumed to reduce the asymmetry of student participation in the interaction. However, there was no significant difference in asymmetry in utterances between the conditions with and without individual preparation. There was no main effect of the preparation for the task on the asymmetry in utterances (F(1,15) = 1.80, p = .20).

The analysis of the transcripts showed that individual preparation enabled the students to use their individual designs as an extra tool during the accomplishment of the task on an average of 8 times during the interactions. Five general ways of using the designs during the accomplishment of the common task could be identified (see Table 4.8). The designs were mostly used during the first phase of collaboration. In this phase students showed and explained their own work. The designs were further used to support proposals, confirmations and criticisms and to choose new topics that had to be dealt with.

Table 4.8 Examples of the use of individual designs in the Individual Preparation conditions (n = 10)

Use of individual designs	Example
-Exchanging ideas at the beginning of the task	*I put the electrons among these (points at his design)*
-Supporting proposal	*Shall we do it this way (points at her design)?*
-Supporting a confirmation	*Yes I am sure it does, because I wrote exactly the same (shows her design)*
-Supporting a statement in case of a conflict	*(consults her design) I think this (points) is the electric circuit*
-Opening a new topic	*What shall we do with the rest (looks at his design)? What do they mean by length?*

4.4.3 Improvement of conceptual understanding

4.4.3.1 Individual learning outcomes

It was expected that participation in elaborative talk about electricity concepts would affect the ability of students to communicate and use their understanding of the concepts and their relations with other concepts or concrete phenomena. This ability was measured in the pre-test and the post-test. Table 4.9 shows the scores on the different units of the pre-test and the post-test for the four conditions taken together. The four groups did not differ from each other in the mean pre-test scores ($F(1,36) = .39$, $p = .76$). T-tests for paired samples were carried out to test for significant differences between the post-test scores and the pre-test scores. Table 4.9 shows the T- and p-values.

Table 4.9 Mean scores and standard deviations of the pre-test and the post-test and results of a T-test for paired samples (n = 40)

	Pre-test		Post-test		T-value	p
	Mean	Sd	Mean	Sd		
Concept definition unit	9.28	4.22	12.08	4.42	6.07	.00*
Problem-solving unit	5.45	2.32	6.60	2.15	3.36	.00*
Essay Question	2.15	1.31	1.95	1.50	-.71	.48
Total	16.88	5.65	20.63	6.01	6.45	.00*

* $p < .05$

In the Concept definition Unit of the post-test students gave more extensive and better formulated descriptions of the meaning of the concepts. Incorrect propositions that appeared less in this unit of the post-test included the confusion between current strength and voltage and the linkage of some magnitudes to the wrong concepts. In the Concept definition Unit the lowest scores were gained for the concepts of electrons and electric energy and the highest score for the concept of resistance. The higher score on the Problem-solving unit reflects that the students were better able to recognize correct relationships between the physical quantities and to apply these relationships to concrete circuits. The post-test scores for the Essay Question were not higher in comparison with the scores on the pre-test. The electric torch question and the flat iron question were probably not of comparable difficulty. The explanations that students gave showed that they had more problems with identifying an electric circuit in the flat iron than in the electric torch.

4.4.3.2 Effects of task characteristics

Based upon the assumption that individual preparation results in more questioning, conflict and a more symmetric participation in interaction, it was expected that the preparation for the task would have an effect on individual learning outcomes. In section 4.4.2.2 it appeared that the individual preparation conditions only showed more questioning. Analyses of variance with the pre-test score as a covariate showed a significant univariate effect of the preparation for the task on the Concept definition Unit of the post-test ($F(1,35) = 5.20$, $p = .03$). Students who prepared individually for the collaborative task scored higher on this unit of the post-test than students who did not prepare individually.

Further, it was expected that students who constructed a poster would score higher on the Essay Question of the post-test because this collaborative task was ‘closer’ to this unit. However, there was no significant effect of the product on this unit of the test ($F(1,35) = .14$, $p = .71$). There even seemed to exist a contradictory pattern. In the concept mapping conditions the students went from a mean Essay Question score of 1.80 in the pre-test to a mean of 2.05 in the post-test, whereas in the poster conditions the students went from a mean Essay Question score of 2.50 to a mean score of 1.85.

4.4.4 Student characteristics and student participation

It was expected that the participation of students in the interaction could also be related to prior knowledge and attitude towards physics. The participation of the students is described by the number of propositions and the number of arguments a student formulated during the group work. To determine whether there were significant correlations between the pre-test scores, the score on the attitude questionnaire and the number of propositions and arguments, the data of the four conditions were pooled. The four conditions did not differ with regard to the pre-test scores and the scores on the questionnaire. On the average the students scored almost half of the 40 points that could be gained for the pre-test (mean = 16.88, sd = 5.65). The participants had a moderately positive attitude towards physics. The mean score for the attitude questionnaire (with a five point Likert scale) was 3.38 (sd = .59).

The only significant correlation found was between the pre-test scores and the number of arguments ($r(38) = .34$, $p = .04$). Students with higher scores on the pre-test formulated more arguments during the interaction. The number of propositions a student formulated did not correlate significantly with pre-test scores ($r(38) = .31$, $p = .06$), although there was a moderately positive correlation.

No significant correlations were found between the number of arguments and scores on the attitude questionnaire ($r(38) = .26$, $p = .12$), and between the number of propositions and scores on the attitude questionnaire ($r(38) = .29$, $p = .08$).

4.4.5 Features of the student interaction and individual learning outcomes

4.4.5.1 Elaborative episodes and individual learning outcomes

The amount of elaboration in student interaction was expected to correlate with individual learning outcomes. Elaborative talk was (on the group level) operationalized as the number of elaborative episodes in the discourse. The frequencies of such episodes were attributed to the individual students. The results of the partial correlational analyses (controlling for the pre-test scores) are shown in Table 4.10. Table 4.10 shows that no significant correlation was found between the number of elaborative episodes in the student interaction and the scores on the post-test as a whole. The highest positive correlations were found in the concept mapping conditions. Complementary analyses with only the scores for the Concept definition and the Essay unit of the post-test showed that the number of elaborative episodes correlated significantly with the scores on the Concept definition Unit in the condition concept map without individual preparation. This significant correlation was mainly due to the categories: elaborated answers (r = .77), collaborative elaboration of conflict (r = .65) and collaborative reasoning (r = .83). No significant correlations between the number of elaborative episodes and the scores on the Essay Question were found.

Table 4.10 Partial correlations between frequencies of elaborative episodes and the score on the post-test (controlled for pre-test scores)

	Post-test				
	1[1]	2	3	4	total
Total Elaborative Episodes	.50	.40	.22	-.18	.07
-elaborated answer	.53	.51	.18	-.01	.15
-collaborative elaboration of conflict	.44	.30	.34	-.16	.18
-individual elaboration of conflict	-.48	.29	-.04	-.25	-.21
-collaborative reasoning	.49	.43	.24	-.32	.14
-individual reasoning	.24	-.11	.15	-.04	-.10

[1] 1 = concept map with individual preparation (n = 10)

2 = concept map without individual preparation (n = 10)

3 = poster with individual preparation (n = 10)

4 = poster without individual preparation (n = 8)

4.4.5.2 Student participation and individual learning outcomes

A correlational analysis was carried out to examine whether the amount and character of individual participation in the discourse correlated with individual learning outcomes. This analysis included the number of arguments and propositions that were formulated by the student. The formulation of arguments was considered to be an indicator of elaborative participation in the discourse. Only in the concept mapping conditions were some moderately positive, but not significant, correlations found (see Table 4.11). The highest correlation was found in the condition concept map without individual preparation: the number of arguments correlated significantly with the scores on the post-test (r(10) = .66, p = .05).

Table 4.11 Partial correlations between frequencies of propositions and arguments (on the individual level) and scores on the post-test (controlled for pre- test scores)

	Post-test				
	1[1]	2	3	4	total
Propositions	.51	.56	.38	-.04	.10
arguments	.54	.66*	.23	-.23	.08

[1] 1 = concept map with individual preparation (n = 10)

2 = concept map without individual preparation (n = 10)

3 = poster with individual preparation (n = 10)

4 = poster without individual preparation (n = 8)

4.4.6 Student evaluations

This section reports the results of the Student Evaluation questionnaire in which the students could give their opinion about the task, the learning and the collaboration. For each item the number of student responses varied because students could also chose the alternative 'I don't know'. These answers were not included in the calculation of the mean item scores.

4.4.6.1 Evaluation of the task

In general, the students liked the group task and considered it to be instructive and not very difficult (see Table 4.12). The students agreed with the benefit of individual preparation for the group task.

The concept mapping task was found to be more difficult than the poster task. Students who made the concept map agreed more strongly that the task was difficult than the students who made the poster ($F(1,34) = 6.50$, $p = .02$).

Table 4.12 Student evaluations of the task*

Item	Mean	Sd	N
1 I think the task is nice	3.0	1.1	31
2 I think the task is difficult	3.7	.96	38
3 I think the task is instructive	3.2	.95	34
4 I think it is useful when you can prepare individually for the task	3.0	.76	37
5 I was confident about my knowledge when we started with the group task	3.3	.94	36

* Scale: 1 completely agree; 2 strongly agree; 3 agree; 4 disagree; 5 strongly disagree; 6 completely disagree

4.4.6.2 Evaluation of the learning

Table 4.13 shows the results of the unit about the learning that took place. The mean scores of the first four items and the last four items were between 'agree' and 'disagree'. With the exception of item 5 a score lower than 3.5 was considered positive and desired.

Table 4.13 Student evaluations of their learning*

Item	Mean	Sd	N
1 I improved my understanding of the meaning of the concepts[1]	3.9	.92	31
2 I improved my understanding of the relations between the concepts[1]	3.7	.98	35
3 I improved my capability of explaining an electric phenomenon or the working of an electric appliance[1]	3.5	1.1	33
4 I am more confident in my knowledge about electricity than before the task[1]	3.1	1.0	37
5 How well do you understand the following concepts?[2]			
- electric circuit	4.5	1.1	37
- voltage	4.1	1.0	38
- current strength	4.1	.80	37
- electrons	4.6	1.1	36
- electrical energy	4.1	1.0	35
- resistance	4.4	1.1	38
6 I learned because I had to explain to my peer[1]	3.6	.76	32
7 I learned because I had to justify my statements[1]	3.3	.74	33
8 During explaining I realised my lack of complete understanding[1]	3.9	1.2	34
9 I learned from the explanations of my peer[1]	3.3	1.1	33

* [1] Scale: 1 completely agree; 2 strongly agree; 3 agree; 4 disagree; 5 strongly disagree; 6 completely disagree

[2] Scale: 1 not at all; 2 very badly; 3 badly; 4 well; 5 very well; 6 completely

The students especially agreed with the statements that they became more confident of their knowledge, that they learned from the explanations of their peer and that they learned because they had to justify their opinions. The standard deviations show that there is a moderate variation in the student evaluations.
An ANOVA showed that students who prepared individually for the tasks agreed more strongly with the statement that they learned from their peers' explanations ($F(1,29) = 10.53$, $p = .00$). The scores on item 5 show that on the average the students gave a positive evaluation of their understanding of the electricity concepts, especially of the concept electrons.

4.4.6.3 Evaluation of the collaboration

Table 4.14 shows the student evaluations of their peer collaborations. Students strongly agreed that the collaboration with their peer was pleasant. The mean scores on the second item show that most students asked their peer when they did not understand. The mean score on the third item shows that, on the average, the students told their peer when they disagreed. The evaluation that the contribution to the product was equal is in line with the small asymmetry that was found in the student participation. The last two questions can be considered indicators of the usefulness of collaboration. There were somewhat more students who disagreed with the statement that they could have made a better product on their own than students who agreed with this statement. The last item shows that the students were quite satisfied with their product.

As expected, the students who prepared individually for the collaborative task more strongly disagreed with the statement that they could have made a product of the same or better quality on their own ($F(1,27) = 4.50$, $p = .05$).

Table 4.14 Student evaluations of the collaboration*

Item	Mean	Sd	N
1 I collaborated pleasantly with my peer[1]	2.3	.90	38
2 I asked my peer when I did not know or understand something[2]	3.3	1.4	38
3 I told my peer when I did not agree with him or her [2]	2.3	1.0	38
4 My contribution to the task was equal to the contribution of my peer[1]	2.7	1.0	38
5 The product would have been of equal or better quality when I had to make it alone[1]	3.7	1.3	31
6 I am satisfied with our product[1]	2.4	.95	38

* [1] Scale: 1 completely agree; 2 strongly agree; 3 agree; 4 disagree; 5 strongly disagree; 6 completely disagree

[2] Scale: 1 always; 2 almost always; 3 frequently; 4 sometimes; 5 almost never; 6 never

4.5 Summary and Discussion

This study was designed to investigate how characteristics of collaborative learning tasks affect the quality of student interaction, and which features of verbal interaction can be related to learning outcomes. In a pre-test post-test two-factorial design, a concept mapping task was compared with a poster task and the effects of a phase of individual preparation for the collaborative task was investigated. The collaborative tasks were considered suitable for improving the use of electricity concepts in their scientific meaning through the verbalization, elaboration, negotiation and co-construction of the meaning of the concepts. The task functioned as a start of a new course on electricity.

The research questions of this study were given in section 4.2. Below I will summarize and discuss the results. First, I try to answer the question whether the concept mapping and the poster task elicited the desired patterns of student interaction. Second, the influence of the task characteristics on the quality of student interaction is discussed. The third section answers the question whether the collaborative tasks contributed to concept learning and whether there were differences between the conditions. Section 4 is devoted to the relationships between student participation and student characteristics. Section 5 discusses the relationships between categories of elaborative talk and outcomes. The student opinions, as they appeared from the questionnaire that was administered after the collaborative learning session, will be briefly discussed in each section. Finally, the last section is devoted to the questions that arose from the results of this study.

4.5.1 Features of the student interaction

The students worked in dyads on a concept mapping or a poster task. I expected that both collaborative tasks would elicit elaborative talk and the verbalization of conceptual understanding (including frequently reported 'misconceptions'). I also hypothesized a symmetric participation in the discourse.

The analyses of the transcripts revealed that in general the talk of the students included much elaboration and that the relative participation of each student was fairly symmetric. The fact that the students said that they contributed equally to the product is in line with the small amount of asymmetry. Approximately a quarter of all utterances consisted of arguments and most talk about the electricity concepts was about relations between these concepts and about relations of the concepts with concrete phenomena. However, there was less talk about other forms of representation and even though the students mostly talked about relations, these relations barely touched the explanatory level. This may be due to a lack of experience with such talk. Most physics textbooks that are used in secondary education really do not explain described regularities, and the assignments do not give much opportunity to practice the formulation or generation of explanations. To engage students in talk about explanations it may be necessary to request a group product that really requires talk at this level. The talk about the electricity concepts reflected the use of misconceptions, especially the confusion between voltage and current strength and the idea that a larger cross-section of a wire results in a larger resistance. Students also linked some concepts to the wrong magnitude or gave incorrect formulas. Only once the (concept mapping) task elicited the verbalization of the idea of 'current consumption', whereas in the literature this idea is described as one of the most frequent misconceptions within the domain of electricity.

At the episodic level elaborative talk was assumed to be reflected in the giving of elaborated answers, the elaboration of conflict and in reasoning. Although question episodes were more frequent than conflict and reasoning episodes, most questions did not lead to elaboration. This was partly due to the fact that most questions were verification questions that were followed by a confirmation. These questions had an important role in monitoring common ground. Although not all questions were answered during the accomplishment of the task, the student-generated questions can be considered a good starting point for further activities in the course because the students become eager to understand the concepts and the relations. The tasks did not elicit many conflicts, but the conflicts that did occur were almost always elaborated individually or collaboratively. Many researchers on collaborative learning stress the potential of collaborative tasks to elicit elaborated answers and the occurrence and elaboration of conflict. In this study, most elaborative talk was not a response to questions or conflicts but occurred in reasoning episodes. Collaborative reasoning occurred more frequently. In the coding scheme we distinguished between individual and collaborative elaboration of conflicts, and between individual and collaborative reasoning. In general, collaborative elaboration appeared approximately as frequent as individual elaboration. Thus, the student interaction not only showed a considerable amount of elaborative talk, but also showed the appearance of collaborative elaboration in the form of argumentation and the co-construction of a reasoning.

4.5.2 Effects of task characteristics on the student interaction

The influence of task characteristics on the quality of student interaction was reflected in the reported differences between the conditions. Both the concept mapping task and the poster task were expected to elicit elaborative talk. Only differences in the propositonal content of student talk were expected. In meeting this expectation in the poster conditions the students talked less about relations between concepts and used the concepts more to describe concrete phenomena. However, the concept map seems to be a better instrument to elicit elaborative talk about concepts than the poster task. It was assumed that drawing and writing activities in the poster task resulted in less talk about the electricity concepts. This finding is in line with conclusions of Bennett and Dunne (1991) who found similar results with tasks that require concrete actions. In the present study we also found more elaboration of conflict and more reasoning in the concept mapping conditions than in the poster conditions. It is possible that the need to resolve a conflict was more strongly felt by students who made a concept map. Talking about relations between certain physical quantities, these students had to choose between two opposite alternatives. For example, the current strength is either directly or inversely proportional to resistance. A concept map requires an explicit answer. On the poster students can write a short story about each concept and its link to a part of the electric torch, whereby it is easier to combine different points of view. The occurrence of more reasoning in the concept mapping conditions may be explained by the observation that many dyads who made a poster linked the electricity concepts to parts of the electric torch but did not construct a reasoning in which the concepts were related to each other or in which the phenomena that occurred in different parts of the electric torch were related. Students who made a concept map more frequently included different relationships between concepts in one reasoning.

Although in schools students are frequently asked to prepare individually for group work, there existed no empirical data on the effects of such a preparation phase. In the present study a condition with individual preparation was compared with a condition without individual preparation. As expected, imposing individual preparation (which lasted for only five minutes) did affect the number of questions the students posed and gave them an extra tool which supported the exchange of ideas and the negotiation of meaning. The individual preparation did not affect the number of conflicts probably because the designs were not detailed or complete enough to reveal clear contradictions. Another possible explanation for the small amount of conflict may be that at the beginning of the task the students were still very uncertain about their ideas. Further, the individual preparation did not affect the degree of asymmetry in student participation which was actually low in all conditions. The nature of the task itself (making a visible product and having only the other available as a source of information) already stimulated equal participation. The students gave a positive evaluation of the usefulness of individual preparation. Students who prepared individually for the collaborative task more strongly disagreed with the statement that they could have made a product of the same or better quality on their own. This confirms the expectation that individual preparation may result in a more positive evaluation of collaborative learning because the students who prepared individually could experience a difference between what they can do on their own and what they can do in collaboration with a peer.

4.5.3 Improvement of conceptual understanding

Although the task only lasted for an average of 26 minutes and the students could not use textbooks or other information resources, students showed more complete, correct and better formulated definitions of the concepts (as was measured in the Concept definition Unit) and were better able to recognize and apply correct relationships between concepts (as was measured in the Problem-solving Unit) in the post-test. However, I did not find a higher score on the Essay Question. Apparently this question was too difficult and the task may not have been 'strong' enough to affect the ability to use the scientific concepts interrelatedly in the description and explanation of a concrete phenomenon. Although most students reported that they found the task instructive, they suggested that they specifically understood the concepts of electrons and resistance. When we consider the results of the post-test, the students overestimated their understanding of the concept of electrons.

Students who prepared individually for the group task had higher scores on the Concept definition Unit of the post-test. It is not likely that this effect was mediated by the amount of elaborative talk. The individual preparation conditions did not show more elaborative talk. However, it is possible that the individual preparation elicited elaboration during the preparation phase that was not verbalized, and therefore not measured, but still affected the use of the concepts in the post-test. The individual preparation conditions showed more verification questions. It is also possible that the students in the individual preparation condition gained more from the conversation because, especially through questioning, they elicited talk that was relevant to the uncertainties that they had already become aware of during individual preparation. This explanation is also in line with differences that were found in student evaluations. The individual preparation conditions did not show more elaborative explanations, however, the students in these conditions more strongly agreed with the statement that they learned from their peers' explanations.

Although the concept mapping conditions showed somewhat more elaboration, the kind of product that was asked for (concept map or poster) had no significant effect on the post-test scores. This may be due to the influence of the scientific quality of the elaborations. In the concept mapping conditions students formulated more incorrect propositions. In the post-test erroneous descriptions and explanations resulted in a lower score. Further, although it was not expected, the students who made a concept map did not score worse on the Essay Question of the post-test than students who made the poster. Talking about the theoretical relations between concepts may be just as good of a preparation for explaining a concrete phenomenon. This suggestion is in line with the assumption that the availability of an integrated conceptual framework makes it easier to apply conceptual knowledge (Eylon & Linn, 1988). In a study by Okebukola (1992) it was found that concept mapping also results in good problem solving results.

4.5.4 Student participation and student characteristics

The results of the correlational analyses do not give much evidence for the suggestion that prior knowledge and the attitude towards physics also have some influence on the elaborative nature of student talk. The finding that students with more prior knowledge formulated more arguments is consistent with results of research on the effects of prior knowledge on elaborative activities with students learning individually. Overall, the correlations that were found between the number of arguments and propositions a student formulated and their score on the pre-test and the attitude questionnaire were not very strong. This might suggest that student characteristics play a smaller role in the formation of the student participation if the task design is strong enough to promote elaborative talk about the concepts and if the students like the task and consider it instructive.

4.5.5 Relationships between individual outcomes and features of the student interaction

The study adds some empirical evidence in support of the hypothesis that individual learning outcomes are related to the quality of student talk during collaborative learning. In this study not only the individual contributions of each participant were described, but also the nature of the discourse. I suggested that positive results of collaborative learning can be explained by both the amount and quality of individual student participation and by the quality of the contingencies of the actions of both participants.

Positive correlations between categories of student talk and the scores on the post-test as a whole were especially found in the concept mapping conditions. The number of arguments a student formulated correlated significantly with the scores on the Concept definition Unit of the post-test in the condition concept map without individual preparation. Furthermore, in the condition concept map without individual preparation the amount of elaboration correlated significantly with the scores on the Concept definition Unit of the post-test. The frequency of elaborated answers, collaborative elaborations of conflicts and collaborative reasoning primarily constituted this significant correlation.

There are a few remarks to make considering these results. First, the fact that significant correlations were only found in the *concept mapping* condition suggests that especially elaboration of the *theoretical relations* between the concepts contributes to the ability to communicate the meaning of the electricity concepts (as was measured in the Concept definition Unit of the post-test). It must be taken into account that most electricity concepts are defined with their relation with other concepts. Second, significant correlations with post-test scores were found within the condition *without* individual preparation. The analyses of the student talk did not give any clues to explain this pattern. It is possible that, although the individual designs supported the asking of questions and the exchange of ideas, they did not function as an extra tool that supports the giving of elaborated answers, the elaboration of a conflict and the co-construction of meanings. Furthermore, individual preparation resulted in the asking of more verification questions that are less likely to result in the giving of long elaborated answers. Third, the significant correlation that was found between the number of elaborative episodes and post-test scores was for a large part due to the positive correlation between the frequency of collaborative reasoning and scores on the post-test. Mercer (1996) suggested that cumulative talk in which students accumulate and integrate ideas is *less* valuable for learning than exploratory talk in which students argue and question. The results of the present study may suggest that cumulative talk can be as valuable for learning provided that this talk is characterized by elaboration as is defined in this study in the category ‘collaborative reasoning’.

Finally, the social interaction can reflect more or less common effort towards understanding of the concepts. The significant correlation that was found between collaborative elaboration of a conflict and collaborative reasoning on the one hand and individual learning outcomes on the other hand, suggests that student interaction that can be considered *elaborative* and at the same time *collaborative* is valuable for concept learning. It must be taken into account, however, that the small number of participants and the finding of a significant correlation in only one condition and with only one unit of the post-test only gives a very small empirical basis for such an interpretation.

4.5.6 Questions that arise from the study

The results of the present study raise a number of questions for further research. The concept mapping task in particular turned out to be powerful in eliciting elaborative talk about the science concepts which contributed to the ability to verbalize the meaning of the concepts. However, the question arises as to whether the concept mapping task becomes even more powerful in eliciting elaboration and collaboration when it is improved. In the present study the concept mapping task did not elicit much talk about relations of the concepts with concrete electric circuits (as in the poster conditions). Further, the concept mapping task did not elicit much talk at the explanatory level of electrons, the idea of current consumption was hardly verbalized and the students did not try to represent relations in a diagram.

Although the tasks stimulated most students to talk about and elaborate on the concepts, they still did not guarantee that all students took the opportunity to participate in a high-quality discourse. To stimulate elaboration in student interaction we have to know why some students do not elaborate on each other's statements or do not answer questions or elaborate conflicts. It is of interest to know if some extra tools (such as textbooks or materials for experimentation) can prevent unresolved conflicts and unanswered questions.

Of particular interest is the question of whether *collaborative* elaboration is valuable for learning. The coding scheme that was used in this study distinguished between individual and collaborative elaboration of conflicts and between individual and collaborative reasoning. However, in the present experiment the coding scheme did not distinguish between elaborated answers given by one participant and co-constructed elaborated answers. It may be a functional distinction that makes it possible to distinguish between 'individual' elaborative episodes and collaborative elaborative episodes.

Finally, although this study generated some empirical evidence for the influence of task characteristics on the quality of student interaction, factors such as motivation and student capacities may also have a role in this. Additional research with a larger number of students is needed to investigate possible relations between student characteristics and student participation in interaction.

The second experimental study tried to answer some of the questions that arose from this first study. The following chapter presents the design and results of the second experimental study.

5 The Second Study

This chapter presents the results of the second experimental study. The first section explains the decision to provide the students with two textbooks as extra tools and to extend the concept mapping task with a phase of elaboration and discusses the possible implications for the quality of the student interaction. The research questions and hypotheses are given in the second section. The third section describes the experimental tasks, the subjects, the procedure and the tests and questionnaires that were used. This section also describes the coding scheme that was developed to analyze the use of the textbook during the group work. In section 4 the results of the study are presented and illustrated with examples of the use of the textbook and student talk during the second phase of the concept mapping task. Finally, the chapter concludes with a summary and a discussion of the main results.

5.1 Improving the Quality of Student Interaction

The results of the first study raised a number of questions for further research. The study showed that the design of the collaborative learning task affected the features of student interaction. In the study a concept mapping and a poster task were compared. The concept mapping task was successful in eliciting elaborative talk about the science concepts. However, the question arose as to whether the quality of the student talk can be improved. The amount, content and character of elaboration and collaboration differed between groups and within groups. First, not all dyads showed a common focus on understanding. Sometimes questions were not answered and conflicts were not resolved, and sometimes the given elaborations were formulated by only one of the students and were not really co-constructed. Second, the first study showed that the concept mapping task did not elicit much interaction in which concepts and their interrelations were used to describe and explain phenomena in concrete electric circuits (as in the poster conditions), and the interaction rarely reached the explanatory level of moving electrons. The students also did not try to represent relations between physical quantities in a diagram.

In the first study the students had only each other as a resource of information and feedback. Further, the cards with the concepts on it and the individual designs (in two conditions) were the only extra tools the students were provided with. The opportunity to use some extra tools may help the students in resolving conflicts and answering questions and may subsequently stimulate elaboration. Another kind of task design may have more potential to stimulate interaction in which theoretical relations are "applied" to concrete circuits and in which the behaviour of electrons is more often discussed. After a renewed search in the literature on physics tasks and a pilot with a new experimental task, it was decided to provide the students with two textbooks as extra tools and to extend the concept mapping task with a phase of elaboration. The potentials and the possible implication for the quality of student interaction of the availability of textbooks and an extended concept mapping task are discussed in the next sections.

5.1.1 Textbooks: extra tools for collaborative elaboration?

The availability and use of textbooks during the accomplishment of a collaborative learning task may affect both the amount and nature of elaboration and co-construction (see also section 2.4.2.2). The use of textbooks may either foster or constrain elaborative interaction and co-construction. These two possibilities are discussed below.

Cunningham, Duffy and Knuth (1993) suggest that from a constructivist point of view a textbook must not be viewed as a "container" of knowledge that "flows" from the book to the learner, but as a resource of information that can be used to construct meaning. Textbooks are an information resource since they provide concept definitions, explanations, problem-solving questions, formulas, graphs, pictures, tables, descriptions of experiments, etc. The information is presented in written form and static graphics, and is organized in a coherent way. Since textbooks provide accurate, detailed and clearly organized information about physics concepts and their interrelationships, they have the potential to assist the students in using these concepts in their scientific meaning. The information in the textbook can be an extra tool to answer questions and an extra resource of feedback. When the students use the textbooks to answer a question or resolve a conflict, it is likely that their search in the textbook is goal directed. Furthermore, the students can elaborate the information that is provided in the textbook.

However, it is also possible that the use of textbooks *constrains* elaborative verbal interaction. In the present study the collaborative learning task functions as an introduction to a new course involving electricity concepts that the students have not worked with for some time. In the context of such a group task it is more likely that textbooks constrain elaboration. In the first experiment, textbooks were not provided because it was considered important that the students verbalize, elaborate and negotiate their own understanding of the concepts. Because the students may attribute authority to the textbooks, it is possible that they will quickly and frequently consult the textbook and engage less in explicating and elaborating their own thinking. The textbooks may also be explored without a clear goal. Information from the textbooks may not be integrated in and compared with the students' own conceptions. Several authors pointed out that such an explicit comparison rarely appears spontaneously (e.g. Chinn & Brewer, 1993; Biemans, 1997). A frequent use of textbooks might result in a better group product because parts of this product will be based upon (correct) information from the textbooks. However, it is likely that the consultation of textbooks during group work will not contribute positively to individual learning outcomes, when this consultation coincides with less communication of the personal understanding of the concepts and less elaboration, integration and explicit comparison of new information with personal understandings.

Comparable with a material group product, textbooks can also be considered aids in conceptual communication and negotiation and co-construction of meaning (see also section 2.4.2.2). An important difference between the concept map and the textbook is that the concept map is dynamically constructed and modified, whereas the textbook is not. How can textbooks support negotiation and co-construction? First, the collaborating students must be able to *find* information that can assist them in justifying or explaining their ideas. However, when they do find such information it is not guaranteed that they will *share* their findings and thoughts. Not sharing the information found in the textbooks and not sharing the thoughts that are related to the reading will hinder coordination and fruitful individual contributions that can be discussed or elaborated. Consequently, it will not support the co-construction of meaning. Second, it is likely that the more schematic and visual forms of representation in the textbooks, such as graphs, tables, models and pictures, can support communication about the abstract electricity concepts and their interrelationships. Crook (1998) argues that, especially with tasks in which abstract terms are involved, the availability of external representations can support the construction of a shared understanding. Patterson, Dansereau and Newbern (1992) did some research on the use of communication aids in cooperative teaching (where two students teach each other parts of a subject). They defined a communication aid as a visual aid that can be used to communicate information. A condition in which the students used traditional text without pictures was compared with a condition in which the students could use a knowledge map (comparable with a concept map). The participants that used the knowledge map during the cooperative teaching sessions performed better than the participants who used the text. Although it was not studied how the communication aids were used, the researchers suggest that the knowledge maps are better communication tools than texts because of their macrostructure and their reduced verbiage.

In sum, textbooks have the potential to support elaborative communication about the abstract physics concepts, the answering of questions and the negotiation and co-construction of meanings. However, when the students think less for themselves, do not compare information from the textbooks with their own understandings, do not integrate the information from the textbooks with their own reasoning and do not share the information found in the textbook, the textbooks might not support, but actually elaboration and co-construction might be constrained.

5.1.2 Provoking different types of elaborative talk

From the first study it appeared that the concept mapping task elicited elaborative interaction, but that it was somewhat constrained to a specific type of elaborative interaction, namely interaction about the relationships between the electricity concepts. However, learning to use the electricity concepts in their scientific meaning also implies improving the ability to describe concrete phenomena in terms of the electricity concepts and their interrelationships, to describe in terms of mathematical and graphical forms of representation, and to explain phenomena in terms of scientific concepts and theories.

In line with the previously described potential of peer interaction (see section 2.3.3), the verbal communication, questioning and negotiation of scientific descriptions and explanations in the context of a collaborative learning task is assumed to improve conceptual understanding. In the course of the interaction, the peers can co-construct meanings, and conceptions may be (re)organized, differentiated, refined and extended through the formulation of ideas, the asking and answering of questions and argumentation. In the present study the collaborative task was meant as a functional introduction of a new curriculum unit about electricity. Talking about multiple kinds of relationships and talking about explanations for these relationships can be considered a more complete preparation for the range of activities throughout the course. How a collaborative concept mapping task might provoke different types of elaborative interaction and how this interaction may contribute to the understanding of the electricity concepts is described in more detail below.

In a concept map about electricity most relations can be described as regularities. Regularities can be formulated as ‘if-then’ relationships. For example, the fact that *I* is proportional to *V* can be expressed by the proposition *‘If V increases, then I will also increase’*. Theories, beliefs, basic principles and laws shared by the community of physicists provide explanations for these relationships between physical quantities. The interrelationships between the physical quantities and the theories that are used to explain these relationships are based upon empirical data (mostly gained from experimental situations) that validate the theoretical constructions (Tiberghien, 1994). Testing hypotheses and providing explanations are not only activities that are central to the discipline, but are also believed to contribute to the understanding of the physics concepts and their interrelationships by students since they can elicit the elaboration of student conceptions. Chinn and Brewer (1993), for example, suggest that deep processing can be fostered by requesting the students to justify or prove their reasoning through the generation of experimental data or the formulation of an explanation.

A concept mapping task may be extended by a phase in which the students are asked to validate the described relations with experimental data and in which the relationships have to be explained by theoretical principles. When the 'if-then' relationships in the concept map are considered hypotheses, these hypotheses can be confirmed or falsified by experimental data. *Designing* experiments to prove the relationships in the concept map may be a good extension of an introduction task because throughout the following lessons of the course the students can carry out the designed experiments to check the accuracy of the designs and the hypotheses. Such an explicit comparison of data from experiments with personally generated hypotheses is advocated by Palincsar et al. (1993), Licht (1990), Biemans (1997) and Chinn and Brewer (1993). Tamir (1989) showed that students find it difficult to make sense of laboratory activities, particularly when relating these activities to the theoretical concepts that are to be learned. A sequence of formulating hypotheses, designing experiments to test them, performing the experiments and comparing the results with the hypotheses may be a good method to improve the contribution of laboratory work to the understanding of the physics concepts. But what exactly is asked for when the students design experiments to prove the 'if-then' relationships in the concept map? First, an adequate experimental design has to be invented. The required equipment has to be negotiated. Most regularities within the domain of electricity can be validated by measurement of the values of the electric quantities in an electric circuit. Consequently, it is necessary to suggest how quantities such as voltage, current strength and resistance will be measured. To make a comparison across experiments possible, constant and variable values must be negotiated. Second, the experimental design has to be described in words and represented in a drawing, e.g. a drawing of an electric circuit diagram with a resistor, a voltage source that can supply different amounts of voltage, and an ammeter to measure the current strength. In this example it must be negotiated how to draw an electric circuit, a resistor, a voltage source and an ammeter. The idea of current consumption and the idea that a change in a circuit has only 'downstream' consequences (see section 2.1.1.1) may be verbalized during the negotiation of the positioning of the ammeter in a circuit diagram. A description of the experiment in this example could be *'the voltage will be increased by the voltage source and the ammeter readings will be observed and recorded along with the different voltage levels'*. Third, a prediction of the outcomes of the experiment should be given. This prediction can be represented in a table or a diagram. For example, a table or diagram can show the voltage levels and the expected ammeter readings. It may be difficult to predict the exact amperage (although it often can be calculated using Ohm's formula), but the prediction may also be formulated in more general terms, for example, *'the amperage will be higher'*. To present the predicted results in a table it must be negotiated how such a table can be drawn. To present the predicted results in a diagram it must be decided which quantities, units and symbols belong to which axes and how the graph must be drawn. It is likely that the electric circuit diagrams and the tables or diagrams that have to be drawn promote communication about these forms of representation and at the same time facilitate communication and negotiation because the reasoning can be made visible and students can point to parts of the drawings while explicating their thoughts.

The other possibility to extend the concept mapping task is to require the students to give explanations for the described regularities. Although the relationships between physical quantities can be represented in equations that provide the possibility of algebraic manipulation, these equations do not reveal the theories that give the relationships meaning (Tiberghien, Psillos & Koumaros, 1995). The results of the first study showed that during concept mapping the students rarely gave explanations for described regularities. Few students tried to answer the question: Which principles underlie the regularity? Within the domain of electricity, regularities are mostly explained by mechanisms that are not directly observable, such as the moving of electrons. For example, the regularity *'if the resistance increases, then the current strength will decrease (with a constant voltage)'* may be explained by the fact that due to higher resistance the free electrons have more difficulty (because of greater friction) moving around. Explanation sentences mostly have the form of *'the reason that A is that B'* or *'A because B'*. An explanation is uttered with the intention to make something understandable, and the person that gives the explanation assumes that the propositions that form the explanation are correct (Achinstein, 1983).

In sum, besides the construction of a network that describes the theoretical relationships among electricity concepts, both designing experiments with which the given relationships can be validated, as well as the giving of explanations for the relationships may be group tasks that can contribute to the elicitation of multiple types of elaborative peer interaction, and thus to the improvement of the understanding of the electricity concepts.

5.2 Research Questions and Hypotheses

The questions of this second study partly overlap with those of the first experimental study. The present study also focuses on the affects of task characteristics on the quality of peer interaction and the learning outcomes, on the relationships between categories of peer talk and outcomes and on relationships between student characteristics and student participation in the interaction. In this study the issue of task characteristics and the quality of peer interaction was addressed by a focus on the way textbooks affect patterns of student interaction and outcomes and on the potential of an extended concept mapping task. This second experimental study attempted to give an answer to the research questions and to test the hypotheses that are presented below.

1 The use of textbooks in a collaborative learning task

a) How do dyads that are provided with textbooks use these textbooks during the group work?

b) *What effect does the use of textbooks during the group work have on the features of the student interaction?*
c) *What effect does the use of textbooks during the group work have on the quality of the group product?*
d) *What effect does the use of textbooks during the group work have on the individual learning outcomes?*
e) *What effect does the use of textbooks during the group work have on the student evaluations?*

An important aim of the present study was to investigate how textbooks are used and how this use affects the quality of student interaction and the outcomes. It was expected that the textbooks wouldl be used often as an extra tool in problem situations in which the students have difficulties answering a question or resolving a conflict. Further, it was assumed that the use of textbooks usually would not be preceded by the formulation of the students' own conceptions and that the information found would most likely not be elaborated. It was expected that pictorial information would be used most often. Finally, it was assumed that the information found in the textbook, would probably be used to construct the group product.
It was hypothesized that frequent use of textbooks during the collaborative work on the introduction task would result in less intense talk about the electricity concepts and less elaborative interaction. The more time that is spent on the consultation of textbooks, the less talk there will be about the concepts and the less elaborative the student interaction. The following reasons underlie this hypothesis. First, talk about the electricity concepts might be less intense if the students spend considerable time consulting a textbook. Second, when the students are uncertain as to their own knowledge and attribute much authority to the information in the textbooks, they might be less engaged in explicating their own thinking and therefore elaborate less on their own. Third, information from the textbooks might not be integrated in and compared with the students' thinking. Several authors stressed the necessity of forcing students to compare new information with their own conceptions because most students do not do this spontaneously.
It was hypothesized that frequent use of the textbooks would result in a better group product because parts of this product would be based upon (correct) information from the textbooks. The more time spent on the consultation of textbooks, the higher the quality of the group product.
However, I assumed that the use of textbooks during the group work would not result in a more adequate use of the electricity concepts in a subsequent situation without a partner and without textbooks (as measured with an individual post-test). When the frequent use of textbooks goes together with less communication of the personal understanding of the concepts and less elaboration, integration and explicit comparison of new information with personal understandings, it will not contribute positively to individual learning results. Therefore, the more time spent on the consultation of textbooks, the lower the performance on the individual post-test.
Finally, it was assumed that the students appreciate the availability of textbooks. The possibility of consulting a textbook was expected to have a positive effect on the experienced task difficulty and the satisfaction with the group product.

2 The construction of the Concept Map and the Elaboration of the Concept Map

Which differences exist in the features of student interaction during the construction of the concept map and during the elaboration of the concept map (designing experiments, representing expected results and giving explanations)?

It was expected that the concept mapping task, extended with an elaboration phase of designing experiments and explaining relationships, would elicit elaborative interaction about the electricity concepts, their theoretical interrelationships, their relationships with concrete phenomena and other forms of representation. The task was further expected to elicit a symmetric participation of the students and the verbalization of scientifically "false" conceptions that are common within the domain of electricity.

Student interaction during the construction of the concept map and during the elaboration phase that follows were to be compared. It was expected that student interaction during the elaboration phase of the task would contain:

a) more talk in which the electricity concepts are related to concrete phenomena
b) more talk in which the electricity concepts are related to other forms of representation
c) more frequent verbalizations of the idea of current consumption
d) more talk on the explanatory level of moving electrons

3 Features of student interaction related to student characteristics and outcomes

a) Is the participation of students in the interaction related to prior knowledge and the attitude towards physics?
b) Are individual learning outcomes related to the amount of elaborative interaction in the group?
c) Are individual learning outcomes related to the participation of the student in the interaction?

In the first study the only significant correlation found was between the number of arguments a student formulated and their score on the pre-test. The relationship between the participation of a student in the interaction, their amount of prior knowledge and their attitude towards physics, were investigated again in the present study. It was hypothesized that a student with more prior knowledge and a more positive attitude towards physics would show a greater and more elaborate participation in the interaction.

It was assumed that the collaborative task would result in an improvement of conceptual understanding. The improved understanding of the electricity concepts was expected to be related to the degree of participation in the student interaction and the amount of elaborative interaction in the group. The larger the participation in the interaction and the more elaborative this participation (on the individual level), the higher the post-test scores will be. The more elaborative episodes in the student interaction (the group level), the higher the post-test scores will be. The results of the first study raised the question of whether the appearance of *collaborative* elaborative episodes in the interaction can be related to individual learning outcomes.

The following section provides a description of the experimental design and the instruments that were used to answer these questions and test the hypotheses.

5.3 Method

5.3.1 Experimental tasks

In a pilot with three dyads of students aged 15 to 16, the concept mapping task with a phase of construction and a phase of elaboration was performed and the results were used to improve the design of the task. The instruction that was given to the participants is included in the Appendix (Ic). In the first study it appeared that individual preparation for the collaborative learning task stimulated questioning and gave the students an extra tool to exchange ideas and negotiate meaning. As in the first study, the students in the actual second study were asked to individually make a design for the concept map before starting to collaborate on the task. The concepts that were given to make such a design corresponded with the concepts that had to be used in the group task. After the individual preparation, the students had to make a network on a large paper (A2) with given concepts such as current strength, voltage and resistance. Related concepts had to be connected and the links that represent the relations between concepts had to be labeled precisely. In the task instruction it was suggested that the students would try to describe the relations between the concepts as much as possible in the format 'when X increases/decreases, then Y will …', since it is easier to design experiments and represent expected results in a graph for relationships that are described in such a format. Contrary to the previous study, the students were not asked to include multiple forms of representation in their concept map, such as magnitudes, formulas, models and diagrams. The use of such multiple forms of representation was fostered in the second phase of the group task.

The concept mapping task was extended with a phase in which the students had to design experiments which would prove the relationships described in their concept map. They were also asked to represent the expected results of the designed experiments in a table or a diagram, and to give an explanation for the nature of the relationships. The students were asked to elaborate each relationship of their concept map. For each relation the students could use a poster (A3) that was already structured in a part for the experiment, the diagram and the explanation (see the example in Appendix Ic). The use of large papers was meant to constrain the appearance of a spontaneous task division.

5.3.2 The textbooks

The students were given two different textbooks to enhance the possibility of being confronted with different ways of explaining the meaning and relationships of the electricity concepts. The two textbooks that were chosen focus on the curriculum as it is taught in intermediate general secondary education, and are frequently used in Dutch schools. *Natuurkunde Overal* (NO) contains a chapter of 41 pages on electricity. The other chapters are about pressure, power and mass, mechanics, atoms, electromechanical appliances and investigational methods. *Systematische Natuurkunde* (SN) contains two chapters on the basic principles of electricity (78 pages). One chapter is about electric charge and the other handles electric current. The other chapters deal with magnetic fields, magnetic induction and atoms. The three chapters (one in *NO* and two in *SN*) that were considered relevant for the collaborative learning task were clearly marked for the students with bookmarkers.

The chapters present information about electrons, current strength, voltage, energy, resistance and the quantities that determine the resistance, such as the length, the cross-section area and the wire substance. The chapters also provide information on power (watt), but this concept was not to be used in the concept mapping task. Both *NO* and *SN* contain texts, sets of questions, assignments for experimenting, illustrated descriptions of experiments, schemes, circuit diagrams, pictures, tables, *I/V* diagrams and diagrams in which several quantities are related to the resistance of a wire. The headings often contain concepts that have to be used in the concept mapping task, for example 'electric energy', 'current, voltage and resistance', 'quantities that determine the resistance', and 'current direction and current strength'. *NO* contains somewhat more pictures and diagrams than *SN*. Compared with *NO*, *SN* gives more information on free electrons and their behaviour in electric circuits. The relations between physical quantities are primarily described in words and formulas and in both textbooks are emphasized with a colored background. Both textbooks do not explicitly present explanations for relationships between physical quantities, although the information given can be used to infer such explanations. Further, both textbooks contain an index, a table of contents and a summary of the information given in the chapter.

5.3.3 Subjects and design

In the study 56 students (of 15 or 16 years of age) from two physics classes in intermediate general secondary education, each in a different school participated. As in the previous study within each class the students were randomly assigned to same-sex dyads. Eight girl-girl dyads, eighteen boy-boy dyads and two mixed-gender dyads (because of uneven number of boys and girls) participated in the study. The students were accustomed to working in groups. Within each class the same number of dyads was randomly assigned to one of the two conditions: a condition in which the two physics textbooks were available and a condition without the availability of textbooks. The students who participated in the study had never worked with the selected textbooks. The design is shown in Table 5.1.

Table 5.1 Number of dyads in the two conditions

With Textbooks	Without Textbooks	Total
14	14	28

5.3.4 Setting and procedure

The procedure of the experiment is shown in Table 5.2. Three weeks before students worked together in dyads they took the pre-test to measure their prior knowledge on the domain of electricity and completed a questionnaire that was intended to measure their attitude towards physics. The collaborative session was started with a brief instruction about making a concept map, describing an experiment, making a diagram and giving an explanation. The examples that were used in this instruction focused on the topic of phase changes (see Appendix Ic). The experiment was carried out in a school room under the guidance of the experimenter (the researcher or a graduate student). During the accomplishment of the collaborative task the students were recorded on video, as was described in section 4.3.3. Before students started to collaborate on the concept map they were asked to make a design for the concept map individually (on an A4 paper). The group work session then lasted for a maximum of 75 minutes, depending on the time students needed to complete the task. The students could spend a maximum of 25 minutes on the concept mapping task (phase A). In the first experiment the students could work for a maximum of 45 minutes on the concept mapping task, but the mean time the students actually worked on the task was about 26 minutes. Further, in this second study the concept mapping task was less extensive than in the first study since the students were not asked to include multiple forms of representation in their concept map. The students could spend a maximum of 50 minutes on the elaboration of the concept map: designing experiments, representing expected results and formulating explanations (phase B). The students were told that it was not a problem if they could not manage to elaborate *all* relations in their concept map. Immediately after the students finished the group task they were asked to answer a questionnaire about the task. The post-test was administered in the next physics lesson (one week later).

Table 5.2 Procedure of the experiment

Activity	Duration in minutes	
Pre-test	35	minutes
Attitude towards Physics Questionnaire	10	minutes
Instruction	5	minutes
Individual preparation	5	minutes
Collaborative task A: Concept Map	25	minutes (max.)
Collaborative task B: Elaboration of the Map	50	minutes (max.)
Student Evaluation Questionnaire	5	minutes
Post-test	35	minutes

5.3.5 Measurement of concept learning

As in the first experimental study, the pre-test and the post-test consisted of three units. These units are described in more detail in section 4.3.4 and in Appendix II. Table 5.3 shows the descriptives of the pre-test and the post-test that were used in this second study.

Table 5.3 Descriptives of the units of the pre-test and the post-test

Unit	Number of items	Maximum score	Response Format	Cronbach's alpha	
				pre-test	post-test
Concept definition	5	20	definition, magnitude/formula and drawing	.58	.64

Problem-solving	6	12	multiple choice with justification of answers	-.21	.25
Essay Question	1	8	essay	-	-
Total	12	40		.43	.46

The Concept definition Unit did not contain the concept 'electric circuit'. In the first study it appeared that many students confused this concept with a switch. The Essay Question in the pre-test asked the students to explain the working of an electric torch. In the post-test the students had to explain the working of a flat-iron. The Problem-solving Unit that was used in the first study was adapted on several points. Three items were kept the same as in the first study. Two items in which the students had to apply a relation between two physical quantities were replaced with an item in which an explanation was asked and an item in which the students had to read and explain a relationship from a diagram. These changes were made as a consequence of the extension of the concept mapping task with a phase of designing experiments, representing the expected results and giving explanations. A Kolmogorov-Smirnov test showed that the scores on the pre-test and the post-test were normal distributions. As in the first study, the Problem-solving Units showed low item homogeneity. The Cronbach's alphas for the complete tests were not high but were still considered acceptable.

An answer key to score the tests was constructed in consultation with two physics teachers. Inter-rater reliability of the scoring of the three units was acceptable. Cohen's Kappa was .88 for the first unit; .87 for the second unit and .81 for the third unit (for twenty tests chosen at random).

5.3.6 Scoring of the group products

Shavelson and Ruiz-Primo (in press) describe three methods for scoring concept maps: convergence scoring, salience scoring and proposition-accuracy scoring. They define a pair of concepts and the labeled line connecting them as a proposition. The convergence score is the proportion of accurate propositions in the concept map out of the total possible valid propositions in a criterion map. The salience score is the proportion of accurate propositions out of all the propositions in the concept map. The proposition-accuracy score is the sum of the accuracy rating assigned to each proposition in the map. In the present study the proposition-accuracy score was used because according to Shavelson and Ruiz-Primo this score better reflects the systematic differences in students' understanding than either the convergence or salience score. The accuracy of the propositions was assessed on a scale from 0 for an inaccurate proposition to 1 for a correct and complete proposition. Propositions in which a relation between the concepts was described accurately but not very precisely were given half a point. An example of such an imprecise label (.5 point) is: *"The current strength depends on the resistance"*. An example of a more precise label (1 point) is *"The larger the resistance, the less current strength"*.

Each description of an experiment, each table or diagram and each explanation was also assessed with zero, a half or one point. When a relationship in the concept mapping task was described incorrectly, the representation of the expected results of the designed experiment was scored on its compatibility with the incorrect relationship. For example, when the students stated that an increased voltage results in an increased resistance, and they represented this relation adequately in a voltage-resistance diagram, the students got one point for the diagram. Seven products chosen at random were scored by a second coder.

Inter-rater agreement was .74 (Cohen's Kappa) for the concept map, .77 for the description of the experiments, .74 for the diagrams and .67 for the explanations.

5.3.7 Measurement of attitude towards physics

To measure the students' attitude towards physics, the same questionnaire was used as in the first experimental study (see Appendix III). A higher score on the questionnaire reflects a more positive attitude towards physics. In this study the Cronbach's alpha reliability turned out to be .89.

5.3.8 Measurement of student evaluations

The Likert-scale questionnaire that measured student evaluations in the first study was adjusted for the second study. The items in which the students could evaluate how well they understood each electricity concept were excluded from this questionnaire since most students in the first study apparently overestimated their understanding. These items were replaced by a question that asked students to write down what they still did not yet understand after completing the collaborative task. Further, two items about the evaluation of the task were added. The students were asked whether they found it useful to be provided with textbooks. They were also asked whether they found it useful to think about the concepts themselves before consulting a textbook. To constrain the number of items, two items about the collaboration with their peer were also excluded from the questionnaire. The items of the Student Evaluations Questionnaire are presented in the result section.

5.3.9 Coding of verbal interaction and the use of the textbook

The coding scheme to describe features of peer interaction was presented in chapter 4 (see also Appendix IVa, IVb an IVc). At the utterance level both communicative functions and proposition categories were identified. At this level two minor changes were made in the coding scheme. The distinction between confirmation (yes) and acceptance (mm mm, okay) was cancelled because it is not an important distinction considering the research questions. The category 'confirmation' now also included utterances such as 'mm mm' and 'okay'. A new distinction was added to the coding of the propositional content of the utterances. Besides the distinction between correct and incorrect propositions, a distinction was also made between propositions that are literally read aloud from a textbook and propositions that are formulated without a textbook or in which a proposition from a textbook is rephrased or interpreted.

Due to some changes in the collaborative task, the interaction of the students was expected to be somewhat different when compared with the interaction in the first study. Therefore, the inter-rater reliability of the coding at the utterance level was checked again. A total of 1622 utterances (from three transcripts chosen at random) was coded by a second person. Inter-rater reliability (Cohen's Kappa) reached .92. Inter-rater reliability of the proposition categories reached .86 (Cohen's Kappa).

At the episodic level a change was made in the coding of the question episodes. In the previous chapter (see section 4.5.6) it was suggested that collaborative elaboration may not only occur in the form of collaborative reasoning or argumentation, but also in the form of a co-constructed elaborated answer. To investigate whether *collaborative* elaboration contributes to conceptual learning, a distinction was made between answers that are formulated by one student and answers that are co-constructed. In the first study the proportion of agreement between two raters coding the episodic categories was 79%. Because the distinction between individually elaborated answers and co-constructed elaborated answers was added to the coding scheme, the question episodes (129) of three transcripts chosen at random were coded by a second person. The proportion of agreement for the coding of the question episodes reached 82% (Cohen's Kappa .69).

A category system to describe the use of the textbooks during the collaborative accomplishment of the task was not developed in advance. The categories predominantly emerged from the data. It was valuable to consider the situations in which the students consulted a textbook and what this consultation contributed to the negotiation and co-construction processes and to the group product. Five transcripts were used to develop a category system that could be reliably used to describe the use of the textbooks. The categories are presented in Table 5.4 and are described in more detail in Appendix IVd.

Table 5.4 Categories that describe the use of textbooks

Main Categories	Subcategories	Cohen's Kappa
1 Verbalization of own ideas before using the textbook	- verbalization - no verbalization	.81
2 Situations in which a textbook is consulted	- question - conflict - uncertainty - partner is writing/drawing/ reading - starting a new part of the task - continuation after a short interruption - looking for confirmation - other	.77
3 Result of the consultation of the textbook	- no result (no verbalization or writing/drawing in the product) - information corresponding with the current topic - information that does not correspond with the current topic	.90
4 Elaboration of the information found in the textbook	- elaboration - no elaboration	.84
5 Reading aloud from the textbook	- reading aloud - no reading aloud	.90
6 The information found in the textbook results in a change in the group product	- a change of the group product - no change of the group product	.88

The consultation of a textbook was defined as a situation in which one or both students read text, look at a picture, scan rapidly over the text or turn the pages. During the transcription of the interaction it was noted when a student consulted a textbook, how much time they spent doing so, and which pages were consulted. Because it was assumed that the use of textbooks could constrain the verbalization of the students' own thinking, it was coded whether the consultation of the textbook was preceded by a verbalization of their own ideas on the current topic. Further, the situation in which a textbook was used was described. The coding scheme distinguished eight situations including a question, a conflict and the start of a new part of the task. It was also assumed that the students would not always elaborate the information found in the textbook. For example, that they would not compare the information from the textbook with their own conceptions and reasoning. It was also valuable to know whether the students shared the information found in the textbook by simply reading the text aloud verbatim. Consequently, it was coded whether the student found some useful information in the textbook, and (when this was the case) whether the information found, corresponded with the reason to consult the textbook, and whether it was elaborated or not. It was also noted whether the finding of information in the textbook resulted in writing or drawing on the group product.

Three transcripts chosen at random were coded by two persons to check for reliability. These transcripts included 54 episodes in which a textbook was consulted. Inter-reliability for the categories turned out to be acceptable (see Table 5.4). Then, the transcripts that were not used to test for inter-reliability were coded with the constructed coding scheme.

5.4 Results

First, a description will be given of the way the textbooks were used during the accomplishment of the collaborative task. Two examples are presented to show how differently the dyads were making use of the available textbooks. Then, the differences in student interaction and outcomes among the conditions both with and without textbooks will be given. Second, the question of which differences exist in the content and patterns of student interaction during the two phases of the task will be addressed. Since the interaction during the concept mapping task was illustrated in the previous chapter, this section presents fragments from student interaction during only the elaboration of the concept map. How did the students discuss the experimental designs, the representation of expected results in a diagram and the explanations for the relationships? Finally, the last section answers the question of whether the features of the student interaction are related to student characteristics and to the individual learning outcomes.

5.4.1 The use of textbooks during collaborative learning

Table 5.5 shows the results of the analyses of textbook use by the collaborating students. The results will be described in the following sections.

5.4.1.1 How frequently were the textbooks consulted?

In the fourteen dyads that could consult a textbook during the collaborative learning task, the textbooks were used an average of 7 times. An average of 32.93% (17.75 minutes) of the total time spent on the task was spent consulting a textbook. However, there was a large variation (sd = 13 minutes) because some dyads consulted the textbook only for one or two minutes, whereas in other dyads most of the time was spent on consultation of a textbook by one or both students.

5.4.1.2 Which parts of the textbooks were consulted?

It was remarkable that during the majority of the time the textbooks were used, the students only turned the pages (42.19%) and scanned rapidly over the text, probably only reading the titles to identify relevant paragraphs. The index and the table of contents were rarely used. Once the students identified a paragraph relevant to the task, they read more carefully. The text fragments with different layouts (for example, printed in bold or on a colored background) were most frequently read. During the construction of the concept map the students primarily read the pages about Ohm's law and about the quantities that determine the resistance of a wire. These relations were printed on a colored background and were illustrated with diagrams. During the second phase of the task (the elaboration of the relationships in the concept map) the students also frequently used the page about Ohm's law. When the students were drawing electric circuit diagrams the page with the symbols of the circuit elements was often consulted. During the design of experiments several students read the assignment for an experiment with which the relations between resistance, length, cross-section area and sort of material could be explored.

Table 5.5 Percentages of textbook use categories (n = 14 dyads) [1]

Main Categories	Subcategories	%
1 Verbalization of own ideas before using the textbook	- verbalization	51.04
	- no verbalization	48.96
2 Situations in which a textbook is consulted	- question	15.63
	- conflict	6.77
	- uncertainty	9.38
	- partner is writing/drawing/reading	18.75
	- starting a new part of the task	25.00
	- continuation after a short interruption	9.90
	- looking for confirmation	6.77
	- other	7.81
3 Result of the consultation of the textbook	- no result	47.40
	- information corresponding with the current topic	38.54
	- information that does not correspond with the current topic	14.06
4 Elaboration of the information found in the textbook	- elaboration	75.25
	- no elaboration	24.75

5 Reading aloud from the textbook	- reading aloud	55.45
	- no reading aloud	44.55
6 The information found in the textbook results in a change in the group product	- a change of the group product	84.16
	- no change of the group product	15.84

[1] Categories 1,2 and 3: percentages of total number of cases in which a textbook was used (192)

Categories 4, 5 and 6: percentages of total number of cases in which information was found (101)

5.4.1.3 Explicating own ideas before consulting a textbook

In half of the cases where students consulted a textbook, this consultation was preceded by a verbalization of own ideas on the current topic (see Table 5.5). In the other half, the students did not verbalize their own understanding and thinking. Consulting a textbook without such verbalization usually appeared at the start of a new part of the task or while their peer was writing or drawing. Further, many questions were immediately followed by consultation of a textbook without an initial attempt to answer the questions independently.

5.4.1.4 In which situations were the textbooks consulted?

The coding scheme distinguished eight categories that described the situations in which a textbook was used. Episodes in which a textbook was consulted but that did not fit in one of the first seven categories were coded as 'others'. No new categories were created because particular situations in the 'other' category did not occur more than ten times. The 'other' category contained, for example, some cases in which a student used a textbook because (s)he remembered that something related to the topic was discussed in the book (*'I read something about that in the book'*).

The most frequent situation in which a textbook was consulted was the start of a new part of the task (see Table 5.5). In most of these cases, one of the students introduced the new part of the task (a new relation, experiment, diagram or explanation to be described/drawn) with a statement such as *'voltage and current strength'* or *'description of the experiment'*. After such a statement the student(s) immediately started to search or read in the textbook and did not try to formulate a proposal of their own. Consulting a textbook at the start of a new part of the task occurred more often during the elaboration phase than during the construction of the concept map. This may be related to the fact that during the elaboration of the concept map, an experiment, table or diagram and an explanation had to be provided for each relationship. These three parts of the second task can each be considered 'new' parts of the task. Another situation in which textbooks were often consulted was when the partner was engaged in writing, drawing or reading. In these situations the students presumably wanted to make a contribution (also from an efficiency point of view), did not want to disturb their partner or were just bored, and therefore they consulted a textbook without verbalizing what they were looking for (probably because they did not know what exactly to search for). Questions and uttered uncertainty were moderately frequent motives to consult a textbook, although in view of the high number of questions in the peer interaction this situation did not occur very often. During the making of the concept map uncertainty was almost twice as frequent a situation in which a textbook was consulted than during the elaboration of the concept map. The students rarely used the textbook as an attempt to resolve a conflict, although it must be taken into account that conflict episodes themselves were infrequent.

5.4.1.5 Results of the consultation of a textbook

Table 5.5 shows that in almost half of the cases in which a textbook was consulted, this consultation had no apparent result. This was partly due to interruptions of the reading or searching in the textbook because of a partner's utterance (for example, a question). In the other cases it was assumed that the student did not communicate something related to the information given in the textbook because the student did not find information which (s)he considered to be useful.

In 39% of the times that the students consulted a textbook, they found some information that corresponded with their initial reason to consult the textbook. In these cases the information that was found corresponded with the topic the students were currently dealing with, was used to confirm a hypothesis, to answer a question or to resolve a conflict. In almost two thirds of the cases in which a question was the motive to consult a textbook, the students formulated an answer with the help of the information found in the textbook. Conflicts were rarely resolved with the assistance of information in the textbook.

Finally, there were also situations (14%) in which the information found in the textbook was verbalized or included in the product, however this information did not correspond with the topic the students were currently working on. Most of the time the finding of such information resulted in a topic change.

The videos and the transcripts of the student interaction also revealed that it sometimes occurred that a student who was reading or searching in a textbook did not react to things that were said by the partner. In these situations the student did not confirm or elaborate a statement of the partner or did not answer a posed question. Such 'disturbances' of the communication can also be considered a result of consulting a textbook.

The students frequently read aloud from the textbook. In the condition with the availability of textbooks 8% of all propositions was read aloud verbatim from a textbook.

Although it was not expected, when the students found some useful information in the textbook, it was usually (75%) elaborated: the information was included in a reasoning or gave rise to a conclusion or a question. Finding useful information in the textbook almost always resulted in drawing or writing on the group product. During the concept mapping task the information found in the textbook was specifically used to label a link between two concepts or to make a new link between concepts. In particular, the relations voltage-current strength, voltage-current strength-resistance and voltage-energy were found or described with the help of the textbook. During the elaboration of the concept map the consultation of a textbook mostly contributed to a description of an experiment and the drawing of a circuit or a diagram. Diagrams in which the relation between resistance and length or the cross-section area is represented were constructed with the help of such diagrams in the textbook. In only one dyad did the information in the textbooks support the students in formulating an explanation.

5.4.2 Two examples of the use of textbooks

The following examples show how differently the dyads were making use of the available textbooks during the accomplishment of the task. In both examples the students talk about resistance and its relationships with other quantities, such as length and the cross-section area of a wire. Monique and Yvette and Aniek and Bregje had comparable scores on the pre-test and on the Attitude towards Physics questionnaire. Monique and Yvonne finished the task in 65 minutes and Aniek and Bregje in 57 minutes and the quality of the group products was comparable (10.5 and 11.5 points). However, the students differed in their improvement in conceptual understanding, as evidenced by the differences between their pre-test and post-test scores. Monique had the same score on the post-test as on the pre-test and Yvette scored only two points higher on the post-test. Aniek and Bregje made considerable improvement. Aniek scored five points higher on the post-test and the post-test score of Bregje was impressively seventeen points higher.
In both examples the utterances of the students are given in two adjacent columns. This makes it easier to see at what moments the utterances or actions are simultaneous, for example when one of the students is making a statement or asks a question while the other student is consulting the textbook. In both dyads, uncertainty, questions and the opening of a new topic were the most frequent situations in which a textbook was consulted.

5.4.2.1 The use of textbooks by Monique and Yvette

Monique and Yvette rarely attempted to answer questions themselves before they consulted the textbook. The first example (Example 5.1) shows that Yvette immediately starts to look up resistance in the textbook after it appeared that neither of them knew the meaning of this concept (line 4). Monique starts to search in the other textbook. Not until they cannot find any useful information about resistance in the textbook does Yvette verbalize her own understanding of the meaning of resistance (line 7). Monique does not react to the definition that Yvette suggests, but reads aloud the relation between current strength and voltage (line 11). Without further elaboration on the relation found in the textbook, Yvette includes it in the concept map. When Monique is reading in the textbook, Yvette proposes two other relations (line 13 and line 17) to which Monique hardly reacts.
The collaboration of Monique and Yvette is characterized by a spontaneous task division. Yvette is making the concept map, while Monique consults the textbook. The verbal communication is restricted to what is minimally necessary to complete the task.
Several times Monique and Yvette included information from the textbook in their concept map, although it was sometimes very obvious that they did not really understand what they copied from the textbook. In line 42, for example, after Monique read the relation between resistance and the cross-section area of a wire, Yvette formulated it exactly opposite and apparently did not even realize that it is illogical that a wire becomes thinner due to an increased resistance, and when she asks Monique to repeat the sentence (line 45), it is probably not because she really wants to understand the relation, but because she wants to include it correctly in the concept map.

5.4.2.2 The use of textbooks by Aniek and Bregje

Example 5.2 describes two fragments of the interaction between Aniek and Bregje. Aniek and Bregje mostly verbalized their own thinking before they consulted the textbook. In the first five lines of the example they verbalize their ideas about the relationship between resistance and the cross-section area. They find their description confirmed by the information that is given in the textbook (line 7).

Aniek and Bregje mostly elaborated the information that they found in the textbook. They tried to compare and integrate the information with their own thinking before they included it in their concept map. The included fragment of their interaction shows some examples. After Aniek verbalized the information as it is given in the textbook (line 9), Bregje tries to draw a conclusion in her own words (line 10). In line 12 Aniek uses the diagram in the textbook as a tool to formulate the nature of the relation. After Aniek read aloud the relationship between length and resistance (line 80), she gives a correct interpretation of that relation. But apparently she realizes that this information does not correspond with her own ideas about the nature of the relation (line 82). Next, Bregje tries to explain the relationship as it is described in the textbook. The fact that Aniek finishes the utterance of Bregje (line 88) shows that she is engaged in the reasoning. Bregje's reasoning is incorrect, but after Aniek points out that she is still not convinced (line 93), Bregje tries to understand the relationship between length and resistance by a comparison with the relationship between cross-section area and resistance. This comparison finally brings her to a correct interpretation of the directly proportional relationship between length and resistance (line 99).

5.4.2.3 Conclusions

These two examples show how the textbooks, when used as an extra tool during collaborative learning, affected the quality of the student interaction. Monique and Yvette specifically used the textbook to complete their product. They attached a great authority to the information given in the textbook and did less thinking for themselves. Aniek and Bregje were more active in communicating their own ideas about the concepts and compared the information found in the textbook with these ideas. They also showed a greater engagement in each other's ideas and reasoning and tried to build on each other's contributions. Aniek and Bregje used the textbooks as an extra tool to understand and co-construct the meaning of the electricity concepts.

Example 5.1 The use of textbooks (1): Monique and Yvette

	Monique	Yvette
1		I don't know what resistance is
2	no, neither do I	
3		then we start with the current strength
4		I'm going to look up resistance (takes SN)
5	(takes NO)	(looks up in SN)
6	(looks up in NO)	(looks up in SN)
7	(reads in NO)	I think the resistance is how difficult the voltage is going through the wire
8	here is something about voltage and current strength (reads in NO)	
9	there is also an experiment, here	
10	(looks in NO)	(looks in NO)
11	apparently the current strength depends on the voltage and the appliance the current is going through (reads out from NO)	
12	(reads in NO)	then we paste voltage (pastes)
13	(reads in NO)	I think energy belongs to that
14	(reads in NO)	you had that too, hadn't you?
15	Yes	
16	(reads in NO)	(pastes cards)
17	(reads in NO)	I also had the resistance with that
18	(reads in NO)	but I don't know whether that's right
19	I think it is	
20	(reads in NO)	(pastes concept)
21	yes it must be	
22	because here is a formula with resistance and voltage (points in NO), thus it belongs together	(draws lines between cards)
…		
36	I wrote nothing against resistance	(looks in SN)
37	it says: in figure 14b you see the relationship between the cross-section area of a constantan wire and the resistance (reads aloud from NO)	
38		(looks in SN)
39		here it also says something
40	the table of experiment 4.3 shows that a twice as large cross-section area results in a twice as small resistance (reads aloud from NO)	
41		diameter and resistance
42		when the resistance is twice as large, the diameter will be twice as small
43	no, when the diameter is twice as large, the resistance will be twice as small	
44		when the (writes)
45		what did it say?

Example 5.2 The use of textbooks (2): Aniek and Bregje

	Aniek	Bregje
1		Yes
2	when this increases	
3		the resistance is smaller
4	the resistance is smaller yes	
5		yes, shall we write that down?
6		when the area is large (writes on her own design)
7	look, it says the same here (points in NO)	
8		okay
9	the relationship between the cross-section area and the resistance is inversely proportional (reads aloud from NO)	
10		oh yes, thus the resistance is smaller
11		okay
12	here, look (points to the diagram in NO), when this increases, this decreases	
…		
80		because the graph goes through its origin, the relationship between length and resistance is proportional (reads aloud from NO)
81	thus, then it would be the longer the wire the larger the resistance	
82	not really?	
83		yes, the larger, yes
84	I think then the resistance will decrease	
85		oh
86	the resistance will decrease, won't it?	
87		the resistance, let me see, when the cross-section area increases (gesticulates with her hand)
88	the resistance decreases	the resistance decreases
89		thus, when this (points to length) the resistance will also decrease
90	yes?	
91	okay, shall we say that?	
92	the longer the length	
93	or doesn't it matter?	
94		they are proportional
95		what was this one (points to the relation between resistance and cross-section area)?
96		was this one also proportional?
97	no, that one was inversely proportional	
98		inversely
99		thus proportional means the larger the wire, the larger the resistance

5.4.3 Differences among the condition with and the condition without textbooks

Did the condition with and the condition without textbooks differ from each other in the features of the student interaction, the individual learning outcomes, the quality of the group product and the student evaluations? These questions will be answered below.

5.4.3.1 Differences in student interaction

T-tests for independent samples were used to test for differences in the appearance of propositional and episodic categories between the two conditions. It was expected that the use of textbooks would have a negative effect on the verbalization of personal ideas about the and on elaborative interaction. The mean ratios of propositions and elaborative episodes in the two conditions are presented in Table 5.6.

Table 5.6 Mean ratios[1] and standard deviations of categories on the utterance and episode level in the two conditions, and results of t-tests for independent samples.

Categories	Condition		p
	With textbooks	Without textbooks	
	Mean (Sd)	Mean (Sd)	
Total propositions	1.69 (.63)	1.62 (.51)	.76
Question Episodes	.41 (.15)	.39 (.16)	.62
Answered questions	.36 (.15)	.33 (.13)	.64
- co-constructed elaborated answers	.04 (.04)	.05 (.04)	.64
- individual elaborated answers	.05 (.03)	.06 (.03)	.61
- short answer	.27 (.12)	.23 (.10)	.36
Not answered	.06 (.03)	.05 (.04)	.72
Conflict Episodes	.09 (.06)	.13 (.08)	.12
Elaborated conflicts	.07 (.06)	.10 (.07)	.15
- collaborative elaboration	.03 (.04)	.07 (.05)	.03*
- individual elaboration	.04 (.05)	.03 (.03)	.91
No elaboration	.02 (.02)	.03 (.03)	.34
Reasoning Episodes	.11 (.05)	.17 (.07)	.02*
- collaborative	.07 (.04)	.11 (.06)	.07
- individual	.04 (.03)	.06 (.03)	.17
Total Ind.-elab. Episodes[2]	.13 (.05)	.15 (.06)	.34
Total Coll.-elab. Episodes[3]	.15 (.09)	.23 (.11)	.02*

[1] Ratios: frequencies divided by the time (in minutes) during which the students worked at the group task

[2] Total Individual Elaborative Episodes = Individual elaborated answers + Individual elaborations of conflicts + Individual reasoning episodes

[3] Total Collaborative-Elaborative Episodes = Co-constructed elaborated answers + Collaborative elaborations of conflicts + Collaborative reasoning episodes

* $p < .05$

A Kolmogorov-Smirnov Test showed that the variables were normally distributed. Although it was assumed that the condition with textbooks would show fewer propositions, the availability of textbooks had no effect on the number of propositions formulated per minute. In addition, in the condition with the availability of textbooks, the relation between the proportion of the time that was spent on consultation of a textbook correlated negatively but not significantly with the number of propositions per minute ($r(14) = -.33$, $p = .25$).

Table 5.6 also shows the results of the analyses on the episodic level. More than half (58%) of all elaborative episodes reflected *collaborative* elaboration. In both conditions question episodes appeared more often than conflict and reasoning episodes. Although most questions were answered, most of the answers given were short answers and not elaborated ones. Elaborated answers given by one of the participants appeared as frequently as co-constructed answers. It was assumed that the condition without textbooks would show more elaborative episodes. This hypothesis was confirmed. In the condition without textbooks, more collaborative elaborative episodes appeared. In the condition without textbooks, more collaborative elaborations of conflicts appeared as did more reasoning. The proportion of the time that was spent on the consultation of a textbook correlated negatively but not significantly with the number of elaborative episodes per minute ($r(14) = -.31$, $p = .29$).

5.4.3.2 Differences in the quality of the group product

In the present study the students were asked to construct a concept map (phase A) and to elaborate the relations in this concept map (phase B). Each relation in the concept map, each description of an experiment, each table or diagram and each explanation was assessed with 0 (incorrect), .5 (partly correct) or 1 (correct) point. Figure 5.1 shows the scores for the parts of the group product in the two conditions.

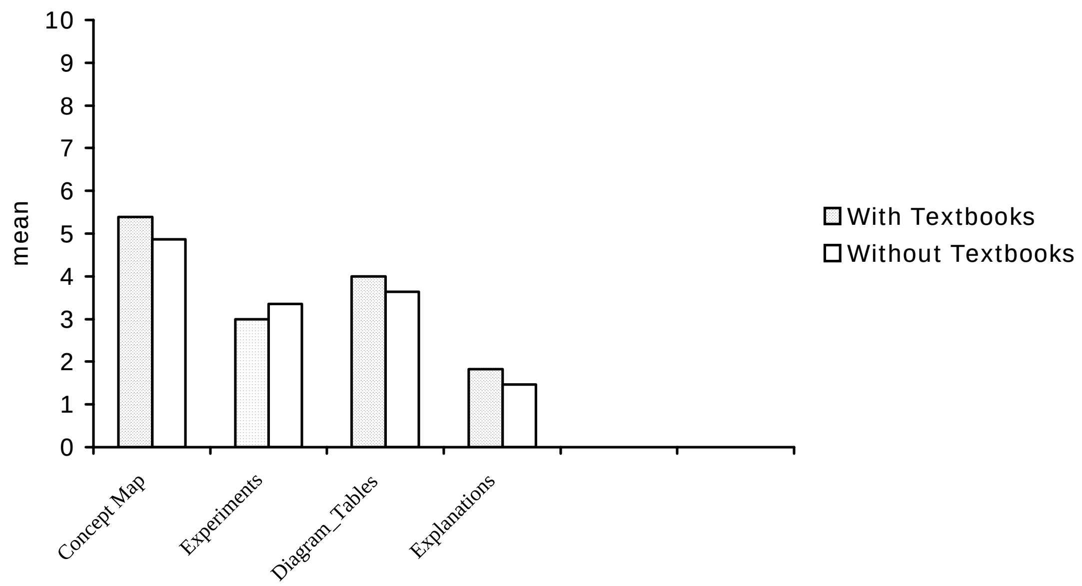

Figure 5.1 Mean scores for group products in the condition with textbooks (n = 14 dyads) and the condition without textbooks (n = 14 dyads)

On the average the students scored 5.13 points for the concept map, 3.18 points for the designed experiments, 3.82 points for the diagrams/tables, and 1.64 points for the explanations. Most group products contained only few correct explanations for the relationships between the electricity quantities. It was expected that the dyads in the condition with textbooks would construct better group products than the dyads in the condition without textbooks. However, there appeared no significant differences in the total score for the group product between the two conditions ($t = .87$, $p = .39$). The product scores in the condition with textbooks ($m = 15.04$, $sd = 4.18$) were not significantly higher than the product scores in the condition without textbooks ($m = 13.71$, $sd = 3.86$). The proportion of the time spent on the use of textbooks also did not correlate significantly with the total score for the group product ($r(14) = .04$, $p = .90$).

5.4.3.3 Differences in individual learning outcomes

The students were expected to improve their ability to communicate their understanding of the concepts, the relationships between concepts and with concrete electric circuits and other forms of representation. The change in this ability was measured by a comparison of the pre-test and the post-test scores. Table 5.7 shows the scores on the different units of the pre-test and the post-test for the two conditions taken together. The differences between the pre-test and the post-test were tested with t-tests for paired samples. The students scored significantly higher on the post-test. This significant difference is due to higher scores on the Concept definition Unit and the Problem-solving Unit. The post-test scores on the Essay Question were almost significantly lower than the scores on this unit in the pre-test. The score on the Essay Question is based upon a score for the number of adequately used electricity concepts and the completeness of the explanation. Only the scores for the completeness of the explanation in the post-test were significantly lower than in the pre-test. As in the first study, the answers that the students gave on the 'flat-iron question' of the post-test showed that the students had problems with recognizing and describing the electric circuit of the appliance.

Table 5.7 Mean student scores and standard deviations of the pre-test and the post-test (n = 56), and results of t-tests for paired samples.

	Pre-test	Post-test	T-value	p
Concept definitions	6.68 (3.13)	8.50 (3.01)	4.26	.00*
Problem-solving	5.45 (1.84)	6.48 (2.19)	2.80	.01*
Essay Question	2.30 (1.24)	1.89 (1.40)	-2.30	.05
Total	13.55 (4.16)	16.86 (4.21)	4.93	.00*

* $p < .05$

It was expected that the availability of textbooks would constrain (elaborative) communication about the electricity concepts and would therefore not contribute positively to the understanding of the concepts. An ANCOVA with the pre-test score as a covariate and the total score on the post-test as a dependent variable showed no main effect of the availability of textbooks ($F(2,53) = .60$, $p = .44$). Table 5.8 presents the pre-test and the post-test scores in the two conditions. In the condition with textbooks there was a negative but not a significant correlation ($r(28) = -.13$, $p = .53$) between the time spent on the use of a textbook and the scores for the post-test (controlling for pre-test scores).

Table 5.8 Mean scores (and standard deviations) on the pre-test and the post-test in the condition with (n = 28) and the condition without textbooks (n = 28)

	With textbooks		Without textbooks	
	Pre-test	Post-test	Pre-test	Post-test
Concept definitions	6.39 (3.14)	8.32 (2.92)	6.96 (3.16)	8.68 (3.14)
Problem-solving	5.54 (1.71)	6.36 (2.30)	5.36 (1.99)	6.61 (2.11)
Essay Question	2.07 (1.30)	1.68 (1.36)	2.54 (1.14)	2.11 (1.42)
Total	13.29 (4.30)	16.36 (4.40)	13.82 (4.06)	17.36 (4.03)

* $p < .05$

5.4.3.4 Differences in student evaluations

Table 5.9 presents the evaluations of the students in the condition with textbooks and the condition without textbooks. In both conditions the students agreed that it is useful to prepare individually for the task, to have textbooks available and to think for yourself before consulting these textbooks. As expected, the students who could consult a textbook found the task less difficult than the students in the condition without textbooks. The hypothesis that the students who could consult textbooks would be more satisfied with their product was also confirmed. Further, Table 5.9 shows that the students agreed, but not very strongly, that the task was instructive and that they improved their understanding of the concepts and the relationships. The students who could consult textbooks found the task more instructive than the students who could not consult textbooks. The students agreed that they became aware of a lack of complete understanding due to explaining. The questionnaire contained an item that asked the students to write down what they still did not understand. The students often posed questions about electrons and energy. Further, they asked questions such as *'what is the difference between voltage and current strength?'*, *'what is the relation between different sort of materials and the resistance?'* One student wrote that she became very curious to learn more about the concepts: *'How must the network be organized? I would like to have an explanation of the way it is all related. I'm very curious now.'* The students who could consult textbooks agreed more strongly that they learned from the explanations of their partner, whereas the students who could not consult textbooks agreed more strongly that they learned from the giving of explanations and that they realized their lack of complete understanding. The students had the experience of a pleasant collaboration and an equal contribution to the task. The students who could consult a textbook agreed more strongly that their contribution was equal.

Table 5.9 Student evaluations[1] and results of t-tests for independent samples.

Item	With Textbooks	Without Textbooks	p
Evaluation of the task			
I think the task is nice	3.18	3.46	.37
I think the task is difficult	3.43	2.64	.01*
I think it is useful when you can prepare individually for the task	2.93	2.71	.28
I think it is useful that you can consult textbooks during this task	2.29	2.43	.60
I think it is useful to try first together before consulting a textbook	2.61	2.71	.70
Evaluation of the learning			
I think the task is instructive	3.07	3.64	.03*
I improved my understanding of the meaning of the concepts	3.43	3.64	.41
I improved my understanding of the relations between the concepts	3.21	3.54	.18
I improved my capability of explaining an electric phenomenon or the working of an electric appliance	3.50	4.04	.05
I am more confident in my knowledge about electricity than before the task	3.21	3.75	.05
I learned because I had to explain to my peer	3.75	3.18	.01*
I learned because I had to justify my statements	3.43	3.29	.53
During explaining I realized my lack of complete understanding	2.75	1.93	.00*
I learned from the explanations of my peer	2.89	3.54	.02*
Evaluation of the collaboration			
I collaborated pleasantly with my peer	2.07	2.36	.32
My contribution to the task was equal to the contribution of my peer	2.57	3.46	.00*
The product would have been of equal or better quality when I had to make it alone	4.04	3.89	.70
I am satisfied with our product	2.64	3.29	.02*

[1] 1 completely agree; 2 strongly agree; 3 agree; 4 disagree; 5 strongly disagree; 6 completely disagree

5.4.4 The two phases of the task: Concept Map and the Elaboration of the Concept Map

Some differences in the content of student talk were expected between the two phases of the task: the construction of the concept mapping and the elaboration of the concept map. The differences that were found between the two phases of the task are presented in the section below. Then the talk of the students during the elaboration phase will be illustrated by some examples.

5.4.4.1 Differences in student talk

The students worked an average of 15.50 minutes on the concept mapping task (phase A) and 38.70 minutes on the elaboration of the relationships in the concept map (phase B). The differences in propositional content between peer talk in phase A and B are shown in Figure 5.2.

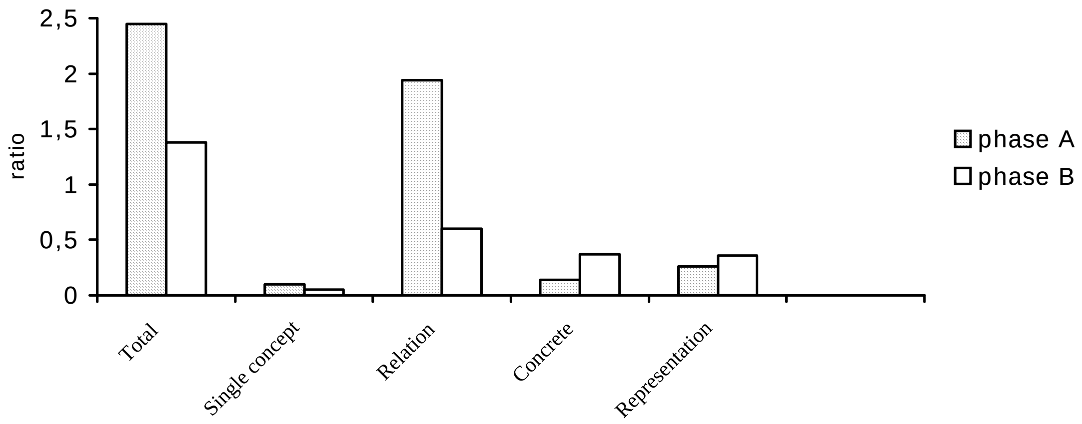

Figure 5.2 Mean ratios of total propositions and proposition categories in phase A and B (n = 28 dyads)

The propositions that were literally read from a textbook are not included in the given numbers. Propositions in which electricity concepts were related to other concepts appeared most frequently. T-tests for paired samples revealed some significant differences between the two phases of the task. First, during the making of the concept map the students talked more intensely about electricity concepts than during the elaboration of the concept map (t = -5.22, p = .00). A finding that might be related to this result is that during the second half of the task (phase B) more off-task talk appeared (t = 4.11, p = .00). Second, as expected, the construction of the concept map showed more talk about relations between the concepts (t = -10.31, p = .00), whereas the elaboration phase showed more talk in which the electricity concepts were used to describe and explain concrete phenomena (t = 4.16, p = .00). During the elaboration phase the students had to describe and draw the experiments with which the relations in the concept map could be verified. Third, it was assumed that the second half of the task (phase B) would elicit more talk about technical and mathematical forms of representations because the students had to draw electric circuits and diagrams. However, the t-test did not show a significant difference between phase A and B (t = 1,15, p = .26).

5.4.5 Examples of student interaction during the Elaboration of the Concept Map

Below some examples are given of interaction during the design of experiments, the representation of the expected results in diagrams and the formulation of explanations. Further, some fragments containing incorrect propositions that reflect the conception of ‘current consumption’ and local reasoning are presented.

5.4.5.1 Talk about experimental designs

In phase B students were asked to design experiments in which the described relations in the concept map could be proven. This part of the task did not only elicit talk about the nature of the experiment but also talk about the way an electric circuit must be built and how it can be drawn using circuit diagram symbols (for example, *a bulb is a circle with a cross* or *a resistor is an oblong shape*). In the following fragment, Anne proposes an experiment to prove the relation between material type and the current strength. In the concept map she and Laura stated that the material type affects the current strength. Anne describes an experiment in which two electric circuits, one with copper wires and the other with iron wires, are compared. Implicitly she states that the current strength is indicated by the brightness of a bulb. She predicts the brightness of the bulbs on the basis of the material of the wires that are used. To clarify her reasoning she draws the circuits that she is describing. Anne specifically utters concrete propositions. She relates electricity concepts, such as material type and conduction, to copper and iron wires and the brightness of a bulb.

Example 5.3 Designing an experiment to prove a relation between current and material type

Anne:	we can do the material type	
Anne:	because when you have got material one	
Anne:	and then you draw an electric circuit with material one	*proposition concrete*
Anne:	that, those wires in the electric circuit are from material one	*proposition concrete*
Anne:	(draws) then you have an electric circuit like this	*proposition representation*
Anne:	bulb (draws)	
Anne:	look, then for example this (draws)	
Anne:	here (points) it is, I don't know	
Anne:	here it is, for example, the material type is, for example, copper	*proposition concrete*
Anne:	that conducts well, doesn't it?	*proposition concrete*
Laura:	mm mm	
Anne:	yes, suppose it conducts well	*proposition concrete*
Anne:	yes, it conducts well	*proposition concrete*
Anne:	and here (points) you have got for example iron	
Anne:	that doesn't conduct, conducts less	*proposition concrete*
Anne:	and then it appears, for example, that the bulb shines bright and that this one is not shining (points)	
Anne:	thus, that has to do with the material type	*proposition concrete*

During the design of experiments many students referred to experiments that they carried out themselves in the physics class. The students referred to such experiences to negotiate how to draw an ammeter or a voltmeter in an electric circuit drawing, or how the physical quantities can be measured. In Example 5.4 , Hans tries to remember how an ammeter had to be connected. When Pim remarks that he thinks that it doesn't matter, Hans draws an electric circuit with an ammeter that is connected parallel to explain what he exactly means. Apparently Pim does not remember any experience that is related to the question how to connect an ammeter. He says that what Hans is saying may be possible, but that he does not know it.

Example 5.4 Designing an experiment with reference to classroom experiences

Hans:	(writes) how did you have to connect an ammeter?	*proposition concrete*
Hans:	parallel or serial?	*proposition concrete*
Hans:	voltmeter was parallel, wasn't it?	*proposition concrete*
Pim:	I think it doesn't matter	
Hans:	yes it does, you had to, look (draws), here a bulb and then you had to connect such a meter like this	*proposition concrete*
Hans:	you know, over the bulb like this (draws)	
Pim:	yes, that may be possible, I don't know	

5.4.5.2 Discussing other forms of representations

The request to represent the expected results of the designed experiment in a table or diagram was meant to provoke talk about other forms of representations. During this part of the task the students discussed how the quantities must be represented in units and symbols. In Example 5.5 Paul and Adrie talk about which magnitude belongs to which axis, and how the relation between current strength (*I*) and voltage (*U*) can be represented in a graph. During their discussion they use the scientific term 'variable', that helps them to decide that *U* must be on the horizontal axis.

Example 5.5 Representing a relation between quantities in a diagram

Adrie:	thus, then we put here (points to the vertical axis)	
Paul:	*U*	*proposition representation*
Adrie:	(writes)	
Paul:	no, the *U* must be beneath	*proposition representation*
Paul:	*U* is variable, isn't it?	*proposition single concept*
Adrie:	mm mm	
Adrie:	(writes) and here we put the *I*	*proposition representation*
Adrie:	thus, when *U* increases, *I* also increases (draws a line)	*proposition representation*
Paul:	yes, but also gradually	*proposition representation*

5.4.5.3 Student interaction on the explanatory level

The students were explicitly asked to give explanations for the 'if-then' relations they described in their concept map. The transcripts of the student interaction showed that the students had difficulties with the generation of such explanations. Some students suggested *'because it isn't otherwise'* or *'some Einstein invented it'*. They presupposed that there is no reason that 'if A then B'; that the relation does not need further explanation. Many students had difficulties distinguishing between a *description* and an *explanation* of a relation between quantities. This appeared from utterances such as '*the explanation, that is what I wrote there (points to labeled link in the concept map)'*, '*the explanation is the longer the wire, the less* *current strength'* and '*wood does not conduct whereas iron does'*. Sometimes Ohm's formula was given as an explanation for a relation between two quantities. This formula is useful when calculating the magnitude of voltage, current strength or resistance when the other two quantities are already known. It gives a quantitative description of the relation between the three quantities. Some of the students, however, suggested that the formula itself explains the relations (for example *'when the I becomes larger in the formula, R becomes smaller'*). Such reasoning was not always incorrect, but does not correspond with what was meant by a scientific explanation of a regularity. Although during the instruction the students were given examples of explanations, and were told that within the domain of electricity explanations often have to do with the flow of free electrons, not all students tried to relate regularities to phenomena on this micro-level.

In some dyads the students discussed the implications of giving an explanation. In these cases usually one of the students was not content with a certain proposal because he or she had the idea that it would not count as a good explanation. For example, a student stated '*actually, this is a description of what happens, but what is the explanation?'* or '*you have to know why, why does the resistance increase?'* In Example 5.6 Niels realizes that he must answer the *why*-question.

Example 5.6 Negotiation of what counts as an explanation

Niels:	yes, things are so, I can't help it	
Niels:	the diameter is more important than the length of the wire	*proposition relation*
Teun:	yes	
Niels:	but, why is that?	*proposition relation*

The next fragment gives an example of how a student tried to give an explanation as was asked in the instruction. Angela gives an explanation for the hypothesis that the material type affects the current strength. She and her peer designed an experiment in which they wanted to compare the shining of a bulb in electric circuits when built out of different material types.

Example 5.7 Generating an explanation

Angela:	yes, the bulb only shines	
Angela:	when it conducts it contains free electrons	*proposition concrete*
Angela:	and free electrons transport the energy	*proposition relation*

Sometimes an analogy was used to generate an explanation. Ricardo and Eric (see Example 5.8) try to explain the relationship between the length of a wire and the resistance. Ricardo starts with the suggestion that the energy has to cover a longer distance. Eric replaces energy with electrons and compares the flow of electrons in a wire with the flow of water in a garden hose. Finally, they are able to write down a scientifically correct explanation.

Example 5.8 Generating an explanation using an analogy

Ricardo:	yes, the energy must cover a longer distance	*proposition relation*
Ricardo:	that is simple	
Eric:	no, no, no	
Eric:	the resistance is larger because the electrons have to cover a longer distance	*proposition relation*
Ricardo:	yes, that's what I am saying	
Eric:	look, when you have such a wire	
Eric:	that is just like with a garden hose	
Eric:	a garden hose of this length (gesticulates) and a garden hose of this length (gesticulates)	*proposition concrete*
Eric:	from which is more water coming?	
Eric:	from which is the water pressure higher?	*proposition concrete*
Ricardo:	yes, but you can't make that comparison	
Eric:	the longer one results in higher pressure	*proposition concrete*
Ricardo:	actually it is a longer wire, and then the electrons have more	*proposition relation*
Ricardo:	then, they have resistance for a longer period	*proposition relation*
Ricardo:	because they have to cover a longer distance	*proposition relation*

5.4.5.4 Incorrect propositions and reactions to incorrect propositions

When conceptions are verbalized the students can become aware of the fact that their conceptions do not correspond with scientific ones or that they can be compared with other interpretations and criticized. The coding scheme distinguished between scientifically correct and incorrect propositions. An average of 12% of the propositions that were formulated in a dyad consisted of incorrect propositions. Sometimes students made errors in linking quantities to the concepts or gave incorrect formulas. During the concept mapping task many incorrect propositions reflected the students' confusion between the concepts of voltage and current strength and the idea that a larger cross-section area results in a higher resistance (see also section 4.4.1.3). During the making of the concept map the students formulated more incorrect propositions per minute ($m = .26$, $sd = .19$) than during the elaboration of the concept map ($m = .16$, $sd = .10$). This difference was significant ($t = -2.55$, $p = .02$). However, as expected, student talk during the making of the concept map contained no verbalizations of the idea of current consumption or of local reasoning, whereas this was verbalized in twelve dyads during the second half of the task. The conception that an electric circuit uses up current and that an intervention in the circuit only affects the part behind the intervention appeared most often when the students were designing their experiments. In Example 5.9 Winnie and Christine wanted to draw an electric circuit with a piece of wood because they hypothesized that a piece of wood would not conduct. Christine suggested that the piece of wood had to be placed between the battery and the bulb. Winnie confirmed this and explained it by the incorrect assumption that there was a current strength between the battery and the piece of wood, but not between the piece of wood and the bulb because, due to the piece of wood, the current could not come back to the battery.

Sometimes the generation of an explanation revealed the notion of current consumption. For example, several dyads explained the fact that the current strength is inversely proportional to the length of the circuit with the proposition '*more current is used up'*.

Example 5.9 Local reasoning

Winnie:	I think we have to measure current strength	
Winnie:	but how can we do that?	*proposition concrete*
Christine:	I think the piece of wood has to be between the battery and the bulb	
Christine:	otherwise, we can't determine whether it conducts	*proposition concrete*
Winnie:	here (points)	
Winnie:	it's between the battery and the bulb	
Christine:	then we must connect these ones, because it results in	
Winnie:	yes, but look, when the current is going like this, then it doesn't come back, does it?	*proposition concrete*
Winnie:	when this does not conduct, it can't come back again	*proposition concrete*
Winnie:	do you understand?	
Christine:	yes	

5.4.6 Features of student interaction related to student characteristics and outcomes

With correlational analyses it was investigated whether the features of student talk were related to student characteristics and to the individual learning outcomes. The results of the correlational analyses are presented in the following sections.

5.4.6.1 Student participation and student characteristics

It was assumed that the participation of students in the interaction might be related to their prior knowledge and their attitude towards physics. To determine whether there were significant correlations between the pre-test scores, the score on the attitude questionnaire and the number of propositions and arguments a student formulated, the data from the two conditions were pooled. It must be taken into account that the scores on the pre-test correlated significantly with the scores on the attitude questionnaire ($r(56) = .29$, $p = .03$).

Significant correlations were neither found between the pre-test scores and the number of propositions ($r(56) = .14$, $p = .29$), nor between the pre-test scores and the number of arguments the students formulated ($r(56) = .21$, $p = .13$). Also no significant correlations were found between the scores on the attitude questionnaire and the number of propositions ($r(56) = .17$, $p = .22$) and between the scores on the attitude questionnaire and the number of arguments ($r(56) = -.17$, $p = .20$).

5.4.6.2 Individual learning outcomes and student participation

It was expected that an active and elaborative participation in the interaction would be positively related to individual learning outcomes. Table 5.10 shows that when the two conditions are taken together, the number of propositions a student formulated correlated significantly with the score on the post-test. Students who made more statements about the electricity concepts had higher scores on the post-test. However, in the condition with textbooks no significant correlation was found. The post-test score correlated positively but not significantly with the number of arguments a student formulated.

Table 5.10 Partial correlations between the number of propositions, arguments and post-test scores in the two conditions (controlled for pre-test scores)

	Post-test Score		
	With textbooks (n = 28)	Without textbooks (n = 28)	Both conditions (n = 56)
Propositions	.30	.46*	.39*
Arguments	.24	.20	.24

* $p < .05$.

5.4.6.3 Individual learning outcomes and elaborative episodes

It was assumed that elaborative interaction in the dyad and, more specifically, episodes that reflect *collaborative* elaboration would be positively related to individual learning outcomes. The frequencies of the elaborative episodes were attributed to the individual students. The results of the correlational analyses (controlling for the pre-test scores) are shown in Table 5.11. It appeared that (when both conditions are taken together) more collaborative elaborative episodes in the student interaction went together with higher total scores for the post-test. The amount of individual elaboration in the interaction was not significantly related to post-test scores.

Table 5.11 Partial correlations between elaborative episodes and post-test scores in the two conditions[1] (controlled for pre-test scores)

	Post-test Score		
	With textbooks (n = 28)	Without textbooks (n = 28)	Both conditions (n = 56)
Individual elaborative episodes	.02	.02	.07
Collaborative elaborative episodes	.28	.22	.32*

* $p < .05$.

5.5 Summary and Discussion

This section tries to answer the research questions that were posed in section 5.2 by summarizing and discussing the results of this study.

5.5.1 The use of textbooks

Important questions in this study were how the students would use textbooks during the accomplishment of the group task and how the consultation of the textbooks would affect the quality of student interaction and the outcomes. The specific questions that were asked in section 5.2 are answered below.

5.5.1.1 How the textbooks were used

It was suggested that the students would use the textbooks frequently because of their uncertainty about the meaning of the concepts and because of the authority that they would attribute to the information in the textbook. As expected, the students that could use textbooks spent a lot of the time that was available for the accomplishment of the group task on the consultation of a textbook, although there was a large variation. It was assumed that the availability of textbooks would be especially helpful in situations in which the students had problems answering a question or resolving a conflict on their own. Questions and conflicts, however, were not frequent reasons to consult a textbook. The most frequent situation in which a textbook was consulted was the start of a new part of the task.

Half of the time the consultation of a textbook was not preceded by an attempt to formulate a proposal or an answer without the help of the information in the textbook. From the transcripts, it was clear that consulting a textbook without verbalizing their own ideas or a question not only appeared frequently in situations when a new part of the task was started, but also in situations in which the partner was drawing, writing or reading. In these latter situations a lack of verbalization may be explained by the desire not to disturb the activity of the partner and from the lack of a clear idea of what to look up in the textbook. In almost half of the cases, the consultation of textbooks consisted of simply turning the pages and did not help the students in the negotiation of meaning and the construction of the required product. In almost half of the cases in which the students consulted a textbook this had no apparent result: the students did not find any useful information. Different factors may explain this. First, many students never formulated a goal when consulting a textbook. This was evidenced when the students consulted a textbook when starting a new part of the task and they seemed to have only a very vague sense of what they were actually looking for. Second, the fact that the students had some difficulties finding information in the textbooks may also be related to their lack of experience using textbooks as a source of information to complete a task that is not set in the textbook itself. The students rarely made use of efficient strategies to search for information, such as using the table of contents or the index. Further, the textbooks that were provided were not written as reference books and this may have hindered the students' ability to look up the requested information. The way the information was represented in the textbooks seemed to influence whether information was found, shared and discussed. The information that was printed in bold or on a colored background was most frequently consulted. The pages with formulas and V/I diagrams related to Ohm's law and the resistance of a wire were frequently used. Formulas, diagrams and electric circuit diagrams especially functioned as extra tools to formulate and negotiate meanings of the electricity concepts and their interrelations.

Although the information found in the textbooks was not frequently compared with the students' own ideas and did not always correspond with the topic the students were currently working on, most information found was shared by reading aloud and was elaborated by means of reformulating the information in their own words, drawing a conclusion or asking a question. The students' elaboration of the information given in the textbook may be explained by the fact that the task did not allow much for exact replication from the textbook because what was asked for was not literally presented in the textbook. Furthermore, most students really tried to understand the concepts and their interrelations. However, in some dyads (see, for example, Example 5.1) the students copied some definitions and experiments from the textbook without real understanding.

5.5.1.2 The effects of textbook use on the quality of the student interaction

It was expected that the use of textbooks during the (introduction) task that was used in this study would inhibit the communication of personal understanding of the concepts and elaborative interaction. The comparison of student talk in the conditions with and without textbooks shows that in general the textbook use constrained elaborative interaction and co-construction.

Although the conditions with and without textbooks did not differ in the *amount* of talk about the electricity concepts, there were some differences in the *nature* of that talk. In comparison with the condition without textbooks, the interaction of the students that used textbooks was characterized by less collaborative elaboration. A possible explanation for this result may be that the availability of textbooks kept the students from explicating their reasoning, questions and conflicts. Both questions and conflicts can elicit (collaborative) elaborative interaction. Questions may be asked but not verbalized. Instead students initially trusted the authority of the textbook. Further, the use of textbooks may have constrained collaborative elaboration because the use of textbooks sometimes went together with a spontaneous task division: one student was looking up and elaborating the information found in the textbook while the other was writing it down or was searching in the other textbook. Finally, when the information from the textbook was elaborated, this elaboration mostly consisted of an interpretation in own words or the drawing of a conclusion, and did not take the form of a collaborative reasoning or a conflict that could elicit collaborative elaboration. This may have to do with the conception that the information in the textbook does not need to be discussed and extended, because it is already 'complete' and 'true'.

5.5.1.3 The effects of textbook use on the quality of the group product

It was expected that the students who could consult textbooks would produce a better group product. However the availability of textbooks did not have an effect on the score for the group product. It is likely that this is due to the fact that in more than half of the cases in which the students consulted a textbook, no useful information was found and used to construct the group product. Second, post-hoc correlational analyses showed that the amount of collaborative elaboration in the student interaction was positively related to the quality of the group product. The condition with textbook showed less collaborative elaborative talk.

5.5.1.4 The effects of textbook use on the individual learning outcomes

Despite the fact that the use of textbooks was associated with less elaborative interaction, the students that could consult a textbook did not score lower on the post-test than the students that completed the task without the help of textbooks. Further, the time spent on the consultation of textbooks did not correlate significantly negative with post-test scores. It is possible that 'individual' non-verbalized elaboration while reading in the textbook, and the acquiring of factual knowledge as a result of reading in the textbook partly compensated for the lack of elaborative interaction. In particular, the factual information found in the textbook, such as the magnitudes, units and symbols, may have contributed to the score on the Concept definition Unit of the post-test, in which the students were asked to give such information.

5.5.1.5 The effects of textbook use on the student evaluations

The hypothesis that the students would appreciate the availability of textbooks was confirmed. As expected, the students who could consult textbooks found the task less difficult and were more satisfied with the group product.

The student evaluations also showed that the students who could consult textbooks found the task to be more instructive. This is likely related with the conception that there is much to learn from a textbook, especially because the students were uncertain about their own knowledge and understanding. Further, although there was no significant difference found in the asymmetry of student participation between the two conditions, the students who could consult textbooks agreed more strongly that they contributed equally to the group product. It is possible that the availability and use of textbooks as an extra tool to accomplish the group task resulted in a less apparent difference in knowledge between the students. The use of a textbook may compensate for the feeling of a smaller contribution to the group product due to less prior knowledge.

Finally, it appeared that the students who had no textbooks available agreed more strongly with the statements that they learned from giving explanations and that they realized their lack of complete understanding. The students who could consult textbooks may have more easily forgotten that they did not understand certain things and that they looked these things up in a textbook. Students who could not consult textbooks may have experienced more strongly the problem of answering a question on their own.

5.5.1.6 Conclusions and further research

The present study gives some insight into the way textbooks are used during a collaborative learning task that functions as the introduction of a new course on electricity, and into how this use affects the patterns of student interaction and the learning outcomes. The fragment of talk from the interaction between Aniek and Bregje (see Example 5.2) was an example of a dyad in which the students tried to use the textbooks as an extra tool to construct a shared understanding of the electricity concepts. However, Monique and Yvette (see Example 5.1) showed that the textbooks can also be used for a quick completion of the task, and that the use of textbooks can go together with less collaborative elaboration. In general the use of textbooks had a negative effect on the amount and nature of elaborative interaction. A positive result was that, contrary to the expectation, most of the information that was found in the textbooks was not only shared but also elaborated by the students, and that the use of textbooks had no negative effect on individual learning outcomes. A less desired phenomenon that occurred was that the students very quickly reached for the textbooks, and that this occurred in situations in which no clear goal was formulated or without initially attempting explanations on their own. Further, in many of the cases where a textbook was consulted, it did not contribute to the accomplishment of the task. In half of the cases the students did not find any useful information.

Future research can focus on the conditions under which students can make an effective use of extra tools such as textbooks during collaborative learning, without constraining elaboration and co-construction. First, the use of textbooks during collaborative learning may be scripted with the help of the task instruction. The frequency and the way textbooks are used may be influenced by such an instruction. Second, it is of interest to investigate in more detail how the features of textbooks influence the use of textbooks in collaborative learning situations, so that textbooks may be improved on this point. It could also be investigated whether, in comparison with information presented in a textbook, information presented on a computer or information presented orally by an expert on the domain (for example, the teacher) has more potential to function as an extra tool to construct a shared understanding. Third, it is of interest to know how the ability to search for information and to share information could be improved. Finally, additional research is also needed with respect to the question of how the conception that a textbook presents 'finished' and 'true' knowledge that does not need further elaboration and discussion can be changed and whether this results in a different way of textbook use in collaborative learning situations.

5.5.2 The two parts of the task: Concept Mapping and the Elaboration of the Concept Map

Which differences existed in the features of student interaction during the construction of the concept map and during the elaboration phase? From the analyses of student interaction in the first study, it appeared that the concept map rarely provoked talk about the moving electrons and talk in which the students use electricity concepts to describe concrete electric circuits. In the first study, the students also did not try to represent relations between quantities in a diagram. In the following sections I try to answer the question of whether the elaboration of the relations in the concept map was a strong task to elicit such interaction.

5.5.2.1 Relating electricity concepts to concrete phenomena

As expected, the design of experiments that was asked for during the elaboration of the concept map elicited more interaction in which the students related the electricity concepts to concrete phenomena. The design of experiments also provoked the verbalization of previously experienced experiments and demonstrations in physics lessons. Such interaction appeared infrequently during the concept mapping task.

5.5.2.2 Relating electricity concepts to other forms of representation

Contrary to expectation, during the elaboration of the concept map the students did not talk more about other forms of representation than during the construction of the concept map. This may be due to the fact that the concept mapping task specifically elicited talk about magnitudes and formulas, whereas the elaboration phase elicited more talk about how to measure quantities, draw electric circuits and represent relations in a graph. Both types of talk were coded as talk about other forms of representation.

5.5.2.3 Verbalization of the idea of current consumption and local reasoning

It was expected that the elaboration of the concept map would be a stronger task to elicit talk about the idea of current consumption and local reasoning. This hypothesis was confirmed. During the concept mapping task the students often confused voltage with current strength and described the relation between the cross-section area of a wire and the resistance incorrectly. The idea of current consumption and local reasoning only appeared during the second half of the task, mostly when the students were designing (and drawing) experiments.

5.5.2.4 Giving explanations for the relations between the physical quantities

The elaboration phase of the task asked for explanations of the 'if-then' relations that were described in the concept map. The transcripts showed that the students had problems giving such explanations. Many students repeated the description of the relation or referred to a formula. Some students discussed what was considered an explanation. Some fragments of the student interaction also reflected student perceptions of the nature of physics. Utterances such as *'because it isn't otherwise'* or *'some Einstein invented that'* may be related to the conception that physics contains well defined and 'finished' knowledge that does not need further explanation. Lemke (1990) and Sutton (1998) suggest that these conceptions are related to the way physics is presented in textbooks and by teachers. Textbooks, for example, rarely show the uncertainty and the controversy that was involved in the establishment of the 'facts'. It can be added that most Dutch physics textbooks at the level of the participating students do not present and discuss theoretical explanations and the way they were constructed. Only recently has the way scientific theories are constructed and used become an explicit goal of the new subject 'general science' that was introduced into the Dutch curriculum of secondary education.

5.5.2.5 Other differences between the two parts of the task

During the construction of the concept map the students talked more intensely about the electricity concepts (more propositions per minute) than during the elaboration of the concept map. Three explanations may be given for this result. First, it may be due to the fact that the elaboration of the concept map required more drawing (electric circuit diagrams and diagrams) and writing activities (descriptions of experimental designs and explanations) than the concept mapping task. In the first study the poster task also showed less intense talk about the concepts. It was assumed that this was related to more writing and drawing during which less talk appeared. Second, it is likely that the students lost some of their concentration during the second half of the task. An indication for this phenomenon is the fact that during phase B significantly more off-task talk appeared. Third, in some dyads the students spontaneously divided tasks during the elaboration of the relations in the concept map. In these dyads the students each elaborated some relations of the concept map on their own. The students each took a paper on which they elaborated a relation that was described in the concept map. The product that was asked for in the second half of the task (elaborate each relation on a different paper) made it easier to divide tasks.

5.5.2.6 Conclusions and further research

The designing of experiments with which the hypothesized relations between electricity quantities can be validated, the representation of expected results in a diagram and the giving of explanations for the relations can be considered a collaborative learning task that can contribute to the elicitation of different types of elaborative peer interaction. The second half of the talk elicited talk about concrete phenomena and about how a relation can be represented in a graph. Further, the task stimulated students to verbalize their experiences by doing experiments, and to verbalize their idea of current consumption and their local reasoning. However, the second part of the task also had some drawbacks. First, compared with the concept mapping task the elaboration phase elicited less intense talk about the electricity concepts. Perhaps this negative result can be partly reduced by using a task that requires less time, inhibits task division, and in which drawing and writing activities take less time. Second, the students had problems with the generation of explanations. It is of interest to know how students can be assisted in the formulation of such scientific explanations. It may be necessary to study how textbooks and teachers deal with giving explanations, as well as successful methods to improve the understanding, formulation and discussion of explanations by students.

5.5.3 Features of student interaction related to student characteristics and outcomes

5.5.3.1 Student participation and student characteristics

It was assumed that the participation of students in the interaction would not only be shaped by the setting, the collaborative learning task and the tools that were available, but that student characteristics such as prior knowledge and the attitude towards physics were also at work. The correlational analyses, however, showed no relationship between student participation and student characteristics. Students with more prior knowledge and a more positive attitude towards physics did not talk more about the electricity concepts and did not formulate more arguments. A significant correlation with the attitude score may not be found because of the general nature of the questionnaire. The attitude towards physics questionnaire gives no specific indication of the attitude towards the domain of electricity, towards a group task and towards the specific group task that was used in this study. A relationship between student participation and prior knowledge within the domain may not be present because, first, all students are already familiar with the terms to be used and have some initial understanding of the concepts and second, because the collaborative learning task may have enough potential to stimulate active participation in the interaction, regardless of the exact level of prior knowledge. Further, the fact that the students knew that they would not be graded for the group product may have contributed to the formulation of statements about the electricity concepts even when they were uncertain about their understanding. Finally, the pre-test scores are primarily based upon the correctness of given answers. The transcripts of the student interaction showed that, specifically during the elaboration phase, the students verbalized their experiences within the domain, regardless of whether these resulted in a correct use of the electricity concepts or not. This shows that experiences within the domain *do* shape the participation and the negotiation in the interaction. It is possible that the amount and the character of the participation of a student in the interaction is related to the amount and nature of experiences within the domain, but less with the correctness of the use of the electricity concepts that a student could show making use of such experiences in the pre-test situation.

5.5.3.2 Individual learning outcomes and student participation

As expected, individual learning outcomes were related to the participation of a student in the interaction. Students that talked more about the electricity concepts had higher scores on the post-test. No significant correlations were found between the post-test scores of the students and the number of arguments that the students formulated. Thus, the way a student used the electricity concepts in the post-test was not related to the *elaborative nature* of their contributions to the interaction, whereas it was related to the elaborative degree of the interaction as a whole (as will be discussed in the following section).

5.5.3.3 Individual learning outcomes and elaborative interaction

It was hypothesized that individual learning outcomes are positively related to the amount of elaboration in the student interaction. From the results of the first study the question arose as to whether *collaborative* elaborative talk is related to individual outcomes. This expectation was confirmed by the results of partial correlational analyses. These analyses showed that more collaborative elaborative interaction in the dyads was associated with higher scores for the post-test. Student talk that is characterized by collaborative elaborative interaction reflects a focus on understanding and the attempt to construct a shared understanding. Collaborative elaboration may contribute to conceptual learning because both students are not only reflecting upon and elaborating their ‘own’ contributions, but also integrating and/or elaborating the input of their partners, which makes the elaboration more intense and possibly results in a more complete and scientific understanding of the concepts.

5.5.3.4 Conclusions and further research

This study did not support the assumption that the amount and nature of the participation of a student in the interaction is related to prior knowledge and the attitude towards physics. It is unclear, however, whether the relationship is not find because of the instruments that were used or whether there exists no strong relationship. Further research is needed to test the assumptions.

Individual learning outcomes were positively related to the number of propositions a student formulated. This supports the assumption that *using* concepts through talking about and ‘with’ them, contributes to concept learning. Further, the results support the hypothesis that especially a collaborative elaborative interaction contributes positively to individual learning outcomes. Additional research must shed more light on the possible explanations for this positive relationship.

6 The Third Study

In the previous study individual learning outcomes from the collaborative learning task were positively related to both the participation of the student in the interaction (the degree to which the student talked about/with the electricity concepts) and the amount of collaborative elaboration in the interaction. Further, the results of the study showed that the quality of the student interaction was shaped by the features of the task. First, the product that was asked for affected the nature of the talk about the electricity concepts. In comparison with the construction of a concept map, the elaboration of the concept map elicited more interaction in which electricity concepts were related to concrete phenomena and to graphical forms of representation. As another result of the designing of experiments, the ideas of current consumption and local reasoning were verbalized. Second, the use of textbooks as extra tools also affected the quality of the student interaction. Although the use of the textbooks did not have a negative effect on individual learning outcomes, it was concluded that the use of textbooks was not optimal, and consequently did not contribute to the elaborative degree of the interaction and to the co-construction of meanings.

The third study built on the results of the second study and focused in particular on the use of a textbook as an extra tool during collaborative learning. Although the second study showed that the extended concept mapping task also had some drawbacks, such as the appearance of less intense talk about the electricity concepts during the elaboration phase and the problems students had with the generation of explanations, I decided to use the same collaborative learning task in the third study. Only some minor changes were made in the task design. In the section below I will discuss the question of how the use of a textbook during the collaborative task might be optimized. Section 6.2 presents the research questions and the hypotheses of this study. After the presentation of the method (section 6.3), section 6.4 presents the results of this third study. Finally, the results are summarized and discussed in the last section.

6.1 Methods to script the use of the textbook

In the second study two textbooks were continuously available during the accomplishment of the group task. Providing two textbooks appeared to have some important drawbacks. First, the study showed several examples of situations in which a student decided to consult a textbook when his or her partner was also consulting a textbook. Most of the time in such situations it was assumed that the students had no clear idea of what they were searching for. Second, situations in which both students were consulting a textbook at the same time, sometimes hindered both the verbalization of the reason to consult the textbook and the sharing of the information found in the textbook. Therefore, in this third study I decided to provide the students with only one textbook.

From the second study it appeared that the students who were provided with textbooks reached for them very quickly even when no clear question had been asked. The consultation of the textbook frequently was not preceded by a verbalization of the students' own ideas on the topic. In many cases, the students did not find any information that could be used to negotiate meaning or to construct the required group product. Further, it appeared that the use of textbooks resulted in less elaborative interaction. It was suggested that this may be related to a lack of explication of reasoning, questions and conflicts and to a spontaneous task division.

The main goal of this follow up study was to examine how the collaborating students could be stimulated to use the textbook in a way that is advantageous for the elaboration, negotiation and co-construction of meanings. This would imply that the students verbalize their own ideas on the topic before they consult the textbook, that they have a clear search goal when they want to consult the textbook and that they find relevant information in the textbook.

In the second chapter (see section 2.4.2.3) the task instruction was described as a potential instrument with which to script the content and patterns of student interaction during collaborative work. Most research that has been done on the structuring of student activities and verbal interaction during group work focused on the assignment of specific roles, the asking of certain types of questions and the giving of explanation prompts (e.g. Webb & Sullivan Palincsar, 1996). However, a task instruction can also script the use of the tools that are available, for example the use of a textbook. The question is, what kinds of scripts result in a productive use of the textbook during the collaboration on the group task? Scripts can differ from each other in the extent to which they structure the activities and the interaction of the collaborating students. Cohen (1994) and Salomon and Globerson (1989) suggested that in the case of conceptual learning, the interaction should not be too heavily structured. O'Donnell (1999), who did some studies into the effects of structuring the interaction through scripted cooperation, stated that a possible drawback of scripted cooperation is that it may not be equally useful for all students. It is possible that a script specifically 'hinders' the students who have a higher level of prior knowledge, are more intrinsically motivated to understand the content and who want to take responsibility for their own learning. The second study showed that some dyads used the textbooks in a productive way, although the use of the textbook was not scripted through the task instruction. In the present study I decided to compare two different kinds of scripts: a script that slightly structures the use of the textbook and a script that is more compelling. The idea is that these scripts influence the use of the textbook, and consequently the features of the student interaction. When the textbook is only used sporadically (when really necessary) and when the use of the textbook goes together with the verbalization of own ideas, the finding, sharing and elaboration of useful information, then it is likely that the use of a textbook during collaborative learning contributes to and does not hinder interaction that is valuable for conceptual learning.

Two ways to influence the use of the textbook were designed: *asking* for the textbook and *answering some questions* each time the textbook is consulted. The students can be instructed to ask for the textbook when they need it. The students are not provided with a textbook, but the textbook is available under the management of another person. Since the textbook is not available immediately, the students must reach a certain threshold before consulting the textbook. When requested, the textbook is provided to the students, and once the students are finished their consultation, it must be returned. Because the students have to negotiate whether they will ask for the textbook, it is likely that they will explicate their question and that their search in the textbook will be goal directed, consequently resulting in a better chance of finding useful information. On the other hand, this script is 'weak' because it does not really force the students to explicate their reason to consult a textbook. A 'stronger' script may force the students to use the textbook more consciously: why do they want to use the textbook, what exactly are they going to search for and do they really find what they are searching for? The students can be given the instruction to answer these questions each time they consult the textbook.

6.2 Research Questions and Hypotheses

In this study the relation between task characteristics and the features of the student interaction was addressed by a focus on how scripting the use of a textbook affects its actual use, the student interaction and the outcomes. Second, the present study also focused on the differences between the two phases of the task: the construction of the concept map and the elaboration of the concept map. Third, it was investigated again whether categories of student talk are related to student characteristics and individual learning outcomes. Therefore, some of the questions overlapped with the questions from the first and the second studies. These questions explored whether the results found in the second study could be replicated in the present study. The present study aimed at answering the questions that are presented below. The questions are followed by the hypotheses that were tested.

1 The use of the textbook during collaborative learning

a) *How is the textbook used during the collaborative learning task when this use is scripted?*
b) *Which effect does the kind of script have on the use of the textbook?*
c) *Is the amount of (elaborative) talk about the concepts related to the time spent on the consultation of the textbook?*

The hypotheses that were made concerning the use of the textbook were based upon the results of the second study in which a group of dyads were provided with textbooks without scripting its use. It was expected that due to scripting the use of the textbook, the students would spend less than a third of the time consulting the textbook, and that, when the textbook is consulted, more than half of these consultations would be preceded by the students' verbalization of own ideas on the topic. It was assumed that the textbook would be consulted the most when a question is asked, that the consultation of the textbook would almost always result in the finding of information that corresponds with the topic the students are currently dealing with, and that the information found in the textbook would almost always be elaborated by the students and then contribute to the construction of the group product.
The following hypotheses were based upon the idea that the instruction to explicitly state the reason to use the textbook has a more positive effect on the use of the textbook than the instruction to just simply ask for the textbook. In comparison with the condition in which the students must ask for the textbook, it was expected that in the explicit condition:

* the textbook is consulted less frequently
* the consultation of the textbook is preceded more often by the verbalization of the students' own ideas on the topic
* the consultation the textbook is preceded more often by a question
* the consultation of the textbook results more often in the finding of information that corresponds with the topic the students are dealing with

It was hypothesized that the use of the textbooks would not hinder (elaborative) talk about the electricity concepts. Consequently, the proportion of the time spent on the consultation of the textbook is not related negatively to the number of propositions and elaborative episodes in the student interaction.

2 The construction of the concept map and the elaboration of the concept map

Which differences exist between the features of the student interaction during the construction of the concept map and the features of the student interaction during the elaboration of the concept map?

In comparison with the construction of the concept map, it was hypothesized that the student interaction during the elaboration of the concept map would contain:

* more talk in which the electricity concepts are related to concrete phenomena
* more talk in which the electricity concepts are related to other forms of representation
* more verbalization of the idea of current consumption and of local reasoning

3 Features of student interaction related to student characteristics and outcomes

a) *Is the participation of students in the interaction related to their prior knowledge and attitude towards physics?*
b) *Are individual learning outcomes related to the amount of elaborative interaction in the group?*
c) *Are individual learning outcomes related to the participation of the student in the interaction?*

It was assumed that students with more prior knowledge and a more positive the attitude towards physics, would show a larger and more elaborative participation in the interaction.

It was hypothesized that individual learning outcomes would be related to both the participation of the students in the interaction and to the features of the student interaction on the group level. The more elaborative the student interaction in which a student participates is, the higher the score on the post-test will be. The larger and more elaborative the participation in the interaction, the higher the score on the post-test will be.

6.3 Method

6.3.1 Subjects and design

Participants were 48 students (aged 15 or 16) from two physics classes in intermediate general secondary education. The two physics classes were from different schools. The students had some experience working in groups. Within each class the students were randomly assigned to same-sex dyads. After this random assignment in one class, it appeared that some of the students would not be able to participate in the task at the scheduled time. This resulted in the change of some same-sex dyads to mixed-gender dyads. In total fifteen boy-boy dyads, three girl-girl dyads and six mixed-gender dyads participated in the study. Within each class the same number of dyads was randomly assigned to one of the two conditions: a condition in which the student had to ask for the textbook and a condition in which the students had to fill out a checklist to answer some questions each time they consulted the textbook. The design is shown in Table 6.1.

Table 6.1 Number of dyads in the two conditions

Checklist	Asking	Total
13	11	24

6.3.2 Experimental tasks

The students had to make a concept map with given electricity concepts on a large paper. The students had to link related concepts and had to label the relations (when possible) in the form of 'if-then' regularities. As in the first and second studies, the students were asked to individually make a design for the concept map before starting the collaboration on the task. The second part of the collaborative learning task asked the students to design experiments with which the relations in the concept map could be proven. During this part of the task the students also had to represent the expected results of the designed experiments in a table or diagram, and they had to give an explanation for the nature of the relation.

Some minor changes were made in the task design. In the second study the students were asked to elaborate all relationships in the concept map. However, the results of this study showed that most students had only time to elaborate four or five, and that relationships that included the concepts voltage and energy were less frequently elaborated. Further, it was hypothesized that due to the instruction to elaborate all relations, the task may have been rushed and therefore may have promoted a task division in some dyads. In contrast with the second study, the students were asked to elaborate only four relationships from the concept map: a relationship that included the concept voltage, a relationship that included the concept current strength, a relationship that included the concept resistance, and a relationship that included the concept energy. To constrain the appearance of a task division during the second half of the task another minor change in the task design was made. It appeared that during the elaboration phase it was easier to make a division of labor, since each relationship had to be elaborated on a new paper. Therefore, in this study, the papers on which the students had to design the experiments and formulate the explanations were stapled. The task instruction is included in the Appendix (Ic).

The students were provided with *Natuurkunde Overal* (NO). In the second study this textbook was more frequently consulted than *Systematische Natuurkunde* (SN). In the condition in which the students had to ask for the textbook, the textbook was under control of the experimenter. Asking the experimenter for the textbook may not be a very naturalistic situation, but it might be compared with asking a teacher or a librarian for the textbook. In the condition in which the students had to state explicitly their reason to consult the textbook, the students were asked to complete a checklist each time they consulted the textbook. The checklist is included in the Appendix (Id). Each time the students consulted a textbook they had to complete three items in the checklist. First, they had to formulate a question that reflected what they were going to search for. What question were they trying to answer with the help of a textbook? Second, the students had to mark a cross next to their motive to consult the textbook. They could choose between three possibilities: 'uncertainty', 'we don't know a certain thing', 'we disagree'. After the students consulted the textbook they had to mark a cross next to whether this consultation helped: 'yes', 'no' or 'partly'.

6.3.3 Setting and procedure

Table 6.2 shows the procedure of the study.

Table 6.2 Procedure of the experiment

Activity	Duration in minutes	
Pre-test	40	minutes
Attitude towards Physics questionnaire	10	minutes
Instruction	5	minutes
Individual preparation	5	minutes
Collaborative task A: Concept Map	20	minutes (max.)
Collaborative task B: Elaboration of the Map	45	minutes (max.)
Student Evaluation questionnaire	5	minutes
Post-test	40	minutes

Three weeks before the students participated in the collaborative learning session the pre-test and the questionnaire were administered during a physics lesson. The experiment was carried out in a room in school under the guidance of an experimenter (the researcher or a graduate student). The session was started with a brief instruction about the task: the concept map, the describing of experiments, the representation of the expected results in a table or diagram, and the formulation of an explanation. As in the second study, the examples that were given related to the topic of phase changes. Before the students worked together on the task, they were given five minutes to make a design for the concept map individually. After this phase of individual preparation the students started to collaborate on the group task. The total time that was given to complete the group task was somewhat less in comparison with the second study (75 minutes). From the results of the second study it appeared that during the second part of the task the amount of off-task talk increased. It was suggested that this involved a partial loss of concentration. In the present study the time that the students could work on the group task was somewhat confined. A maximum of 20 minutes could be spent on the construction of the concept map and a maximum of 45 minutes could be spent on the elaboration of four relations from the concept map. The student interaction was videotaped. After the students finished the group task they were asked to complete the questionnaire that was meant to measure their evaluations (see section 5.3.8). The post-test was given in the next physics lesson, one week later.

6.3.4 Measurement of concept learning

The pre-test and the post-test consisted of three units, in conformity with the tests in the first and second studies. The units were described in more detail in section 4.3.4. Some changes were made in the items that were included in the test. The units of the pre-test and the post-test are described in Table 6.3. Appendix II contains some examples of the items that were used in the tests.

Table 6.3 Descriptives of the units of the pre-test and the post-test

Unit	Number of items	Maximum score	Response Format	Cronbach's alpha	
				pre-test	post-test
Concept definition	5	20	definition, magnitude/formula and drawing	.62	.75
Problem-solving	12	12	multiple choice	-.04	.13
Essay Question	1	8	essay	-	-
Total	18	40		.53	.55

In the previous studies the Problem-solving Unit had a low item homogeneity. In an attempt to increase this item homogeneity in the present study, the number of problem-solving items was doubled. To limit the time needed to complete this unit, contrary to the tests that were used in the previous studies, the students did not have to account for their answers. The first and second studies showed that the Essay Question about the flat iron (post-test) was more difficult than the question to describe and explain the working of a battery torch (pre-test). It was decided to use the Essay question about the battery torch in both the pre-test and the post-test. The Concept definition Unit that was used in this study was the same as in the previous study.

Although I attempted to increase the item homogeneity of the Problem-solving Unit, the Cronbach's alpha of both the pre-test and the post-test was still low (see Table 6.3). The reliability of the Concept definition Unit and of the tests as a whole were considered to be acceptable. Only the scores on the pre-test and the post-test as a whole were used in the correlational analyses and the analyses of variance. A Kolmogorov-Smirnov test showed that the scores of the pre-test and the post-test were distributed normally.

The scoring of the Concept definition Unit and of the answers on the Essay Question were not checked for interrater reliability again. From the first and second studies it appeared that the Cohen's Kappas were acceptable: .88 for the Concept definition Unit and .81 for the Essay Question.

6.3.5 Measurement of attitude towards physics

The students' attitudes towards physics were measured with a questionnaire. The same questionnaire was used as in the first and the second study (see Appendix III). Cronbach's alpha was acceptable (.86).

6.3.6 Coding of verbal interaction and the use of the textbook

The coding scheme that was used to analyze the student interaction was introduced in chapter four and included in the Appendix (IV). The changes that were made in the episode categories were described in the previous chapter (section 5.3.9). At the utterance level the coding scheme distinguished several communicative functions and several types of propositions (statements about the electricity concepts). At the episodic level the coding scheme distinguished different types of elaborative talk and reactions to incorrect propositions. From the first and second studies it appeared that the coding on the utterance

(Cohen's Kappa for the communicative functions was .92 and for the proposition categories .86) and on the episode level (proportion of agreement 79%) had an acceptable inter-coder reliability.
A category system to describe the use of the textbook was introduced in the previous chapter (see section 5.3.9 and Appendix IVd). In the present study the same category system was used. In the second study the coding of the use of the textbook was checked for reliability. Cohen's Kappa for the different categories reached from .77 to .90.

6.4 Results

The following sections present the results of this third experimental study. The first sections focus on the use of the textbook. First, a description is given of the way the textbook was used. This description will be illustrated with examples. Differences between the two kinds of scripting the use of the textbook will be presented. Second, the question of whether the amount of talk about the electricity concepts is related to the time spent on the consultation of the textbook, will be answered. Then, the results of the t-tests that were conducted to test for differences in student talk between the two phases of the task will be presented. Finally, questions concerning the relations between features of student interaction, student characteristics and student outcomes will be answered.

6.4.1 The scripted use of the textbook

6.4.1.1 How were the textbooks used?

It was expected that scripting the use of a textbook would limit the frequency with which the textbook was consulted. The analyses of the textbook use in the present study (the two conditions taken together) showed that the consultation of the textbook was indeed confined. The students worked on the average 50.38 (sd = 13.24) minutes on the group task. On the average, the students used the textbook 3.83 (sd = 2.79) times during the accomplishment of the group task and spent 7.88 (sd = 6.09) minutes on the consultation of the textbook. This was 14.71% (sd = 9.53%) of the total time that was spent on the group task.
It was expected that the scripting of the use of the textbook would stimulate the students to verbalize their own ideas on the topic before they sought information in the textbook. It was hypothesized that in more than half of the cases in which the textbook was consulted, this consultation would be preceded by the verbalization of own ideas on the topic by one or both students. This hypothesis was confirmed. On the average 67.09% (sd = 26.12%) of the cases in which the textbook was consulted, this consultation was preceded by a verbalization of own ideas.
Figure 6.1 shows that the formulation of a question and uncertainty were the most frequent situations in which the textbook was consulted. This confirms the hypothesis that scripting the use of the textbook stimulates the students to formulate what they do not know or understand, and what exactly they are going to search for in the textbook. The textbook was rarely used when the partner was writing or drawing.

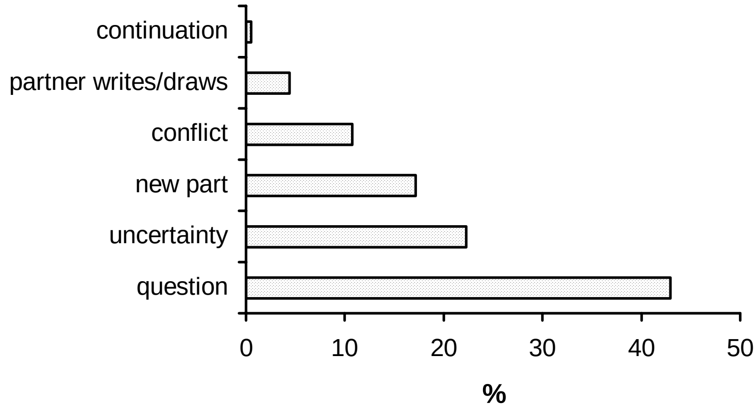

Figure 6.1 Situations in which the textbook was used in percentages of total number of textbook use (n = 24)

It was expected that scripting the use of the textbook would promote the opportunity that the students would find some useful information in the textbook, due to the explication of what they were searching for. The results showed that in the present study, the students usually found useful information in the textbook. On the average 77.22% (sd = 26.55%) of the cases in which the textbook was consulted resulted in the finding of information that corresponded with the topic the students were dealing with. Further, as expected, the finding of information in the textbook most of the time resulted in the elaboration of this information (69.05% of the cases in which information was found, sd = 36.91%) and contributed to the completion of the group product (82.28% of the cases in which information was found, sd = 29.14%).

6.4.1.2 Two examples of the consultation of the textbook when scripted

Example 6.1 shows how a textbook is used in the condition in which the students had to ask for the textbook. This example also illustrates the quick finding of information in the textbook. Wilma and Pim are working on the concept map. Wilma asks how voltage can be related to the resistance. Pim reacts to the question by saying that he does not know and suggests that both voltage and current strength can be related to resistance. Without an attempt to answer the question themselves, Wilma suggests that they ask for the textbook (line 8). Pim nods assent and the experimenter gives the students the textbook (line 9). Wilma and Pim quickly find the information they are searching for (line 13 and 14). They share the textbook and the information that is given in it. After reading aloud, Wilma only rephrases the relationship that is described in the textbook in her own words (line 15, 16), but does not really elaborate the information given in the textbook. However, the information found in the textbook helps Wilma and Pim with the construction of their concept map. Pim starts to reorganize some relationships in their map. The total time that was spent on the consultation of the textbook in this episode was two and a half minutes.

Example 6.1 Answering of a question with the help of the textbook (that is asked for)

1	Wilma	but what has voltage to do with resistance?
2	Pim	I don't know
3	Wilma	it must all, in the end everything has to be related
4	Pim	yes, okay
5	Pim	isn't it both (points) like this, current and voltage (pastes concepts)
6	Pim	like this (pastes concepts), I am just trying
7	Wilma	yes, that's what I also do
8	Wima	shall we ask for the textbook then?
9	Exper.	that's okay (gives the textbook)
10	Wilma	(turns over the pages in the textbook)
11	Pim	here (points in the textbook) this is a resistor
12	Wilma	Yes
13	Wilma	the current through both wires is equal (reads aloud from the textbook)
14	Wilma	a larger resistance means that you need a higher voltage (reads aloud from the textbook)
15	Wilma	thus, you need a larger voltage, you need a larger voltage to get current
16	Wilma	thus, the larger the resistance, the more voltage you need to get the same current strength (points in their concept map)
17	Pim	yes
18	Pim	now voltage, then it is like this (removes concepts)

In the following example Jelle and Hans also spent two and a half minutes on the consultation of the textbook. They decided to use the textbook to resolve a conflict. Jelle and Hans worked in the condition in which they were asked to complete the checklist. Only after an extended elaboration of their conflict about voltage and energy did Jelle and Hans decide to consult the textbook (line 55). They first exchanged their arguments, making use of the environment they were working in (lines 4,10, 15), and initially thought that they would not need the textbook (lines 6 to 8). When the students finally decided to use the textbook, Jelle wrote the following question on the checklist: *'must voltage be preceded or followed by energy?'*. As in the previous example, these students quickly found the information they were looking for. In line 61 Jelle explicitly verbalized exactly what they had to search for. The information that was found in the textbook was elaborated and helped Jelle and Hans to resolve their conflict (lines 74 to 78).

Example 6.2 Elaboration of a conflict with the use of a textbook (with checklist)

1	Jelle	because voltage, without voltage there's no energy (points)
2	Hans	but without energy there's also no voltage
3	Hans	energy provides current
4	Jelle	no, because there's voltage on the power-point (points to power-point on the

		wall)
5	Jelle	thus, then it's
6	Hans	(takes textbook)
7	Jelle	no, no, we don't need that yet (puts textbook back)
8	Hans	Okay
9	Jelle	there's voltage on it
10	Hans	yes, on number twenty-one (the power-point has a number)
11	Jelle	yes, Jesus
12	Jelle	in any case, there's voltage on it
13	Jelle	and there's no energy in it
14	Jelle	when I connect an appliance, then you can get energy out of it
15	Jelle	for example, the camera
16	Hans	Yes
17	Jelle	then you get energy out of it
18	Jelle	yes, then you get energy out of it
19	Jelle	do you understand, thus there must always be voltage before energy
20	Hans	yes, but also energy before voltage
21	Hans	because energy is used
…		
55	Hans	looking up
56	Jelle	first, you have to write down what you're looking up
57	Hans	[(turns over the pages in the textbook)]
58	Jelle	[disagree (writes on the checklist)]
59	Hans	power and voltage (reads paragraph title from the textbook)
60	Hans	(turns over the pages in the textbook)
61	Jelle	I think you better look up energy
62	Hans	electric energy (reads paragraph title from the textbook)
63	Hans	look, the energy (reads in the textbook)
64	Hans	to provide towns with electricity there must be a generating station (reads aloud from the textbook)
…		
73	Hans	look, they call it the energy resource (points to definition in the textbook)
74	Jelle	yes, do you see that now?
75	Jelle	thus the power-point (points) is an energy resource
76	Jelle	the power-point that's what you get energy from
77	Jelle	and thus not, energy provides current
78	Jelle	voltage provides the energy

6.4.1.3 Differences between the conditions

It was assumed that the students in the condition with the checklist would consult the textbook less frequently than the students who had only to ask for the textbook. It was expected that the instruction to complete the checklist would function as a higher threshold to use the textbook. Table 6.4 shows the frequencies and the time spent on the consultation of the textbook (in minutes and as a proportion of the total time spent on the task) in the two conditions. A t-test showed, as expected, that in the condition with the checklist the textbook was less frequently consulted than in the condition in which the students had to ask for the textbook. The table also shows that in this checklist condition relatively less *time* was spent on textbook consultation.

Table 6.4 Means and standard deviations of the time spent on the task and on the consultation of the textbook between the two conditions and the results of t-tests for independent samples.

	Checklist (n=13)		Asking (n=11)		p
	Mean	Sd	Mean	Sd	
Time spent on the task (in minutes)	49.00	15.38	52.00	10.67	.59
Frequency of textbook use	2.62	1.39	5.27	3.38	.03*
Time spent on the consultation of the textbook in minutes	5.66	3.98	10.52	7.23	.07
Proportion of the time spent on the consultation of the textbook	10.55%	5.91%	19.64%	10.85%	.02*

* p < .05

Table 6.5 presents a description of the use of the textbook in the two conditions as well as the results of the t-tests. It was expected that the instruction to complete the checklist would be a stronger script to stimulate the students to figure things out on their own before seeking help in the textbook than when simply asking for the textbook. However, on this point no significant differences were found between the two conditions.

As expected, in the condition in which a checklist had to be completed, the consultation of the textbook was preceded more frequently by a question than in the condition in which the students had to ask for the textbook. Table 6.5 shows a significant difference between the two conditions. It must be added that, in the checklist condition situations in which a question was not *verbalized*, but was only written on the checklist also appeared, for example, in case of uncertainty or a conflict.

Table 6.5 Mean percentages[1] and standard deviations of categories of textbook use and the results of t-tests for independent samples.

Categories of textbook use	Checklist (n=13)		Asking (n=11)		p
	Mean %	Sd	Mean %	Sd	
1 Verbalization of own ideas before using the textbook	70.64	28.78	62.48	22.84	.47
2 Situations in which a textbook is consulted					
- question	56.67	35.42	26.45	19.40	.02*
- conflict	16.53	22.59	3.77	9.17	.09
- uncertainty	13.47	18.01	32.79	32.13	.09
- partner is writing/drawing	1.67	5.77	7.69	11.54	.16
- starting a new part of the task	10.00	19.54	25.82	23.78	.10
- continuation after a short interruption	.00	.00	1.11	3.51	.34
3 The consultation of the textbook results in information that corresponds with the topic currently dealt with	81.97	29.93	71.99	22.66	.40
4 Elaboration of the information found in the textbook	79.55	33.20	57.50	38.98	.18
5 Reading aloud from the textbook	71.97	33.39	54.64	23.26	.19
6 The information found in the textbook results in a change in the group product	92.42	17.26	71.13	35.95	.11

[1] Categories 1,2 and 3: percentages of total number of cases in which the textbook was used
Categories 4, 5 and 6: percentages of total number of cases in which information was found

The following example illustrates a situation in which a question was not verbalized but was only formulated on the checklist. Niek and Joran drew a line in their concept map between voltage and current strength and between current strength and resistance. Niek gave the formula that according to him, describes the relations between these quantities. However, he was uncertain about the formula and suggested two possibilities: it is either *I divided by V* or the other way round. Joran only knew that one quantity remained the same. He suggested that they consult the textbook and Niek agreed. On the checklist, Niek wrote the question *What is the formula for resistance?* He put a cross against the statement that they were uncertain. Niek did not verbalize the question that he was writing on the checklist. In the textbook Niek and Joran found the formula they were talking about (line 20). The formula was a confirmation of one of the possibilities that Niek suggested. Niek marked on the checklist that they found what they were looking for, and after that he wrote the formula in the concept map. In this case the textbook helped the students to relate the physics quantities in a way that corresponded with the scientific formula.

Example 6.3 Consultation of a textbook (with checklist) in a situation of uncertainty

1	Niek	R is I divided by V
2	Niek	or R is V divided by I
3	Joran	(looks in the individual design of Niek)
4	Niek	I don't know that
5	Joran	voltage, or the current strength stays the same
6	Joran	one of these two
7	Niek	the current strength
8	Niek	I don't know
9	Joran	(pastes current strength next to voltage)
10	Niek	(draws lines between the concepts)
11	Joran	we can also look it up
12	Niek	yes, that's okay
13	Niek	[(writes on the checklist)]
14	Joran	[(turns over the pages in the textbook)] it's just like our chemistry textbook
15	Niek	yes
16	Niek	(points on the summary page of the textbook)
17	Joran	(turns over to the next page)
18	Niek	V divided by I
19	Joran	(reads in the textbook)
20	Niek	(points to the formula of Ohm in the textbook)
21	Joran	(turns over the pages and reads a paragraph)
22	Joran	(turns over the pages and reads a paragraph)
23	Joran	(closes the textbook)
24	Niek	(writes on the checklist)
25	Niek	(writes a sentence near the line in the concept map)

Contrary to expectation, the condition with the checklist showed no significantly higher mean percentage for the finding of information. It was expected that the checklist would result in a more goal directed search in the textbook, consequently increasing the chance of finding useful information. With regard to the use of the information found in the textbook, no differences were expected between the two conditions. Table 6.5 shows that on this point no significant differences were found between the two conditions, although there seems to be a tendency of more elaboration of the information found, more reading aloud from the textbook and a more frequent use of the information in the group product in the checklist condition.

6.4.2 Textbook use and features of student talk

Because it was hypothesized that scripting the use of the textbook would result in sporadic textbook use that is characterized by verbalization of own ideas and the finding and elaboration of useful information, it was expected that the use of the textbook would not hinder elaborative interaction. Correlational analyses (Pearson) were conducted to test the hypothesis that in any case no *negative* relation would exist between the time spent on the consultation of the textbook and the intensity of (elaborative) talk about the electricity concepts. Table 6.6 shows the results of the correlational analyses. As expected, no significant negative relation was found between the proportion of time spent on the consultation of the textbook and the number of propositions and elaborative episodes per minute. No significant positive relation was found, either.

Table 6.6 Correlations between the occurrence of categories of student interaction and the proportion of time spent on the use of the textbook.

	Proportion of time spent on the use of the textbook		
	Checklist (n = 13)	Asking (n = 11)	Both conditions (n = 24)
Propositions[1]	-.14	-.11	-.06
Elaborative episodes[1]	.11	.00	.08

[1] ratio's: number of propositions and elaborative episodes per minute

6.4.3 Differences between the construction of the Concept Map and the Elaboration phase

The students worked an average of 15.46 minutes on the concept mapping task (phase A) and 34.92 minutes on the elaboration of the relations in the concept map (phase B). The differences in propositional content between peer talk during phase A and B are shown in Figure 6.2. The propositions that were literally read aloud from the textbook are not included in the given numbers.

In the concept map the students had to relate the electricity concepts and label their relations. During the elaboration of the concept map the students had to describe and draw the experiments with which the relations in the concept map could be verified. They had to draw electric circuits and diagrams with which the expected results could be represented. It was hypothesized that phase B (the elaboration of the concept map) would show more talk in which the electricity concepts are related to concrete phenomena and more talk in which the electricity concepts are related to other forms of representation. *T*-tests for paired samples confirmed these hypotheses. Phase A showed more talk about relations between the electricity concepts ($t = -8.25$, $p = .00$), whereas phase B showed more talk in which the electricity concepts were used to describe and explain concrete phenomena ($t = 7.37$, $p = .00$). Phase B also elicited more propositions about other forms of representation ($t = 5.53$, $p = .00$).

Further, during the concept mapping task the students talked more intensely about electricity concepts than during the elaboration of the concept map ($t = -2.13$, $p = .04$). This difference was also found in the second study. It was suggested that this difference might be related to the drawing and writing activities required in the elaboration of the concept map and the fact that during the second half of the task more off-task talk appeared. In this study the elaboration of the concept map also contained more off-task utterances than the construction of the concept map ($t = 2.13$, $p = .04$).

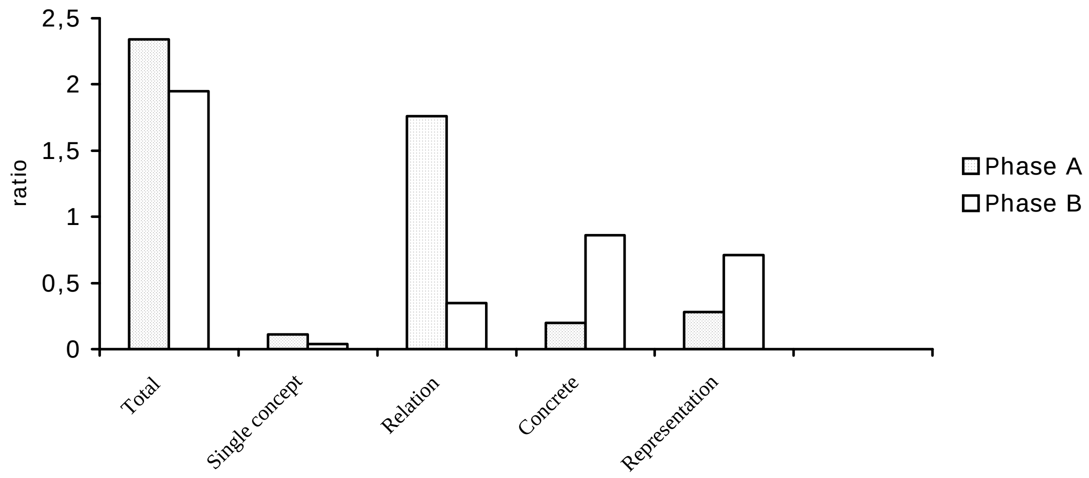

Figure 6.2 Mean ratios of propositions and proposition categories in phase A and B (n = 24 dyads)

As in the previous study, it was expected that the elaboration of the concept map would show more verbalization of the idea of the 'consumption' of current strength and of local reasoning. This hypothesis was confirmed. In the transcripts of student talk during the construction of the concept map, in only one dyad did incorrect propositions reflect the idea of current consumption. In the transcripts of the elaboration of the concept map, incorrect propositions that reflected the idea of current consumption or local reasoning were found in eleven dyads.

6.4.4 Features of student interaction related to student characteristics and outcomes

6.4.4.1 Student characteristics and student participation

It was expected that the participation of a student in the interaction could also be related to his or her prior knowledge and attitude towards physics. However, in the second study no empirical evidence for such a relationship was found. To test the hypothesis again, correlational analyses were also conducted in the present study. The mean score on the pre-test was 14.54 (sd = 4.24), approximately a third of the maximum score. The mean score on the five points Likert scale attitude questionnaire was 3.47 (sd = .44). This is a moderately positive attitude. For the second time, no significant correlations were found between the pre-test score and the number of propositions a student formulated ($r(48) = .12$, $p = .43$) and between the pre-test score and the number of arguments the student formulated ($r(48) = .13$, $p = .38$). Also no significant correlations were found between the score on the attitude questionnaire and the number of propositions ($r(48) = .01$, $p = .95$) and arguments ($r(48) = -.01$, $p = .96$). The pre-test scores did not correlate with the scores on the attitude questionnaire ($r(48) = .07$).

6.4.4.2 Student participation and individual learning outcomes

Table 6.7 shows the scores on the pre-test and the post-test. A t-test for paired samples showed that the students improved their understanding. The post-test scores were significantly higher than the pre-test scores. The kind of script for the use the textbook had no effect on the post-test score. An ANCOVA ($F(2,45) = .38$, $p = .54$) showed that the post-test scores of the students in the conditions with the checklist ($m = 18.50$, $sd = 3.98$) did not differ significantly from the scores of the students who had to ask for the textbook ($m = 19.86$, $sd = 5.32$).

Table 6.7 Mean student scores and standard deviations of the pre-test and the post-test ($n = 48$) and results of t-tests for paired samples.

	Pre-test	Post-test	T-value	p
Concept definitions	7.33 (3.10)	10.38 (3.81)	6.71	.00*
Problem-solving	4.90 (1.55)	5.77 (1.70)	2.99	.00*
Essay Question	2.38 (1.25)	2.98 (1.39)	3.10	.00*
Total	14.54 (4.24)	19.13 (4.64)	7.50	.00*

* $p < .05$

A question that was related to the individual learning outcomes was whether the individual learning outcomes are related to the participation in the interaction. It was assumed that the more students talked about the meaning and the relationships of the electricity concepts, the higher their scores on the post-test would be. This hypothesis was confirmed. The number of propositions a student formulated correlated significantly positive with the scores on the post-test (see Table 6.8).

Table 6.8 Partial correlations between the number of propositions and post-test scores in the two conditions (controlled for pre-test scores)

	Post-test Score		
	Checklist (n = 26)	Asking (n = 22)	Both conditions (n = 48)
Propositions	.29	.37	.33*
Arguments	.16	.42	.25

* $p < .05$.

The hypothesis that a more elaborative participation of the students would be positively related to individual learning outcomes was not confirmed. The number of arguments a student formulated did not correlate significantly with the scores on the post-test.

6.4.4.3 Elaborative episodes and individual learning outcomes

It was expected that students who participated in a student interaction characterized by more elaborative talk would have higher scores on the post-test. To test this assumption the frequencies of the elaborative episodes in the student interaction were attributed to the individual students. Partial correlational analyses showed that both individual and collaborative elaborative talk were significantly related to post-test scores (see Table 6.9). The more individual and collaborative elaborative episodes that appeared in the student talk, the higher a student scored on the post-test. The highest correlations were found for individual reasoning (.52), collaborative reasoning (.52) and individual elaborated answers (.41). The correlations with the number of collaborative elaborations of conflicts (.38), individual elaborations of conflicts (.28) and co-constructed elaborated answers (.28) were somewhat lower. The condition with the checklist showed a positive but not significant correlation between the amount of collaborative elaboration and the score on the post-test.

Table 6.9 Partial correlations between the number of elaborative episodes and post-test scores in the two conditions[1] (controlled for pre-test scores)

	Post-test Score		
	Checklist (n = 26)	Asking (n = 22)	Both conditions (n = 48)
Individual elaborative episodes	.46*	.68*	.50*
Collaborative elaborative episodes	.21	.68*	.46*

* p < .05.

6.5 Summary and Discussion

This experimental study was conducted to investigate the effects of two scripts that were meant to elicit a productive use of a textbook during the collaborative concept mapping task. Further, the study was intended to see if differences that were expected between the two parts of the task and that were found in the previous study would be found again in the present study. Finally, this study again examined the relationships between the features of the student interaction, student characteristics and individual learning outcomes. The results of the statistical and qualitative analyses will be summarized and discussed in the sections below. In some cases the results will be compared with the results of the second experimental study. Although the present study was not an actual replication of the second study due to some minor changes in the product that was asked for and the scripting of the use of the textbook, the results of the present study gain more meaning when they are compared with the results of the previous study. The design and the hypotheses of the present study were for a large part based upon the results of the previous study. However, the reader has to take into account that differences between the previous and the present studies could not be tested statistically.

6.5.1 The use of the textbook during collaborative learning

6.5.1.1 How the textbook was used

In the second study I investigated the way textbooks were used during the accomplishment of the collaborative learning task without any instruction on how to use the textbooks. In this follow-up study I wanted to see whether scripting the use of the textbook would improve the function of the textbook as an extra tool to answer questions and to negotiate and co-construct the scientific meanings of the electricity concepts and whether or not it would hinder students in engaging in the explicit verbalization and elaboration of their own thinking on the topic. The analyses of the transcripts showed that the scripted use of the textbook rose to the expectations. Only a small part (15%) of the time that was spent on the task was spent on the consultation of the textbook (in the previous study the students consulted the textbook twice as often). I conclude that scripting the use of the textbook was successful in keeping students from immediately reaching for the textbook without a clear need to do so. This gave the students more room for the verbalization, elaboration and negotiation of their own understanding of the concepts. The script was not focused on changing the students' attitudes with respect to the value of trying things on your own first and of not relying too much on the authority of the textbook. Such a change of beliefs and attitudes may have an extra positive influence on the way extra tools, such as a textbook, are used during collaborative work. Scripting the use of a textbook, however, might be a good start in such a change. In one of the examples given in this chapter (Example 6.2) one of the students wanted to negotiate his own ideas first and communicated to his partner that they did not need the textbook yet.

In the present study a 'strong' and a 'weak' scripting of the use of the textbook were compared. It was expected that the students who had to complete a checklist (the 'strong' script) would consult the textbook less frequently than the students who had only to ask for the textbook (the 'weak' script). This hypothesis was confirmed. In the 'asking' condition the textbook was consulted twice as often as in the checklist condition. I explain this difference by the fact that the checklist, in which students had to state explicitly why they wanted to use the textbook, functioned as a higher threshold to consult the textbook.

In more than half of the cases in which the textbook was consulted, this consultation was preceded by the verbalization of the students' own ideas on the topic. Contrary to expectation, in the checklist condition the consultation of the textbook was not preceded more frequently by the verbalization of own ideas on the topic. At this point, the use of the textbook might be improved further. Apparently the script was not strong enough in stimulating the verbalization of own ideas. Both in the asking and in the checklist conditions, the students were not asked to explicitly state their own ideas before consulting the textbook. Perhaps such a question could be included in the checklist. The students could be asked, for example, not only to write down what question they would like to answer with the help of the textbook, but also what the answer might be. In this way the students can show that they tried to figure it out on their own before they sought help. Such a 'checklist' or 'logbook' could also be involved in the evaluation or the marking of the group work. This might also be important when we want students to share the idea that investing in the completion of a checklist is valuable. It must be taken into account, however, that a lack of verbalization of own ideas may in some cases simply be due to a lack of knowledge or understanding. The textbooks were used most often in such situations. Students might find it very difficult to discuss possible answers or to formulate hypotheses about a topic on which they experience knowledge gaps.

As pursued, the verbalization of a question turned out to be the most frequent situation in which the textbook was consulted. In the previous study a new part of the task and the writing, drawing or reading of the partner were the most frequent situations in which a textbook was used. The asking of questions during collaborative learning was considered important because it stimulates the students to reflect on their own understanding and to become more conscious of the gaps in their understanding. Further, a clearly formulated question has the potential to elicit an elaborated answer given by the partner or co-

constructed by both participants. Finally, it was assumed that when the students have problems answering a question on their own, seeking help in other information resources is more goal directed once a clear question is formulated. It was expected that the formulation of a question prior to the consultation of the textbook, would occur more often in the checklist condition than in the asking condition. This hypothesis was confirmed. In the checklist condition the consultation of the textbook was preceded by a question twice as frequently as in the asking condition. It was assumed that, whereas in the asking condition the students are not forced to formulate what they are going to search for in the textbook, the checklist forces the students to formulate a question. On the checklist the students had to note what question they wanted to answer with the help of the textbook. In the asking condition, starting a new part of the task was in a quarter of all cases enough reason for the students to consult the textbook. In the checklist condition, starting a new part of the task and uncertainty without the verbalization of an explicit question combined, made up almost a quarter of the situations in which the textbook was consulted. In these situations the question was only formulated on the checklist, but not verbalized. In these cases only the students who wrote down the question may have gained a sharper notion of what exactly they were going to look up in the textbook. Further research could focus on the question of whether the *verbalization* and *negotiation* of the question that has to be written on the checklist might be stimulated even more.

The textbook can only function as an extra tool to negotiate and construct the meaning of the concepts when relevant information is found in the textbook. In more than 75% of the cases in which a textbook was used, this use resulted in the finding of information that corresponded with the topic the students were dealing with (in the previous study corresponding information was found in only 39% of the cases). I explain this result by the assumption that the script stimulated the students to consult the textbook only in situations in which they really needed help. The idea is that the negotiation of this need for help and the formulation of what they were going to search for resulted in a more goal directed search in the textbook, consequently resulting in finding useful information more frequently. However, although most of the time the students found useful information in the textbook, an unexpected result of the study was that in the checklist condition the consultation of the textbook did not result more often in the finding of information. I expected that the checklist would result in a more goal directed search in the textbook and would therefore make the students more successful in finding information. I took a closer look at the transcripts attempting to figure out the nature of the cases in which the students did not find useful information in the textbook. It turned out that in the checklist condition only 11% of all cases in which a textbook was consulted did students' simply not *find* information. There were also cases in which the students simply stopped searching in the textbook because one of the students came up with a proposal or answer that made the students decide that it was not necessary to search any further. In the asking condition a failure to find information in the textbook occurred twice as often (23%). Although this difference between the conditions also did not reach the significance level ($p = .18$), it gives some evidence for the statement that there is a tendency for students in the checklist condition to have more success in finding information than in the asking condition.

Finally, almost all information that was found in the textbook was shared and elaborated by the students and was used to complete the group product. These findings are in line with the results of the previous study.

6.5.1.2 Textbook use and the features of the student interaction

The results of the previous study showed that a frequent use of textbooks during the collaborative learning task had a negative effect on the amount of elaborative talk. In this study it was assumed that scripting the use of the textbook would influence the use of the textbook and remove the negative effects of this use on the student interaction. It was expected that the scripts would promote textbook use that was confined to situations in which students have problems answering a question or in the elaboration of a conflict, that stimulates the students to verbalize their own ideas before consulting the textbook and to find, share and elaborate relevant information. The transcripts showed that this was the main pattern of textbook use in the present study. I suggested that such a use of the textbook would not hinder talk that is valuable for concept learning: talk about the meaning and the relations of the concepts and elaborative talk. In this study only correlational analyses could be conducted, so that no conclusions can be drawn about the existence of a real causal relationship. Correlational analyses showed that the amount of talk about the electricity concepts was not significantly related to the proportion of time that was spent on the consultation of the textbook. A small negative coefficient was found, but this coefficient was considerably smaller than in the previous study. The number of elaborative episodes, also did not correlate with the time spent on the consultation of the textbook. In the previous study a negative coefficient was found whereas in the present study a positive (but not significant) correlation was found in the checklist condition. This study was specifically intended to remove the negative effects of textbook use on the features of student talk. The correlational analyses confirmed the hypothesis that the use of the textbook would in any case not coincide with *less* (elaborative) talk about the concepts. Future studies might focus on the question of under which conditions the use of extra tools during collaborative learning, such as a textbook, might even be *positively* related to the amount of elaborative talk.

6.5.2 The construction of the Concept Map and the Elaboration of the Concept Map

In this study I also wanted to see whether the differences in student talk between the two parts of the task found in the previous study could also be found in the present study. It was expected that the student interaction during the elaboration of the concept map would contain more talk in which the electricity concepts are related to concrete phenomena and other forms of representation, and also verbalizations of the idea of current consumption and of local reasoning. All of these hypotheses were confirmed. Further, as in the previous study, another difference between the two parts of the task was found. Again, during the construction of the concept map the students talked more intensely about the electricity concepts (indicated by the number of propositions per minute) than during the elaboration of the concept map. One of the explanations that was given in the previous study was that during the second half of the task, in several dyads the students divided the task: each of them elaborated some relationships from the concept map. Such a task division lessened the need to verbalize and negotiate. In the present study the papers that had to be used for the elaboration of the relations in the concept map were attached to each other. Further, the students were instructed to elaborate only four relations from the concept map. These changes were made to prevent a task division. In the present study a division of the relations that had to be elaborated did not occur. In some dyads one of the students was the writer or drawer, while in other dyads the students wrote or drew in turn. The other explanations that were given to explain the fact that during the second half of the task the students talked less about the concepts, were the appearance of more writing and drawing activities and a loss of concentration. These explanations are also applicable to this study. The transcripts of the second half of the task showed more drawing and writing activities and more off-task utterances.

6.5.3 Features of student interaction related to student characteristics and outcomes

In the previous study the pre-test and the attitude scores of individual students did not correlate significantly with the number of propositions and arguments a student formulated. The results of this study replicated this finding. It is possible that relationships among prior knowledge, attitude towards the subject and the participation of the students were not found because they were mediated by the composition of the dyads or because the attitude questionnaire used in these studies was too 'general' to apply to the motivation for the domain and the sort of group task. Further, the mean score and standard deviation on the attitude questionnaire showed that the participants shared a moderately positive attitude towards physics. We must take into account that due to the fact that the participants chose the subject in their examination program that, as a group, they were somewhat homogeneous. Another explanation for the absence of relationships may be that student characteristics were less important than task characteristics and the dynamics of the interaction itself in shaping the participation of individual students. In the previous chapter (section 5.5.3.1), I suggested that the fact that the pre-test scoring was primarily based upon the correctness of the answers may be a possible explanation for the fact that no significant correlations were found between pre-test scores and the participation in the interaction, although the transcripts clearly showed that previous experiences within the domain were brought into the discussion. Both issues will be further elaborated in the general discussion.

It was expected that individual learning outcomes would be related to both the amount of individual participation in the interaction and the amount of elaboration in the student interaction. This hypothesis was for a large part confirmed. The more a student talked about the electricity concepts and the more elaborative the talk was in the student interaction in which he or she participated, the higher his/her score was on the post-test. However, the elaborative degree of the participation of the student (measured as the number of arguments a student contributed to the interaction) was not significantly related to the post-test scores. Further, it should be noted, that *both* the number of individual elaborative and collaborative elaborative episodes correlated significantly with post-test scores, whereas in the previous study no significant correlation was found for individual elaborative talk. The degree of co-construction can be considered lower in individual elaborative episodes than in collaborative elaborative episodes because in these situations, the reasoning only contains verbal contributions of one participant. It is possible that in the second study the individual learning outcomes did not correlate positively with the number of individual elaborative episodes because in this study a division of labor occurred more often and therefore students were less engaged in each other's reasoning. It is likely that a student who was busy with drawing or writing or with the consultation of a textbook listened less carefully to the reasoning of his or her partner. In the present study the students may have been more engaged in each other's reasoning, and therefore the difference between 'individual' elaborative episodes and 'collaborative' elaborative episodes may have been smaller.

7 General Conclusions and Discussion

7.1 Introduction

This dissertation dealt with the following key questions: 'How do features of a collaborative learning task affect student interaction?' and 'What kind of student interaction contributes to the learning of physics concepts?'. The previous chapters reported the results of the three experimental studies that were carried out. Participants of the studies were students of intermediate general secondary education who had chosen physics in their examination program. The collaborative learning tasks that were used functioned as an introduction of a new course about electricity and had to be accomplished in dyads. This chapter contains a summarization and a general discussion of the results of the three experimental studies, so that the two main research questions can be answered. In doing this, I also include a discussion of the method that was used to analyze the student interaction. Finally, I will give some recommendations for future research and educational practice.

7.2 Results of the three empirical studies

The specific results of each study were summarized and discussed in the fourth, fifth and sixth chapters. Each study had its own specific research questions and the studies differed in the experimental tasks that were used and the tools that were provided. The tests that were administered also differed somewhat on several aspects. However, all studies concerned the learning of electricity concepts, used a pre-test post-test design and analyzed student talk with the same coding scheme (although some minor changes were made in the second study). Further, in all studies, in either one (study 1) or both (study 2 and 3) conditions the students prepared individually for the task and a concept mapping task was used. In this section, I draw some general conclusions. Further, the instruments that were constructed to analyze the quality of the student interaction are discussed.

7.2.1 How do features of the collaborative learning task affect student interaction?

An important aim of this study was to contribute to the theory about how features of collaborative learning tasks affect the quality of the student interaction and consequently the individual learning outcomes. Recently, Derry (1999) concluded that there is still very little theory about the relationship between task characteristics and the quality of the student interaction. This holds even more strongly for forms of face-to-face collaborative learning in which students share both activities and tools (Webb & Sullivan Palincsar, 1996; Rogoff, 1998). Of particular interest of this thesis was the question of how features of a collaborative learning task influence the appearance of talk about and with the electricity concepts, of elaboration and of co-construction of meanings in the student interaction. In the first chapter I discussed three important features of collaborative learning tasks: the product that is asked for, the tools that are available and the script that is given to describe the nature and sequence of activities the group has to be engaged in. In the three experimental studies, a systematic comparison was made between student interaction and learning outcomes of students working on different types of task designs. Analyses of variance were used to test for significant differences between conditions. In the first study (chapter 4) a concept mapping task was compared with a poster task in which students had to explain the working of an electric torch with given electricity concepts, and the effects of a phase of individual preparation was investigated. The second study (chapter 5), compared a condition with and a condition without the availability of textbooks during the group work. The third study (chapter 6) focused on the effects of two different kinds of scripts for the use of the textbook during the group work. In both the second and third studies, a comparison was also made between student interaction during the construction of a concept map and during the elaboration of the relations in this concept map.

Below I will first draw some general conclusions about the importance of the product that is asked for. Second I will pay attention to the way tools affect the quality of the student interaction. Finally, the role of the instruction will be discussed.

The group product that is asked for

The products that were asked for were concrete material products (on large papers) which allowed for more than one right answer. The products were assumed to elicit a symmetric participation in the interaction, elaborative talk about the concepts, verbalization of frequently occurring misconceptions within the domain, and co-construction. The analyses of the student interaction showed that such interaction appeared in all studies and that there was some commonality in the nature of the interactions. On the average the student interaction contained three to six elaborative episodes per ten minutes (the variation is due to the conditions in which the students worked). In each study somewhat more than half of all elaborative episodes consisted of collaborative elaborative episodes. The tasks specifically elicited elaboration in the form of reasoning that was not directly related to a question or a conflict. The students asked a lot of questions, in particular verification questions. Despite these commonalities, some differences were found that were related to the specific product that was asked for.

In all studies the collaborative construction of the concept map showed significantly *more talk* about the electricity concepts than the collaborative construction of a poster (study 1) or the collaborative elaboration of the relationships of the concept map (study 2 and 3). This difference was explained by the observation that both the making of a poster and the elaboration of the relationships in the concept map (designing experiments, representing expected results in a table or diagram and formulating an explanation) elicited more writing and drawing activities than the making of a concept map. This result adds to the evidence of Bennett and Dunne (1991) for the assumption that tasks that require a lot of concrete activities elicit less abstract talk. In the second and third studies a complementary explanation was given for the differences in talk about the concepts. In these studies the dyads first constructed a concept map and then they were asked to elaborate the relationships in their concept map. Less talk about the concepts during this second phase of the task may also be the result of a loss of concentration. During the second phase of the task more off-task utterances were also found.

In the first study the student interaction during the concept mapping task also appeared to contain *more elaborative talk* in the form of elaboration of conflict and reasoning than the student interaction during the poster task. Contrary to the poster task in which the students could combine different points of view in one explanation, the concept map required explicit statements about the relationships between the concepts. The students may have experienced a stronger need to resolve a conflict. Further, the poster task required students to describe the phenomena that occurred in the different parts of the electric torch, but did not stimulate students to relate these phenomena to each other. The concept mapping task, in which a concept could be related to several other concepts, enabled the students to also construct reasonings that included more than one relationship.

The group product that was asked for also had an important influence on the *propositional content* of the student interaction that it elicited. First, when students made a concept map, they primarily talked about the theoretical relationships between the physics concepts. The task of explaining the working of an electric torch (the poster task in study 1), and the task of designing experiments and representing expected results in a table or diagram (study 2 and 3) however, elicited more talk in which the theoretical concepts were related to concrete phenomena and to mathematical forms of representation. Second, during the concept mapping task in the first study the students rarely discussed the explanatory mechanisms of moving electrons. Therefore, in the second and third studies the students were also asked to give an explanation for the nature of the relationships between the physical quantities. The analyses of the student talk showed that the students did talk more about the behavior of the electrons, but that many dyads had difficulties with giving explanations. Third, the interaction during the construction of the concept map did hardly show a verbalization of the idea of current consumption and local reasoning, whereas both can be considered frequently occurring ‘misconceptions’. When students had to design experiments to prove the relationships in their concept map and had to draw electric circuits, these misconceptions were verbalized and discussed more often. Finally, during the design of experiments the students made more explicit use of previous experiences within the domain. They often explained or shared the experiments that they carried out in physics classes. The concept mapping task did not elicit much similar talk.

The tools that are available

In the studies that were reported on in this thesis, a distinction can be made between tools that are closely related to the product that is asked for, such as the product that is constructed including the concept cards that had to be used on it, and extra tools, such as the individual designs (the product of individual preparation) and textbooks. Below I will draw some general conclusions about the role of these tools.

The product in the process of formation functioned especially as an extra tool to communicate and negotiate meaning, and to support the co-construction of meanings and reasoning. The students frequently pointed to the product (for example the network, a drawing of an electric circuit or a diagram) while they were trying to verbalize and negotiate their understanding. The cards with the physics concepts that had to be used in the concept mapping and poster task encouraged students to really talk about the meaning of these concepts and to use these concepts in their reasoning (see also Roth & Roychoudhury, 1994; Roth & Roychoudhury, 1993).

The individual designs that were a concrete result of the phase of individual preparation for the collaborative learning task, were used as an extra means to exchange and share personal ideas and ways of reasoning. They were used to support proposals, confirmations, criticisms and to determine the next topic that had to be dealt with.

In the second and third studies the students were provided with an extra tool: either one or two textbooks. In the second study a condition in which students were provided with two textbooks was compared with a condition in which the students were not provided with textbooks at all. In the third study all dyads were provided with one textbook, but in one condition the students had to ask for the textbook each time that they wanted to use it and in the second condition the students had to fill out a checklist each time that they wanted to use the textbook. On the basis of the literature and the results of the first experimental study, it was suggested that a textbook has the potential to support talk about the abstract physics concepts, the use of the physics concepts in their scientific meanings, elaboration and co-construction. The second study showed that, without any instruction about how to use the textbooks, the students very frequently reached for the textbook. This was explained by the fact that it had been some time since the students had dealt with the electricity concepts and they were uncertain about their knowledge, thus attributing much authority to the textbook. In half of the cases, the students did not initially verbalize their own ideas on the topic, only turned the pages over and did not find any useful information in the textbook. It was suggested that this was related to the finding that the students frequently consulted the textbook at the start of a new part of the task or when their partner was writing or drawing (and not when the students had problems with the resolution of a conflict or the answering of a question). The students often had no clear goal of what to look for in the textbook. The second and third studies both revealed more positive aspects of the way the students used the textbook during the collaborative learning task. When the students found some useful information in the textbook, this information was usually shared (through reading aloud or elaboration of the information) and elaborated, and the information contributed to the construction of the group product. In particular, text that attracted attention by a different layout, drawings and diagrams were used as extra tools to negotiate and co-construct meanings. This underlines the role of the mode of representation of the information as a facilitator of negotiation of meaning (see also Roschelle, 1992; Patterson et al., 1992; Veerman, 2000).

The second study showed that, without scripting the use of the textbook, the use of the textbook during the group work had a significant negative effect on the number of elaborative and collaborative elaborative episodes in the student interaction. The condition without textbooks showed significantly more collaborative elaborative episodes than the condition in which the textbooks were available. It was suggested that the availability of textbooks kept the students from explicating all of their questions and disagreement. Both questions and disagreement can elicit elaborative talk. Further, the task division that sometimes occurred during the consultation of a textbook may have resulted in less collaborative reasoning. Despite the fact that the dyads that used textbooks during the collaborative learning task produced less elaborative talk, the students of these dyads did not perform worse on the post-test. Acquiring factual information though reading and the appearance of non-verbalized elaboration of the information found, may have compensated for the lack of elaborative talk. The third study indicated that the use of the textbooks can be scripted, so that it does not constrain elaborative talk and the co-construction of meanings. The effects of this scripting are described in more detail below.

Scripting student activities during collaborative learning

A task division and an assignment of roles were considered to be inadequate to script the activities in a collaborative learning task (in which students share activities and materials) that aimed at improving conceptual understanding. I studied two other forms of scripting that I considered to be suitable for collaborative concept learning in dyads, and that to my knowledge were not investigated before. Both forms of scripting did not directly, but more indirectly scripted the patterns of student interaction.

In the first study (chapter 4), I investigated the effects of a phase of individual preparation. The students had to individually make a design for the concept map or the poster in five minutes. This preparation phase was considered valuable because it had been some time since the students had dealt with the electricity concepts that had to be used and because it was assumed that it could enhance a symmetric participation in the interaction, the appearance of conflict and the asking of questions. The individual preparation did not affect the degree of asymmetry in participation in the interaction. However, asymmetry was low in all dyads. The individual preparation also did not affect the number of conflicts. It was suggested that this was related to the fact that the designs were too incomplete and general to reveal clear contradictions. It is also possible that the students were too uncertain about their ideas to defend their own design or to critique the design of their partner. Imposing individual preparation did affect the number of questions the students posed. Most of these questions were verification questions and did not elicit elaborated answers, but had an important role in the negotiation and co-construction of meanings. The students who prepared individually for the collaborative learning task had higher scores on the post-test. I suggested that they gained more from the conversation because, through questioning, they elicited talk relevant to their uncertainties that they had already become aware of during individual preparation.

In the third study (chapter 6) the use of the textbook during the group work was scripted with an instruction to ask the experimenter for the textbook or with the instruction to fill out a checklist each time the students wanted to consult the textbook. On the checklist the students had to formulate the question that they wanted to answer with the help of the textbook, mark with a cross their motive to consult the textbook (not knowing something, uncertainty, disagreement) and (after they consulted the textbook) whether the consultation yielded an answer, or help or relevant information. This scripting was, based on the results of the second study, meant to improve the functioning of a textbook as an extra tool to answer questions and to negotiate and co-construct the scientific meanings of the electricity concepts. The results of the study showed that the scripting had a positive influence on the use of the textbook and consequently on the quality of the student talk. The textbook was used half as much as in the second study. The posing of a question now was the most frequent situation in which the textbook was consulted. In more than half of the cases the textbook consultation was preceded by the verbalization of own ideas and possible answers. In more than three quarters of the cases in which the textbook was used, this resulted in the finding of information that corresponded with the topic the students were dealing with. I conclude that the script succeeded in stimulating the students to negotiate the need for help and the formulation of what they wanted to look up in the textbook. This resulted in a more goal directed search in the textbook, and consequently in the finding of useful information. As expected, at some points the instruction to use the checklist turned out to be a stronger script than the instruction to just ask for the textbook. Asking the students to state explicitly why they wanted to use the textbook (the checklist condition) functioned as a higher threshold to consult the textbook than just asking for the textbook. In the checklist condition the textbook was consulted half as much as in the asking condition. The consultation of the textbook was preceded significantly more often by a question in the checklist condition, than in the asking condition. In the second study it was found that the use of the textbooks had a negative effect on the amount of elaborative talk. The correlational analyses in the third study showed that the amount of elaborative talk was not related to the scripted use of the textbook. I concluded that the scripts that were used were successful in removing possible negative effects of textbook use on the quality of the student interaction. However, since no significant positive correlation was found, the scripted use of the textbook did not coincide with *more* elaborative talk.

7.2.2 What kind of student interaction contributes to the learning of physics concepts?

A second aim of the study was to contribute to the theory about the relationship between the features of student interaction during collaborative learning and the learning of concepts, in particular the learning of physics concepts. In the second chapter I explained how I tried to build on both constructivist and socio-cultural perspectives on learning and interaction. In the studies that are reported in this thesis, a change in the ability to use the electricity concepts in their scientific meaning was measured by means of a comparison between scores on a pre-test and a post-test. T-tests showed that in *all* studies the scores on the post-test were significantly higher than the scores on the pre-test. Correlational analyses were conducted to investigate whether categories that described the features of the interaction and the way an individual student contributes to this interaction (his or her participation in the interaction), were related to the performance of individual students in a subsequent situation in which they were asked to use the same physics concepts. First, I shall discuss the relationship between individual learning outcomes and the participation of the students in the interaction. Second, I shall discuss the relationship between individual learning outcomes and the features of the student interaction measured on the episodic level that reflects the contingencies of the actions of both participants.

Individual learning outcomes and participation in the student interaction

The participation of the individual student was operationalized as the number of arguments and propositions this student formulated. Although in all studies moderately positive correlations were found between post-test scores and the number of arguments a student formulated, only in the first study did I find a significant correlation. Some arguments, however, were related to the procedure of the task. It is possible that when only arguments would have been chosen in which an electricity concept was used, the correlations would have been somewhat higher. Further, the number of propositions a student formulated may also be considered to be an indicator of elaborative participation since almost all propositions were statements about relations of electricity concepts with either other concepts, concrete phenomena or other forms of representation. Several authors stated that such a focus on meaningful relationships promotes a qualitative understanding of the relationships between the physical quantities that can be represented in formulas and that must be used in problem solving tasks (White & Fredriksen, 1987; Psillos & Koumaros, 1993). In the first study, the concept mapping conditions showed moderately positive but not significant correlations between the post-test scores and the number of propositions a student formulated. In the second and third studies however, I found significant positive correlations. Formulating more statements about the electricity concepts during the collaborative learning task coincided with a higher score on the post-test. This finding empirically supports the suggestion that students learn physics concepts by using them; by ‘talking science’ (Duit & Treagust, 1998; Lijnse, 1994; Palincsar et al., 1993; Lemke, 1990). Positive relationships between the talk of a student and his or her learning results are mostly explained by the idea that verbalization in a communicative setting promotes elaborative activities, such as the active use of preconceptions, the construction of meaningful relations and the explicit comparison of different conceptions. Through verbalization and the burden of giving coherent explanations, the students can gain a greater clarity for themselves, can become aware of inconsistent reasoning and knowledge gaps, and ideas can be questioned or criticized (Damon & Phelps, 1989; Teasley, 1995; 1986; Webb & Sullivan Palincsar, 1996; Cohen, 1986; Carter & Gail Jones, 1994; Brown & Palincsar, 1989; Dillenboug et al., 1995). Most empirical evidence that has been found until now, however, came from studies in which the students worked in *cooperative* learning groups in which the students often have their own work sheets or in which a task division is imposed. The research that is presented in this thesis gives such evidence for collaborative learning groups and more specifically for the learning of physics concepts.

Individual learning outcomes and features of the student interaction

Many studies in the socio-cultural line of research on student interaction specifically focus on the way collaborating students negotiate and co-construct meanings. From this perspective, results of collaborative learning are not explained by the study of the activities of individual students, but by a study of the features of the collaborative activity, in particular the negotiation and co-construction processes that appear. Most of these studies, however, do not distinguish between degrees of co-construction and/or do not attempt to relate the amount of co-construction in the student interaction to individual learning outcomes. In my research I tried to describe elaboration as a social process, and operationalized it as the giving of an elaborated answer to a question, the construction of a reasoning and the elaboration of a conflict. Elaborative episodes were categorized as ‘individual’ elaboration when the elaborated answer or the reasoning, was formulated by only one student and when in case of conflict only one student justified and explained his or her point of view. ‘Collaborative’ elaboration was operationalized as the co-construction of elaborated answers, collaborative reasoning and the collaborative elaboration of conflicts. In all three experimental studies I found a significant positive correlation between the number of collaborative elaborative episodes in the student interaction and individual learning outcomes. What are possible explanations for this relationship? First, collaborative elaboration may be more intense. Both students are actively engaged in elaborative activities at the same time. They are not only reflecting upon and elaborating their own understanding but are also integrating and/or elaborating the input of their partners. Second, meanings and reasonings that are co-constructed may be considered more correct because they are shared with another person. In new situations in which the students have to use the same concepts but cannot discuss possible answers with a partner, the *co*-constructed meanings and reasonings may be ‘reconstructed’ and used again. A third possible explanation is that co-constructed meanings and reasonings are more complex and from a scientific point of view are more correct. Some support for this hypothesis may be found in a study of Sizmur and Osborne (1997). They analyzed the verbal interaction of primary school children working together on a concept map, and made a comparable distinction between elaboration that was achieved either individually or collaboratively. They found that the collaboratively elaborated exchanges were more likely to result in the incorporation of a scientifically valid proposition in the concept map.

In the last study (chapter 6) I found a significant positive correlation between the number of *individual* elaborative episodes (individual elaborated answers, individual elaboration of a conflict, individual reasoning) and individual learning outcomes, whereas in the second study the frequency of such episodes did not correlate significantly with post-test scores. A possible explanation for this result is that in the last study the individual elaborative episodes reflected a more common focus on understanding and the attempt to construct a shared understanding. In the third study the difference between 'individual' elaborative episodes and 'collaborative' elaborative episodes may have been smaller. In the second study (chapter 5), the appearance of a task division and the use of the textbooks that were available resulted in situations in which a student was busy drawing, writing or consulting a textbook and was therefore less engaged in the reasoning of his or her partner. Although in individual elaborative episodes only one student formulates the reasoning, these episodes still can differ in the degree to which the other student is engaged in this reasoning. The reasoning can therefore be more or less 'shared'. This underlines the value of the idea of Crook (1998) who suggested that collaborative engagement defined as the will to make an effort to reach mutual understanding, is an important underlying condition for a productive interaction.

7.2.3 An instrument to analyze the quality of the student interaction

The need for a systematic, detailed and multiple dimensional analysis of the social interaction during the collaborative work in dyads resulted in the construction of a comprehensive and fine-grained coding instrument. I consider this instrument to be an important product of the research. The value of the instruments that were used to analyze student interaction is briefly discussed in the sections below.

Analyzing student talk in collaborative learning settings

The increasing interest in collaborative learning has heightened the need for adequate instruments to describe social interaction in educational settings. Analyzing talk that is generated by collaborative learning tasks requires a different descriptive system than talk that is generated by students who cooperate, but do not work on a joint product and share both activities and tools. For example, the category 'elaborated help' as it was defined by Webb (1989) and frequently used in other studies, was not very useful in the context of my research. In the case of collaborative tasks, questions are relevant for the completion of the common product and can be considered to be a problem for both students. Therefore answers must not be considered 'help' that is given by one student to another. A question can be answered by either one of the participants or by the participants together. Considering the collaborative learning setting and the researc questions of this research, I thought it of more interest to know whether or not a question is answered, whether a short or an elaborated answer is given, and whether elaborated answers are given by just one student or are co-constructed. Speaking of 'giving' and 'receiving' help also reflects a single focus on the activities of individual students and somewhat neglects the co-constructed nature of the student talk.

Building on constructivist, socio-cultural and domain specific theories on learning

The value of this study resides partly in the construction of a coding scheme that is based on both constructivist and socio-cultural perspectives on student interaction and learning, and on more domain specific theories of learning physics concepts. In line with the constructivist idea of the importance of the activity of the learner, my coding scheme focused on the participation of each student. How much did each student talk about the concepts and how elaborative was this participation? It was suggested that in a collaborative learning environment elaboration of the meaning of concepts is, on the utterance level, reflected in the formulation of arguments and propositions in which the physics concepts are related to each other, to a concrete phenomenon or to another form of representation.

The situated and socio-cultural perspectives on learning bring in new and powerful constructs, such as negotiation, co-construction, shared thinking and collaborative engagement. However, there are still few instruments in which these abstract constructs are operationalized for empirical research. I tried to describe elaboration not only as an individualistic activity, but also as a social and situated activity, as something that is co-constructed. At the episodic level elaboration is reflected in the giving of elaborated answers on questions, the elaboration of conflict and in reasoning. Explaining and reasoning can also be considered *social* processes that contribute to the understanding of each other and the achievement of a mutual understanding. Such an interpretation of elaboration is more in line with the socio-cultural perspective on learning. Further, the idea of learning as a situated and mediated process also directs our attention to the fact that the situation and the material tools that are used are an integral part of the co-construction processes. In the second and third studies I used a coding scheme with which the use of textbooks during the collaborative learning could be described in detail and could be related to other features of the student interaction.

In sum, the analyses on the utterance and episodic level contributed differently to the understanding of the interaction. The analysis at the utterance level makes it possible to get information about the participation of each student in the social activity. The episodic level of analysis is more appropriate to grasp the dynamic and co-constructed nature of talk, and the way material tools support or constrain verbalization, negotiation and co-construction.

Finally, while constructing a coding scheme to analyze student interaction, I did not want to lose sight of the specific features of the domain and the learning goals that were aimed for. The collaborative learning session was meant to contribute to concept learning within the domain of physics by students of the higher levels of secondary education. Thus, the interaction including the nature and level of the elaboration that is aimed for, is defined differently than when collaborative learning is meant to contribute to the adequate use of, for example, maps within the domain of geography. Therefore, aside from analyzing the communicative dimensions of the interaction, in this study I believed it was important to also take into account the propositional content of the utterances. When concept learning is described as a change in the way students use the concepts in situations that require this use, it is important to describe to what extent students actually talk about and 'with' the concepts, and whether frequently occurring misconceptions within the domain are verbalized and discussed.

7.2.4 Conclusions

In sum, the studies revealed that talking about the meaning and relations of the concepts, using these concepts to describe and explain phenomena within the domain, and participating in an interaction that is characterized by collaborative elaboration contribute to the learning of concepts. The research showed that the design of the task has a very important role in enhancing the *need,* the *willingness* and the *possibilities* to talk about the meaning of the concepts, to use the concepts in descriptions and explanations, to elaborate and to co-construct meanings. First, the three studies revealed that the product affects: the intensity with which students talk about the concepts, the elaborative nature of the interaction, the propositional content of the interaction, the explicit use of previous experiences within the domain, and the type of misconceptions that are verbalized. A product that is highly congruent with the thinking and reasoning that is aimed for, and that elicits only a minimum number of necessary ‘secondary’ activities (for example, drawing and writing), has more potential to elicit a productive interaction. Second, the research showed how the quality of the student interaction during a collaborative learning task can be influenced by means of scripting the sequence of activities and the use of extra tools. I do not know of the existence of previous studies in which a phase of individual preparation, the use of textbooks, and the scripted use of textbooks and its effects on the quality of the student interaction was investigated empirically. I tried to study textbooks as potential tools to support the verbalization, negotiation and co-construction of meanings. The second and the third studies showed that textbooks can only function as such a tool when the students are able to find useful information, when they share this information and when they can compare it with hypotheses and answers that they tried to formulate before they consulted the textbook.
Finally, the instrument that was used to analyze the student interaction can also be considered a valuable result of the research. The coding schemes focus on both the activities of individual students and of the group, different types of elaboration, degrees of co-coconstruction, the propositional content of the talk, and the use of textbooks. The coding schemes are useful for both a more qualitative description of transcript fragments, and for a quantitative and multiple dimensional analysis of a large number of transcripts. Each analysis can contribute in its own way to the description and explanation of the nature of student interaction, and to the way this interaction enables the learning of concepts.

7.3 Recommendations for Future Research

A challenging task for further research is the further description and explanation of the complex interplay between the quality of collaborative learning activities and the factors that comprise and shape these activities. I suggest that future research on collaborative concept learning works from a more inclusive approach that incorporates both the social and the more individual aspects of learning, and consequently considers both the changing participation of individual students and the quality and dynamics of student interaction as useful units of analysis (see also Van Boxtel, 2000). Based upon the results of the research, I would like to make the following recommendations for future research.

Questions concerning generalization

The methods and results of the research cannot easily be generalized to other domains, other levels of education, and to tasks that have other functions in a curriculum. It is of interest to know what a productive interaction looks like in the context of, for example, learning history, geography or biology concepts. Students must be stimulated and assisted in questioning, reasoning, arguing and explaining specific to the demands of the domain. Two research projects that focus on the learning of history concepts in collaborative peer workgroups and that partly build on the results of this thesis are recently started (Capaciteitsgroep Onderwijskunde Universiteit Utrecht 1999; 2000). In the research that was presented in this thesis the collaborative learning tasks functioned as an introduction on a new chapter on electricity. The results of the presented studies may possibly be generalized to other such introduction tasks in comparable domains. However, collaborative learning tasks that are accomplished during the course (for example laboratory tasks) or as a closing of a course (with or without an individual or group reward) aim for other learning goals and therefore also for patterns of student interaction that are in accordance with these goals. Further, the research was confined to social interaction in dyads. The results cannot be generalized to the participation of students in larger groups and the quality of the interaction in larger groups. The results can also not be generalized to groups in which the teacher has an important role as a coach and/or expert within the domain. Some promising research on such collaborative learning environments is done from the idea of a ‘community of learners’ (e.g. Brown & Renshaw, 1996; Barab & Duffy, in press). Brown and Renshaw (1996) suggest that a teacher can facilitate concept learning by assisting students to reconceptualize their everyday thinking in the language of the subject. I propose that, comparable with the detailed study of the consultation of the textbook, it is investigated in which situations collaborating students ask the help of a teacher, whether the students first try to figure things out on their own, whether the students ask clear questions, and what is done with the information and/or feedback given by the teacher. Although there is increased attention on the role of the teacher as a coach or facilitator of students taking more responsibility for their own learning in co-operative or collaborative learning groups (e.g. Elshout-Mohr & Dekker, 2000; Andriessen & Veerman, 2000), the role of the teacher as a participant in small collaborative learning groups is still quite unclear.

The role of the tools that are provided

New studies should be conducted to shed more light on the way extra tools are used during collaborative learning and how they can support, provoke or constrain the use of concepts, elaborative interaction and co-construction. Scripting the use of the textbook, as was described in the third study, succeeded in the elicitation of a desirable pattern of textbook use so that the textbook use did not have a negative effect on the amount of elaboration and co-construction. Further research must focus on the question of under which conditions do textbooks or other tools *promote* the use of concepts in their scientific meaning, elaboration and co-construction. In such studies, also the role of textbook features, features of the script, and the attitude of students towards textbooks and to ‘looking things up’ are worthwile to be investigated. Computer supported collaborative learning may have some advantages (see also Kanselaar, de Jong, Andriessen, & Goodyear, in press). For example, drawing and writing on the computer may be less time consuming than on paper. Visual and dynamic representations on the computer may be stronger tools to assist students in talking about theoretical concepts and in negotiating and co-constructing meanings (see also Veerman, 2000; Baker, Hansen, Joiner & Traum, 1999; Roschelle, 1992). Scripting the use of information during collaborative learning may be more effective when it is computer supported.

Future research can also focus on tools that can support students in the generation of explanations for relationships between physical quantities. It appeared that the participating students had severe problems with this. Sullivan Palincsar and Herrenkohl (1999) report positive results of a method called Collaborative Problem solving in Science (CPS), in which students are stimulated to give molecular-level, accurate and complete explanations.

The role of student characteristics

I made the assumption that what a student 'brings' to the collaborative learning session due to previous experiences within the domain is also at work in shaping the student's participation in the interaction. The only significant positive correlation was found in the first study. Students with a higher score on the pre-test formulated more arguments during the group work. In the second and third studies I found a positive, but not significant correlation between pre-test scores and the number of arguments a student formulated. In none of the studies did I find a significant correlation between pre-test scores and the number of propositions (statements about the electricity concepts) a student formulated, although the correlations were positive. Also, no significant correlations were found between the score on the questionnaire that measured the attitude towards physics and the number of propositions and arguments a student formulated.

It is possible that the participation of a student in the interaction *is* related to their prior knowledge and attitude towards physics, but that I simply did not find it. The lack of a significant correlation may be interpreted as an effect of restriction of range. The participating students shared a moderately positive attitude towards physics (having all chosen the subject in their examination program) and some initial understanding of the meanings of the electricity concepts that had to be used. Furthermore, students were randomly assigned to sex-homogeneous dyads. No dyads consisted of students who scored either very low or very high on both the pre-test and the attitude questionnaire. It is also possible that the instruments that were used to measure prior knowledge and attitude were not adequate. First, the internal homogeneity of the pre-test in all studies was not very high. Second, the pre-test score was for an important part based upon the correctness of the answers, whereas the participation of the students was not operationalized as the number of correct statements about the electricity concepts, but as the number of statements and the number of arguments. Third, the pre-test measured the ability of the students to use the electricity concepts in a written mode, whereas the participation of the students in the interaction involved spoken language. Research using a pre-test and a post-test that are more congruent with what is asked for in the interactive setting (see also Webb, 1995), might generate other results. The attitude questionnaire may have been too general. It focused on the attitude towards physics, and not specifically on the theme of electricity. The motivation at the start of the task, the willingness to understand the electricity concepts, the willingness to reach a *shared* understanding, and the perceived relevance of and interest in the task may be more important factors that shape the participation of the student in the interaction. New instruments need to be designed to study the role of such factors in collaborative learning situations.

Another possibility is that in collaborative learning situations the relationship between student characteristics and the activities that students show in an educational setting is weaker in collaborative learning situations than in less interactive learning situations. It is possible that the collaborative task, the broader setting, and the interaction with the partner are more important. Studies that did find significant relationships between pre-test scores and the behaviour of a student during a task are mostly studies in which both the pre-test and the student activity that is studied take place in an individualistic setting, thus without the possibility of a verbal interaction with another person. In an interactive setting the student may more easily remember and use relevant previous experiences within the domain (for example an analogy told by the teacher or an experiment that was carried out), because of the need to be understood by the partner and the need to negotiate meanings. Thus, the performance of a student in an 'individualistic' setting (such as a pre-test) may not be a good predictor of the performance of a student in an interactive setting. A collaborative learning task that has a strong potential for eliciting an active and elaborative participation of each student, some initial understanding of the concepts to be used and the existance of a minimum amount of personal motivation to understand the concepts and to collaborate may be enough to generate an active and elaborative participation of each student.

Instruments to analyze student interaction and to present the results of these analyses

The instruments with which the student talk was analyzed in this research, can be improved on several points. I will discuss four issues. First, the coding scheme that was presented to analyze the student talk on the episodic level contained mutually exclusive, but not exhaustive codes. In line with the research questions, only question, conflict and reasoning episodes were coded, whereas the other fragments were not. The use of exhaustive codes makes it easier to describe the extent to which the interaction of a dyad is elaborative or co-constructive, for example, expressed in percentages. Second, during the analysis of the transcripts, my attention was drawn to some dimensions that I did not cover with my coding scheme, but that appeared to be of some importance. While coding the episodes in which the students gave an elaborated answer on a question, elaborated a conflict or constructed a reasoning, I did not take into account the level (for example, concrete or abstract, or descriptive or explanatory) and accuracy of the elaborations, and the question of whether conflicts were resolved with a compromise or with the 'winning' of one of the points of view. This relates to the question of how inclusive and refined a coding scheme must be to answer the research questions. Does the increased amount of work and time balance the potential surplus value of an even more detailed analysis? Third, in the coding scheme co-construction was defined as an elaborative episode (for example a reasoning or an elaborated answer) in which both participants make a verbal and propositional contribution to the elaboration. However, the extent to which students are able to coordinate their activities by verifying whether their partner shares ideas and understandings (e.g. Erkens, 1998), through maintaining the focus on the same topic (e.g. Veerman, 2000), and through the sharing of information from extra information resources can be considered important conditions for the appearance of collaborative elaboration. They may be considered as indicators of co-construction or of the more broader constructs of collaboration. The same holds true for the extent to which the students praise and encourage each other and are able to compromise. Further, co-construction may also be reflected in the degree of labor division among the participants (Dillenbourg, 1999). Some of these aspects were analyzed through the coding on the utterance level and the coding of the use of textbooks, but the codes were not integrated into one coding scheme.

Fourth, analyzing student talk on different levels and dimensions is a very labor-intensive job and therefore utilizing computer programs can make the task easier and less time consuming. The analyses in this research were predominantly performed with the computer program Winmax (Kuckartz, 1998). However, this program did not enable a linkage between the codings on the different levels and on the different dimensions. Erkens (1998) is currently developing the program Multiple Episode Protocol Analysis (MEPA), with which transcripts can be analyzed on multiple dimensions. Such programs are important in facilitating the analysis of large numbers of transcripts in a profound way. Another problem that concurs with complex and refined analyses of student talk is the method with which to present the results in a clear and understandable way. In this thesis several examples of student interaction were presented for illustrative and explanatory purposes. Kumpulainen and Mutanen (1999) recently developed a promising method to 'map' the nature and dynamics of student interaction. Such techniques are valuable contributions to elevate the use of qualitative descriptions and interpretations of (fragments of) transcripts above the level of 'anecdotal use'. Aside from and together with more quantitative analyses of student interaction, such detailed and systematic qualitative analyses contribute to the insight into how exactly the interaction is constituted by the participation of the collaborating students, previous and subsequent activities, the collaborative learning task, the features of available tools and the broader setting, and how the participation of the students is shaped by the features of the interaction and the other dimensions. Together with experimental studies, 'case studies' that systematically describe the participation of a student in subsequent situations (less or more interactive) on the same dimensions may contribute to the generation of explanations for relationships between features of student interaction and the participation of students in previous and subsequent situations, such as were found in this research.

7.4 Recommendations for Educational Practice

The realization of the research goals was also considered relevant for educational practice. The research generated knowledge about the conditions under which collaborative learning contributes to the learning of (physics) concepts, and it can contribute to the design of collaborative learning tasks that have a high potential to elicit a productive student interaction. My recommendations are concerned with the necessity to 'talk science', the possibilities of using the developed tasks in schools, and the need to carefully design collaborative learning tasks.

Asking students to use the concepts to be learned

The research provided additional empirical support for the assumption that students learn concepts by using them, in particular by using them in spoken language in a collaborative learning situation. The teachers can model the requested kind of talk by using the concepts in their scientific meaning, by asking verification and higher order questions, giving and asking for arguments, building on and criticizing the contributions of others, and by making high demands on the way students communicate with the domain specific concepts. However, the students must be given enough opportunity to talk about the meaning of the concepts, to use the concepts themselves in describing, explaining, predicting, discussing and evaluating phenomena within the domain.

Using the developed collaborative learning tasks in educational practice

The tasks that were designed in the context of the research can be used in educational practice (see also Van Boxtel, submitted; Van Boxtel, 1999; Van Boxtel, 1999a; Van Boxtel, 1997). On the whole, one could conclude that the tasks, in particular the concept mapping task, are successful in eliciting collaborative elaborative talk about the concepts and that they contribute to the improvement of conceptual understanding. In addition, the participating students gave a positive evaluation of the tasks. The tasks are not strong enough to change the use of misconceptions into the use of conceptions in their scientific meaning. As introduction tasks, however, they can be a good starting point to foster students to verbalize their conceptions, discuss them, and elicit the need to test assumptions and extend understanding. The group products that are asked for are a good instrument for the teacher to diagnose rather quickly the use of misconceptions. I suggest that the collaborative learning tasks of this research can also assist the students in taking more responsibility for their own learning during the course. Eventually with the help of the teacher, the students can determine and carry out activities to check and/or improve their concept map and the hypotheses and explanations they formulated. Further, the group products that are made (the concept map, poster or the elaborations of the relationships in the concept map) can be presented and discussed in the class. In this way the product can also be a good starting point to discuss the question of what constitutes proof for a relationship and what constitutes an explanation within the domain of physics. When the tasks are used in educational practice it must be taken into account that the students need to have some initial understanding of the concepts and the ways of reasoning within the domain, and that they have some basic collaboration skills. It may also be necessary to practice the making of a concept map and the design of experiments and formulation of explanations.

The need to carefully design collaborative learning tasks

Most teachers have some experience with cooperative learning but probably less with collaborative learning. Teacher educators and manuals for group work often stress the need to impose a task division, to assign roles, and to carefully compose the groups. However, as shown in this research, such measures are not always necessary (or even suited) to promote a symmetric participation and a productive student interaction that contributes to an improvement of conceptual understanding. The studies in this thesis show that the design of the task is a very powerful instrument to affect the quality of the student interaction. The task must be primarily designed on the basis of the kind of student talk that is thought to be productive. This requires a clear idea about the activities in which the students need to be engaged. Group products that are large enough to be shared, that contain visually represented information, that do not require many concrete activities such as drawing and writing at the cost of ‘abstract’ talk, and that force the students to actually use the scientific concepts and discuss their meanings and relationships, have the potential to stimulate and assist students in the verbalization, negotiation and co-construction of meanings.

When students are provided with extra tools, such as textbooks, computer programs, or materials to experiment with, these tools must also be evaluated on their potential to support and stimulate the sharing and elaboration of information. Further, it should be questioned whether the students can make productive use of these tools. Otherwise extra training or the scripting of the use of the tools may be necessary to prevent that the use of the tools constrains elaborative interaction and collaboration.

In sum, when designing collaborative learning tasks, it must be taken into account that to realize a productive student interaction, the students do need some assistance with verbalization, negotiation and co-construction.

Summary

This thesis deals with the quality of the interaction between students who collaborate in dyads on a task that focuses on the learning of physics concepts. Collaborative learning has a strong potential to contribute to the learning of physics concepts because it gives students the opportunity to talk both about and 'with' the concepts. Considerable amounts of research examine the ways and the conditions under which student interaction facilitates learning. The collaborative learning task is viewed as a factor that has an important influence on the quality of the interaction and the learning outcomes. However, many studies of the effects of different types of group tasks focused mainly on results and not on the interaction processes. The studies that did focus on these processes primarily dealt with cooperative peer workgroups. Less is known about the influence of task characteristics on interaction processes in collaborative peer workgroups in which the students work simultaneously on a common product without an imposed task or role division. In this thesis this type of group work is described with the term 'collaborative learning'. The goal of my research was to gain more insight into how features of collaborative learning tasks affect the quality of student interaction, and to contribute an answer to the question of which types of student interaction facilitate the learning of physics concepts.

Chapter 2 provides a description of the (socio)constructivist, socio-cultural and more domain-specific theories and empirical studies which were used as a theoretical framework of my research. I discuss the literature about the problems that students appear to have with the learning of physics concepts and the explanations that are given for these problems. Then, I give an outline of the cognitive constructivist and the socio-cultural perspectives on the learning of concepts. The constructivist perspective merely focuses on individual cognitive activities and stresses the need for elaboration, such as the active use of prior knowledge, the recognition and acknowledgement of problems and attempts to solve these problems, and looking for meaningful relationships. The socio-cultural perspective includes the idea of learning as a situated process, as a process of changing participation, as mediated by cultural symbols and artifacts and as the joint construction of knowledge. In this thesis I work from the idea that the construction of conceptual knowledge may be described in terms of both individual and social processes. I define the learning of physics concepts as a change in the way the learner participates in situations that require the use of the scientific concepts and forms of reasoning. More specifically, the learning of physics concepts is described as the growing ability to think, speak and act with physics concepts in their scientifically agreed upon meanings. I then discuss two lines of research that focus on the question of how social interaction between students can facilitate learning. The first line of research examines the idea that the verbalization and exchange of ideas and strategies leads to elaborative cognitive processes. The second line of research is based upon the idea that in social interaction, knowledge is co-constructed and that mediational tools can play an important role in the negotiation and co-construction of meanings. Trying to build on the results of both lines of research, I come to the hypothesis that student interaction that is specifically characterized by talk about and 'with' the physics concepts, elaboration and a continuous attempt to achieve a shared understanding of the concepts making maximum use of the available mediational means, contributes to the learning of physics concepts. However, such a productive student

interaction is not guaranteed. Chapter 2 concludes with a discussion of the task characteristics that can affect the quality of the student interaction. Commonalities amoung collaborative learning tasks include shared goals, tools, activities and equal participation opportunities for the students. However, collaborative learning tasks can still differ from each other in the kind of group product that the students work on, the tools that are available and the script that imposes a certain sequence of particular activities or that structures student interaction and the use of the resources that are available.

Chapter 3 presents the main questions and the method of the research. The main questions of the research were how features of collaborative learning tasks affect the student interaction and what kind of student interaction contributes to the learning of physics concepts. These questions were addressed in three experimental studies.
Subjects of the three studies were students of the higher classes of intermediate general secondary education who worked together in dyads on a collaborative learning task that functioned as the introduction to a new course about electricity. To study whether participation in peer interaction has a positive effect on the way a student uses the physics concepts, a pre-test post-test design was chosen. The dialogues of all participating dyads were transcribed. I developed a coding scheme (see chapter 4 and the Appendix) to describe the talk about the physics concepts, the appearance of elaboration and the degree to which this elaboration is more or less co-constructed (individual and collaborative elaboration). The coding scheme focuses on the features of the participation of each student, such as the degree to which the student talks about the concepts and the elaborative nature of the contributions of the student, and on the features of the interaction that are described on the episodic level with different types of question, conflict and reasoning categories. In all studies it was investigated whether the participation of students in the interaction was related to student characteristics such as prior knowledge (measured with the pre-test) and the attitude towards physics (measured with a questionnaire). In all studies it was also investigated whether post-test scores were related to features of the student interaction and the participation of the student.

The first experimental study (chapter 4) specifically focused on the role of the group product. A concept mapping task in which the students had to make a network of concepts was compared with a poster task in which the students had to explain the working of an electric torch using certain physics concepts. In both tasks the students were given cards labeled with the concepts to be used and they were asked to also include mathematical forms of representation (formulas, diagrams, drawings) in their product. This study also investigated the influence of scripting a phase of individual preparation before starting collaborative activities on the quality of the student interaction and individual learning outcomes. In two conditions the students were asked to individually make a design for the concept map or poster. This individual preparation lasted for five minutes. Forty students participated in the study. The same-sex, but subsequently randomly composed dyads were assigned to one of the four conditions: concept map with individual preparation, concept map without individual preparation, poster with individual preparation and poster without individual preparation.

On the basis of the results it can be concluded that the concept mapping task was, in several ways, a stronger task than the poster task. The students that made a concept map talked more intensely about the physics concepts, probably because they spent less time on writing and drawing. The interactions in the concept mapping conditions also showed more argumentation to resolve a conflict and reasoning. As expected, the students who made a concept map talked less about concepts and their relations to concrete circuits or phenomena. They also rarely talked about the behaviour of electrons as a possible explanation for the described regularities. Both in the concept mapping and in the poster conditions the students did not include diagrams and the conception of current consumption was rarely verbalized (although it is described as a frequently occurring misconception in the literature). The nature of the group product (concept map or poster) did not affect the individual learning outcomes.

As expected, individual preparation resulted in the asking of more questions and in higher post-test scores. It is not likely that the higher learning outcomes were mediated by the amount of elaborative talk, because the individual preparation conditions did not show more elaborative episodes. It was suggested that these students gained more from the conversation because, especially through questioning, they elicited talk that was relevant to the uncertainties and knowledge gaps that they had already become aware of during individual preparation. Contrary to the expectations, the individual preparation conditions did not show more conflicts probably because the designs were not detailed or complete enough to reveal clear contradictions, and because the students were still very uncertain about their ideas. Further, the individual preparation did not affect the degree of asymmetry in student participation which was actually low in all conditions.

The study did not result in much empirical evidence for the assumption that the degree to which a student talks about the concepts and the elaborative nature of his or her contributions, is also related to his or her prior knowledge and attitude towards physics. A positive significant correlation was only found between the number of arguments a student formulated and the score on the pre-test.

The students scored significantly higher on the post-test than on the pre-test. A positive correlation between post-test scores and the number of arguments a student formulated was only found in the condition concept mapping without individual preparation. No positive correlation was found with the number of utterances about the concepts. In this condition scores on the post-test were also positively related to the number of elaborated answers, collaborative elaborations of conflicts and collaborative reasonings.

The second study (see chapter 5) mainly built on the results of the first study and focused on the question of how textbooks are used during the accomplishment of the collaborative task and how this use affects the quality of the student interaction. The second study also focused on the question of whether the concept mapping task that was used in the first study could be improved.

In the second study 56 students from the higher classes of intermediate general secondary education participated. Dyads were assigned to a condition in which two physics textbooks with a chapter about electricity were available and a condition without the availability of textbooks. In both conditions the students worked on a more comprehensive concept mapping task. During the first phase of the task the students were asked to construct a concept map in which they had to describe the relationships between the concepts as much as possible in the format of regularities. During the second phase of the task the students were asked to elaborate each relationship that they described in the concept map on a separate poster. They were asked to design an experiment with which the given relationship could be validated, to represent the expected result in a table or diagram and to give an explanation for the nature of the relationship.

I hypothesized that without structuring, the use of textbooks might not stimulate but actually constrain an elaborative interaction about the physics concepts, as well as the negotiation and co-construction of meanings. This would also imply that the consultation of textbooks might result in a better group product but not in a better understanding of the physics concepts.

Most of the assumptions were confirmed. The analyses of the use of the textbooks (for more details about the instrument that was used see chapter 5 and the Appendix) showed that the students who worked in the condition with the textbooks very quickly reached for the textbooks, often without the formulation of a clear goal of what to search for and without initially attempting explanations on their own. The textbooks were mostly consulted when students started a new part of the task (a new relation or experiment) or when the partner was writing, drawing or also consulting a textbook. The textbooks were used less to answer a question or to resolve a conflict, whereas it was assumed that, especially in these situations, a textbook could be a valuable tool. In half of the cases where a textbook was consulted the students did not find any useful information. Most information that was found, however, was shared and also elaborated. In particular text fragments with a different layout and pictures were often consulted. The use of textbooks had a negative effect on the amount and nature of elaborative interaction. The interaction in the condition with textbooks was characterized by significantly less (collaborative) elaboration. The conditions did not differ from each other in the quality of the group product probably because the students rarely found useful information in the textbooks. No differences were found regarding the individual learning outcomes, either. A possible explanation is that individual non-verbalized elaboration while reading in the textbook, and the acquiring of factual knowledge as a result of reading, partly compensated for the lack of elaborative interaction.

As expected, the second half of the task included more talk in which electricity concepts were used to describe concrete phenomena while allowing discussion about the described regularities to be represented in diagrams. During the design of the experiments the idea of current consumption was often verbalized. However, during the elaboration of the relationships of the concept map the students talked less intensely about the electricity concepts, probably because drawing and writing activities took more time and because a task division more often appeared. Finally, the transcripts and the group products showed that the students had problems with the generation of explanations.

It appeared that participation of the student in the interaction was not related to either prior knowledge or attitude towards physics.

The students performed better on the post-test than on the pre-test. Students that talked more about the electricity concepts had higher scores on the post-test. Post-test scores were also related positively to the amount of collaborative elaboration in the interaction (the number of co-constructed elaborated answers, collaborative elaboration of conflicts and collaborative reasoning).

The third and last study (chapter 6) investigated whether scripting the use of a textbook during the group work stimulated the students to use the textbook in a way that was not disadvantageous for the verbalization, elaboration and co-construction of meanings. In this study the dyads were provided with one textbook. Two scripts were compared in this study. In one condition (11 dyads) the students were instructed to ask the experimenter for the textbook when they needed it and to give it back after consultation. In the other condition (13 dyads) the students had to fill out a checklist each time they wanted to consult the textbook. On this checklist they had to explicitly state exactly what they were going to search for (in the form of a question), their reason for using the textbook, and, after the consultation of the textbook, whether they found what they were searching for. It was expected that the checklist would be a stronger script than just the need to ask for the textbook. The analyses of the textbook use and the quality of the student interaction showed that the scripted use of the textbook rose to the expectations. Compared with the second study, the students spent much less time on the consultation of the textbook. The posing of a question now was the most frequent situation in which the textbook was consulted. In more than half of the cases the textbook consultation was preceded by the verbalization of own ideas. In more than three quarters of the cases in which the textbook was consulted, useful information was found. The instruction to use the checklist turned out to be a stronger script than the instruction to just ask for the textbook. In the checklist condition the textbook was consulted less frequently than in the asking condition and the consultation was preceded more often by a question. In both conditions the amount of elaboration in the interaction was not significantly related to the time that was spent on the consultation of the textbook.
The third study also replicated some results from the second study. The student interaction during the second phase of the task showed more talk in which the electricity concepts were related to concrete circuits and more verbalizations of the idea of current consumption than the student interaction during the construction of the concept map. Again, during the elaboration of the concept map the students talked more intensely about the electricity concepts than during the construction of the concept map. It also appeared that the participation of the student in the interaction was not related to either prior knowledge or attitude towards physics. As in the second study, the students who talked more about the electricity concepts had higher scores on the post-test. Further, the scores on the post-test were related positively to both the amount of individual elaboration (the elaboration formulated by just one of the students) and the amount of collaborative elaboration (both students contribute to the elaboration) in the interaction.

Chapter 7 draws some general conclusions and gives some recommendations for further research and educational practice. First, I conclude that the design of the task affects the need, the willingness and the possibilities to talk about the meaning of the concepts, to elaborate and to co-construct meanings. The group product that students are asked to make affects the intensity with which students talk about the concepts, the elaborative nature of the interaction, the propositional content of the interaction, and the type of misconceptions that are verbalized. Scripting a phase of individual preparation has a positive effect on the asking of questions and on individual learning outcomes. The results of the second and third studies suggest that textbooks can only support the verbalization, negotiation and co-construction of meanings when the students do not immediately reach for the textbook, when they are able to find useful information, when they share this information and when they compare it with hypotheses and answers they tried to formulate before they consulted the textbook.

Second, it can be concluded that talking about the meaning and relations of the concepts, using these concepts to describe and explain phenomena within the domain, and participating in an interaction that is characterized by collaborative elaboration contribute to the learning of concepts.

Finally, the instruments that were designed to analyze the quality of the student interaction can also be considered a valuable result of the research. The coding schemes focus on both the activities of individual students and of the group, different types of elaboration, degrees of co-construction, the propositional content of the talk, and the use of textbooks. Each analysis can contribute in its own way to the description and explanation of the nature of the student interaction, and to the way this interaction contributes to the learning of concepts.

Since the results of the research cannot easily be generalized, further research of collaborative concept learning is needed in other domains, school levels, and with group tasks that have another function in the curriculum and tasks that are accomplished in larger groups. Suggestions for further research are also concerned with the role of the teacher and computer supported tools and with the question of student characteristics, such as prior knowledge and motivation, have a less important role in shaping the quality of the student activities in collaborative learning settings than in less interactive settings.

The thesis is closed with some recommendations for educational practice. It is stressed that students must have enough opportunity to talk about the concepts that have to be learned. Collaborative learning tasks that are meant to contribute to the learning of concepts need to be carefully designed because the quality of the interaction can usually be traced to features of the task. Group products that can be shared, that contain visually represented information, that do not require many concrete activities such as drawing and writing at the cost of elaborative talk about the content, and that force the students to actually use the scientific concepts, have the potential to contribute to a productive interaction. When students are provided with extra tools, such as textbooks, a computer program, or materials to experiment with, it is important to evaluate these tools on their potential to support and stimulate elaborative talk about the concepts, and the negotiation and co-construction of meanings.

Samenvatting

Dit proefschrift gaat over de kwaliteit van de interactie tussen leerlingen die in tweetallen samenwerken aan een taak gericht op het leren van natuurkundige begrippen. Samenwerkend leren heeft een grote potentie om bij te dragen aan begripsontwikkeling omdat leerlingen zo de gelegenheid krijgen om over en met de begrippen te praten. Er is redelijk veel onderzoek gedaan naar de wijze waarop en onder welke condities interactie tussen leerlingen het leren faciliteert. De taak waaraan de leerlingen samenwerken wordt beschouwd als een factor die een belangrijke invloed heeft op de kwaliteit van de interactie en de leeruitkomsten. Veel studies naar het effect van verschillende soorten groepsopdrachten richtten zich echter vooral op uitkomsten en niet op de interactieprocessen zelf. Andere studies richtten zich wel op deze processen maar hadden vooral betrekking op cooperatieve werkvormen. Er is minder bekend over de invloed van taakkenmerken op interactieprocessen bij vormen van samenwerkend leren waarbij leerlingen gelijktijdig aan een gemeenschappelijk product werken zonder opgelegde taak- of rolverdeling. Deze vorm van samenwerkend leren wordt in dit proefschrift aangeduid met de term ‘collaborative learning’. Doel van mijn onderzoek was meer inzicht te krijgen in de wijze waarop kenmerken van samenwerkingstaken de kwaliteit van de interactie beïnvloeden en een bijdrage te leveren aan de beantwoording van de vraag wat voor soort interactie bijdraagt aan het leren van natuurkundige begrippen.

Hoofdstuk 2 bespreekt de (socio)constructivisitische, socio-culturele en meer domeinspecifieke theorieën en empirische studies die het theoretisch kader vormden van mijn onderzoek. Ik bespreek de verklaringen die in de literatuur worden gegeven voor de problemen die leerlingen blijken te hebben met het leren van natuurkundige begrippen. Vervolgens ga ik in op de cognitivistisch constructivistische en de socio-culturele perspectieven op het leren van begrippen. Het cognitivistische perspectief richt zich vooral op individuele cognitieve activiteiten en benadrukt de noodzaak van elaboratie, zoals het actief gebruik van voorkennis, het (h)erkennen van problemen, het zelf proberen op te lossen van die problemen en het leggen van betekenisvolle relaties. Vanuit het socio-culturele perspectief wordt leren beschreven als een gesitueerd proces, als een verandering in de manier waarop leerlingen participeren in situaties, als gemediëerd door culturele symbolen en artefacten en als de gezamenlijke constructie van kennis. In dit proefschrift werk ik vanuit de idee dat het verwerven van conceptuele kennis beschreven kan worden in termen van zowel individuele als sociale processen. Ik definieer het leren van natuurkundige begrippen als een verandering in de manier waarop de lerende participeert in situaties die vragen om het gebruik van natuurkundige begrippen en manieren van redeneren. Meer specifiek beschrijf ik het leren van natuurkundige begrippen als de groeiende bekwaamheid te denken, te praten en te handelen met de natuurkundige begrippen in hun wetenschappelijke betekenis. Vervolgens bespreek ik twee onderzoekslijnen die gerelateerd zijn aan de vraag hoe sociale interactie tussen leerlingen het leren kan faciliteren. In de ene onderzoekslijn gaat men uit van de veronderstelling dat het verwoorden en uitwisselen van ideeën en aanpakken leidt tot elaboratieve cognitieve processen. De andere onderzoekslijn is gebaseerd op de idee dat in sociale interactie kennis geco-constructeerd wordt en dat materiële hulpmiddelen een belangrijke rol kunnen spelen in het onderhandelen en samen construeren van betekenissen. Op basis van de resultaten van beide onderzoekslijnen kom ik tot de hypothese dat met name een interactie die gekenmerkt wordt door intensief praten over en met de natuurkundige begrippen, elaboratieve bijdragen van de participerende leerlingen en een voortdurende poging om tot een gedeeld begrip te komen waarbij maximaal gebruik wordt gemaakt van de middelen die voor handen zijn, bijdraagt aan het leren van natuurkundige begrippen. Het is echter niet vanzelfsprekend dat zo'n productieve interactie bij samenwerkend leren plaatsvindt. Hoofdstuk 2 sluit af met een bespreking van de wijze waarop taakkenmerken de kwaliteit van de interactie kunnen beïnvloeden. Samenwerkingstaken hebben met elkaar gemeen dat de samenwerkende leerlingen verondersteld worden doelen, hulpmiddelen en activiteiten te delen en dat ze een gelijke kans hebben om deel te nemen. Samenwerkingstaken kunnen echter verschillen in het soort groepsproduct dat gevraagd wordt, de hulpmiddelen die beschikbaar zijn en het script dat een bepaalde volgorde van activiteiten kan opleggen of waarmee de interactie en het gebruik van beschikbare hulpmiddelen gestuurd wordt.

Hoofdstuk 3 presenteert de hoofdvragen en de methode van onderzoek. De centrale vragen zijn: hoe beïnvloeden kenmerken van samenwerkingstaken de interactie en wat voor soort interactie draagt bij aan het leren van natuurkundige begrippen? In drie experimentele studies werden deze vragen onderzocht.
Deelnemers van de drie studies waren leerlingen uit de vierde klas van het HAVO die in tweetallen samenwerkten aan een taak die bedoeld was als een zinvolle start van een lessenserie over electriciteit. Een pre-test post-test design werd gekozen om te kunnen beoordelen of het samenwerken aan de taak een positieve invloed heeft op de wijze waarop een leerling de natuurkundige begrippen gebruikt. Alle gesprekken van de participerende tweetallen zijn getranscribeerd. Ik heb een codeersysteem ontwikkeld (zie hoofdstuk 4 en de bijlagen) om het praten over de natuurkundige begrippen, het voorkomen van elaboratie en de mate waarin die elaboratie meer of minder geco-construeerd is (individuele en collaboratieve elaboratie) te beschrijven en zo interacties in verschillende condities systematisch te kunnen vergelijken. Het codeersysteem richt zich op kenmerken van de participatie van elke leerling (de uitspraken als eenheid van analyse) en op kenmerken van de interactie die op episodisch niveau kunnen worden beschreven, zoals vraag-antwoord sequenties, conflict-episoden en redeneringen. In alle studies is onderzocht of de participatie van leerlingen in de interactie gerelateerd is aan leerlingkenmerken zoals voorkennis (gemeten met de voortoets) en de beleving van het vak natuurkunde (gemeten met een vragenlijst). Ook is in alle studies onderzocht of scores op de natoets gerelateerd zijn aan kenmerken van de interactie en de participatie van de leerling in die interactie.

De eerste experimentele studie (hoofdstuk 4) richtte zich met name op de rol van het groepsproduct. Een concept mapping taak waarin leerlingen een netwerk van begrippen moesten maken is vergeleken met een postertaak waarin leerlingen de werking van een zaklamp met natuurkundige begrippen moesten beschrijven. Bij beide opdrachten kregen leerlingen kaartjes met daarop de te gebruiken begrippen en werd leerlingen gevraagd ook meer wiskundige representatievormen (zoals formules, grafieken en tekeningen) in het groepsproduct op te nemen. In de eerste studie is tevens onderzocht welke effecten individuele voorbereiding op de samenwerkinstaak heeft op de kwaliteit van de interactie en op de leeruitkomsten. In twee condities moesten de leerlingen direct voorafgaand aan het samenwerken in vijf minuten een individueel ontwerp maken voor de concept map of de poster. Veertig leerlingen namen deel aan het onderzoek. De sekse-homogene maar verder at random samengestelde tweetallen werden aselect toegewezen aan één van de vier condities: concept map met individuele voorbereiding, concept map zonder individuele voorbereiding, poster met individuele voorbereiding en poster zonder individuele voorbereiding.

Op basis van de resultaten kan geconcludeerd worden dat de concept mapping taak op een aantal punten een sterkere taak bleek te zijn dan de postertaak. De leerlingen die een concept map maakten praatten intensiever over de natuurkundige begrippen, waarschijnlijk omdat ze minder tijd besteedden aan het schrijven en tekenen. Ook werd in de concept mapping condities meer geargumenteerd om conflicten op te lossen en werden meer redeneringen geformuleerd. De leerlingen die een concept map maakten spraken echter minder over begrippen in relatie tot concrete schakelingen of verschijnselen en nauwelijks over het gedrag van elektronen als mogelijke verklaring voor de beschreven wetmatigheden. Zowel in de concept mapping condities als in de poster condities namen leerlingen geen grafische representaties op in hun product en werd de conceptie van stroomverbruik (in de literatuur als veel voorkomende misconceptie beschreven) nauwelijks geverbaliseerd. De aard van het groepsprocuct (concept map of poster) had geen effect op de individuele leeruitkomsten.

In overeenstemming met de verwachting, leidde individuele voorbereiding tot het stellen van meer vragen en hogere scores op de natoets. Het is niet waarschijnlijk dat de hogere leeruitkomsten gemediëerd werden door een elaboratievere interactie, omdat de condities met individuele voorbereiding niet meer elaboratieve episoden bevatten. Verondersteld werd dat deze leerlingen meer profijt hadden van de interactie omdat zij met name door het stellen van vragen een interactie op gang konden brengen die aansloot bij de onzekerheden waarvan ze zich al bewust werden tijdens de individuele voorbereiding. De condities met individuele voorbereiding bevatten in tegenstelling tot de verwachting niet meer conflicten, waarschijnlijk omdat de individuele ontwerpen niet uitgewerkt en compleet genoeg waren om duidelijke tegenstellingen te laten zien en omdat de leerlingen nog erg onzeker waren over hun ideeën. Individuele voorbereiding had ook geen effect op de mate van symmetrie in de deelname aan de interactie. In alle condities participeerden de leerlingen in ongeveer gelijke mate in de interactie.

Er werd nauwelijks empirische ondersteuning gevonden voor de veronderstelling dat de mate waarin leerlingen praten over begrippen en de mate waarin de participatie elaboratief is gerelateerd is aan voorkennis en de beleving van het vak. Er werd alleen een positieve relatie gevonden tussen het aantal argumenten dat een leerling formuleert en diens score op de voortoets.

De leerlingen scoorden significant hoger op de natoets dan op de voortoets. Alleen in de conditie waarin leerlingen een concept map maakten zonder individuele voorbereiding hingen scores op de natoets positief samen met het aantal argumenten dat een leerling formuleerde. In deze conditie hingen scores op de natoets ook positief samen met het aantal elaboratieve antwoorden, collaboratieve elaboraties van conflicten en geco-construeerde redeneringen in de interactie.

De tweede studie (zie hoofdstuk 5) bouwde voor een belangrijk deel voort op de resultaten van de eerste studie en richtte zich in de eerste plaats op de vraag hoe schoolboeken gebruikt worden tijdens het samenwerken aan de taak en hoe dit gebruik de kwaliteit van de interactie beïnvloedt. Op de tweede plaats was het onderzoek gericht op de vraag of de concept mapping taak uit de eerste studie verbeterd kon worden. Aan de tweede studie namen 56 leerlingen uit 4 HAVO deel. Tweetallen werden aselect toegewezen aan een conditie waarin leerlingen tijdens de samenwerkingstaak twee schoolboeken konden raadplegen met daarin een hoofdstuk over elektriciteit en een conditie waarin geen schoolboeken beschikbaar waren. De leerlingen werkten in beide condities aan een meer omvattende concept mapping taak. In de eerste fase van de taak moesten leerlingen een concept map maken waarbij relaties tussen begrippen zoveel mogelijk in de vorm van wetmatigheden moesten worden beschreven. Gedurende de tweede fase van de taak moesten de leerlingen de relaties in de gemaakte concept map verder uitwerken. Voor elke relatie moesten de leerlingen op een apart vel een proef beschrijven waarmee de relatie bewezen kon worden, de verwachtte resultaten van de proef in een tabel of grafiek weergeven en tenslotte een verklaring formuleren voor de aard van de relatie.

Ik veronderstelde dat zonder verdere instructie over het gebruik van de schoolboeken, de schoolboeken een elaboratieve interactie over de natuurkundige begrippen, het onderhandelen en samen construeren van betekenissen eerder zou beperken dan bevorderen. Gerelateerd aan deze veronderstelling was de hypothese dat het gebruik van schoolboeken wellicht wel zou leiden tot betere groepsproducten maar niet tot een beter begrip van de natuurkundige begrippen.

De meeste veronderstellingen werden bevestigd. Uit de analyse van het boekgebruik (zie voor details over het gebruikte instrument hoofdstuk 5 en de bijlagen) bleek dat de leerlingen in de conditie met schoolboeken de schoolboeken zeer frequent gebruikten en meestal zonder verbalisering van wat precies werd opgezocht en wat ze zelf al wisten over het betreffende onderwerp. De schoolboeken werden vooral geraadpleegd in situaties waarin leerlingen aan een nieuw onderdeel van de taak begonnen (een nieuwe relatie of een nieuw experiment) en in situaties waarin de partner schreef, tekende of ook opzocht, en veel minder in situaties waarin leerlingen problemen ondervonden bij het zelf beantwoorden van een vraag of het oplossen van een meningsverschil. In de meeste gevallen vonden de leerlingen geen bruikbare informatie in de boeken. Als er informatie werd gevonden werd die vaak wel gedeeld en ook geëlaboreerd. Met name de informatie die in een afwijkende lay-out was gepresenteerd en illustraties werden veel geraadpleegd. Het gebruik van de schoolboeken had een negatief effect op de kwaliteit van de interactie. De interacties in de conditie waarin schoolboeken werden gebruikt bevatten minder (collaboratieve) elaboratie. De condities verschilden echter niet ten aanzien van de kwaliteit van de groepsproducten, waarschijnlijk omdat de leerlingen nauwelijks bruikbare informatie in de schoolboeken vonden. Ook waren er geen verschillen ten aanzien van de individuele leeruitkomsten. Een mogelijke verklaring hiervoor is dat het gebrek aan elaboratieve interactie gecompenseerd werd door niet geverbaliseerde elaboratie tijdens het lezen en het verwerven van meer feitelijke kennis uit het boek.

Zoals verwacht spraken de leerlingen tijdens de tweede fase van de taak meer over begrippen in relatie tot concrete schakelingen en discussieerden ze over de wijze waarop de beschreven wetmatigheden in een grafiek konden worden weergegeven. Tijdens het ontwerpen van proeven kwam in veel tweetallen de opvatting dat stroom verbruikt wordt ter sprake. Wel werd bij het uitwerken van de concept map minder intensief over de natuurkundige begrippen gesproken dan tijdens het maken van de concept map, waarschijnlijk omdat tijdens de tweede helft van de taak meer geschreven en getekend moest worden en leerlingen vaker spontaan taken verdeelden. Tenslotte bleek uit de transcripten en de producten dat de leerlingen veel moeite hadden met het geven van verklaringen voor relaties.

De participatie van de leerling in de interactie bleek niet gerelateerd te zijn aan de voorkennis en de beleving van het vak natuurkunde.

De leerlingen behaalden betere prestaties op de natoets dan op de voortoets. De prestaties van leerlingen op de natoets hingen positief samen met de mate waarin leerlingen tijdens de interactie hadden gesproken over de natuurkundige begrippen. Verder hingen de individuele leerprestaties positief samen met de hoeveelheid collaboratieve elaboratie in de interactie (het aantal geco-construeerde elaboratieve antwoorden, collaboratieve elaboratie van conflicten en geco-construeerde redeneringen).

In het derde en laatste onderzoek (hoofdstuk 6) is onderzocht of het structureren van het gebruik van het schoolboek leerlingen stimuleert het boek te gebruiken op een manier die niet nadelig is voor de verbalisatie, elaboratie en co-constructie van betekenissen. In deze studie kregen de tweetallen de beschikking over één schoolboek. Twee scripts zijn met elkaar vergeleken. In de ene conditie (13 tweetallen) moesten leerlingen als ze het boek wilden raadplegen het boek vragen aan de proefleider en het na raadpleging weer teruggeven. In de andere conditie (11 tweetallen) moesten leerlingen iedere keer dat ze het boek wilden raadplegen een checklist invullen. Daarop moesten ze aangeven welke vraag ze met behulp van het boek wilden beantwoorden, wat de reden was om het boek te raadplegen en –na raadpleging- of ze een antwoord hadden gevonden op hun vraag. Verwacht werd dat het invullen van de checklist een sterker script zou zijn dan het vragen om het boek. De analyse van het boekgebruik bevestigde de meeste hypothesen. De leerlingen besteedden veel minder tijd aan het raadplegen van het boek dan in de tweede studie. Het boek werd vooral geraadpleegd naar aanleiding van gestelde vragen. In meer dan de helft van de gevallen waarin het boek geraadpleegd werd gebeurde dit nadat leerlingen eerst hadden geprobeerd zonder hulp van het boek tot een voorstel of een oplossing te komen. In meer dan driekwart van de gevallen vonden leerlingen in het boek bruikbare informatie. Verondersteld werd dat het onderhandelen over wat precies opgezocht zou worden resulteerde in doelgericht opzoeken en daarmee in het vaker vinden van bruikbare informatie. Het moeten invullen van de checklist bleek op een aantal punten een sterker script dan het vragen om het boek. In de checklist conditie raadpleegden de leerlingen het boek minder vaak en werd het raadplegen vaker voorafgegaan door het formuleren van een vraag. In beide condities was er geen verband tussen de hoeveelheid elaboratie in de interactie en de tijd die besteed werd aan het raadplegen van het boek.

In de derde studie werden ook een aantal resultaten van de tweede studie gerepliceerd. Tijdens de tweede fase van de taak (het uitwerken van de relaties uit de concept map) werd meer gesproken over begrippen in relatie tot concrete schakelingen en werd de opvatting dat stroom verbruikt wordt vaker verwoord. Opnieuw bleek dat tijdens de tweede fase van de taak de leerlingen minder over begrippen spraken dan tijdens het maken van de concept map. Ook bleek de participatie van de leerling in de interactie niet gerelateerd aan de voorkennis en de beleving van het vak natuurkunde. Net als in de tweede studie scoorden leerlingen die meer uitspraken deden over de natuurkundige begrippen hoger op de natoets. De scores op de natoets hingen verder positief samen met zowel de hoeveelheid individuele elaboratie in de interactie (waarbij de elaboratie van één van de leerlingen afkomstig is) als met de hoeveelheid collaboratieve elaboratie (waarbij beide leerlingen bijdragen aan de elaboratie).

Hoofdstuk 7 bevat de algemene conclusies en doet enkele aanbevelingen voor verder onderzoek en voor de onderwijspraktijk. Op de eerste plaats concludeer ik dat de samenwerkingstaak van invloed is op de noodzaak, de wil en de mogelijkheden om over de betekenissen en de relaties van de natuurkundige begrippen te praten, om betekenissen te elaboreren en samen te construeren. Het groepsproduct dat leerlingen moeten opleveren heeft invloed op de intensiteit waarmee leerlingen over de begrippen praten, het elaboratieve karakter van de interactie, de inhoud van de interactie en op het type misconcepties dat ter sprake komt. Het voorschrijven van individuele voorbereiding heeft een positief effect op het stellen van vragen en op de individuele leeruitkomsten. De resultaten van de tweede en de derde studie suggereren dat schoolboeken het verbaliseren, onderhandelen en samen construeren van betekenissen alleen ondersteunen wanneer leerlingen niet te snel een beroep doen op deze boeken, wanneer ze in staat zijn relevante informatie te vinden, wanneer ze gevonden informatie met elkaar delen en wanneer ze die vergelijken met hypothesen en antwoorden die ze besproken hebben voordat ze het boek raadpleegden.

Op de tweede plaats kan geconcludeerd worden dat het praten over de betekenissen en de relaties tussen de begrippen, het gebruiken van de begrippen om verschijnselen binnen het domein te beschrijven en te verklaren, en het participeren in een interactie die gekenmerkt wordt door collaboratieve elaboratie bijdragen aan het leren van begrippen.

Tenslotte kunnen ook de instrumenten die ontwikkeld zijn om de kwaliteit van de interactie te analyseren beschouwd worden als waardevolle resultaten van het onderzoek. De codeersystemen richten zich op zowel de activiteiten van de individuele leerlingen als die van de groep, op verschillende soorten elaboratie, niveau's van co-constructie, de inhoud van de interactie en het gebruik van boeken tijdens het samenwerken. Elke analyse kan op zijn eigen manier bijdragen aan de beschrijving en de verklaring van de aard van de interactie en de wijze waarop deze interactie bijdraagt aan het leren van begrippen.

Omdat resultaten van dit onderzoek niet zonder meer generaliseerbaar zijn is verder onderzoek naar samenwerkend begrippen leren nodig in andere domeinen, schooltypen en bij samenwerkingstaken die een andere functie hebben in het curriculum of uitgevoerd worden in grotere groepen. Verdere suggesties voor vervolgonderzoek naar samenwerkend leren hebben betrekking op de rol van de docent en van computerondersteunde hulpmiddelen en op de vraag of bij samenwerkend leren leerlingkenmerken zoals voorkennis en motivatie wellicht minder van invloed zijn op de kwaliteit van de leeractiviteiten dan bij meer individuele settings.

Het proefschrift wordt afgesloten met een aantal aanbevelingen voor de onderwijspraktijk. Benadrukt wordt dat leerlingen voldoende gelegenheid moeten krijgen om over en met de begrippen die geleerd moeten worden te praten. Samenwerkingstaken die bedoeld zijn om een bijdrage te leveren aan begripsontwikkeling moeten zorgvuldig ontworpen worden omdat de kwaliteit van de interactie voor een belangrijk deel terug te voeren is op kenmerken van de taak. Met name groepsproducten die gedeeld kunnen worden, visuele representaties bevatten, niet teveel vragen om teken- en schrijfactiviteiten ten koste van een meer inhoudelijke en elaboratieve interactie en die leerlingen dwingen de te leren begrippen te gebruiken kunnen bijdragen aan een productieve interactie. Wanneer leerlingen de beschikking krijgen over extra hulpmiddelen zoals boeken, computerprogramma's of materialen om te experimenteren, dan is het belangrijk om te evalueren in welke mate deze hulpmiddelen het praten over de begrippen en het samen construeren en elaboreren van begripskennis kunnen stimuleren en ondersteunen.

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Appendix

Appendix Ia Instruction for the Concept Mapping Task (Study 1)

Task:

Together you are going to make a concept map about **electricity** in which you have to give the concepts that are labeled on the cards a place. Draw the relationships that you think exist between the concepts as lines or arrows. Near these lines or arrows write what -according to you- the concepts have to do with one another. Before you make the concept map together, each of you will make a design for it individually[1].

How to proceed?

Make a *design* for the concept map **individually**. Try to put together the concepts that you think are related to one another. Draw lines between the concepts that you think are related to one another. Attention! This is only a preparation. It is not necessary to make a complete concept map. You have five minutes for this preparation[1].

Then you are going to make the concept map **together**. Exchange what you invented in your design[1]. Try to come to an agreement about what the concept map is going to look like. Try to come to an agreement about the way the concepts can be organized on the large paper. Try to use all the concepts. The concepts are written on post-it notes so they are easy to remove. Try also to come to an agreement about the lines and arrows that can be drawn between the concepts. During this consultation you can use the pencils.

When you agree on the organization of the concepts and the lines, you can use the pens.

* Write near all lines and arrows what the concepts that you linked have to do with one another. Do this as precisely and clearly as possible.
* Try to include magnitudes, units, symbols and formulas in the concept map.
* Try to include diagrams or drawings in the concept map to make a concept or a relation clearer

How to work together?

It is meant that you both contribute to the concept map and try to come to an agreement, that you both understand what is in your concept map, that you give each other the opportunity to propose, criticize and question, that you try to answer each other's questions and that you listen to each other's arguments in case of disagreement and try to resolve disagreement.

How much time do you have?

You have 45 minutes to accomplish this task. Five minutes to make a design individually[1] and 40 minutes to make the concept map together. Let me know when you think you are finished with the concept map.

[1] The sentences about the making of an individual design were excluded from the instruction that was given in the condition concept mapping without individual preparation.

Appendix Ib Instruction for the Poster Task (Study 1)

Task:

Together you are going to make a poster in which you try to explain as well as possible how an **electric torch** works through the use of electricity.

Attention! It's not only about the parts of the electric torch. Your poster must show *why* an electric torch works. You have to explain this using several physics concepts. Before you make the poster together, each of you will make a design for it individually[1].

How to proceed?

Make a design for the poster **individually**. Write the concepts where you want to use them in an explanation. You can draw lines from the concepts to parts of the electric torch. Think of what you would explain at these points. Attention! This is only a preparation. It is not necessary to make a complete poster. You have five minutes for this preparation[1].

Then you are going to make the poster **together**. Exchange what you invented in your design[1]. Try to come to an agreement about what the poster is going to look like. You can use the concepts on the post-it notes to come to an agreement about where you are going to use the concepts to explain something. Try to use all the concepts. During this consultation you can use the pencils.

When you agree on the design of your poster you can use the pens.

* An electric torch is already drawn on the paper. You can complete this drawing when you think this is necessary.
* Try to use the given concepts in your explanation.
* Try to include magnitudes, units, symbols and formulas in your explanation.
* Try to include diagrams or drawings in the poster to make your explanation clearer.

How to work together?

It is meant that you both contribute to the poster and try to come to an agreement, that you both understand what is on your poster, that you give each other the opportunity to propose, criticize and question, that you try to answer each other's questions and that you listen to each other's arguments in case of disagreement and try to resolve disagreement.

How much time do you have?

You have 45 minutes to accomplish this task. Five minutes to make a design individually[1] and 40 minutes to make the poster together. Let me know when you think you are finished with the poster.

[1] The sentences about the making of an individual design were excluded from the instruction that was given in the condition poster without individual preparation.

Appendix Ic **Task Instruction (Study 2 and 3)**

INSTRUCTION

Goal of the Task

You are going to make a concept map about electricity together. You already know the concepts that you are going to use from previous years. It is good to brush up on your conceptual knowledge before you begin another chapter about electricity:

-What do the concepts mean?

-How are they related?

-How can you prove/explain this?

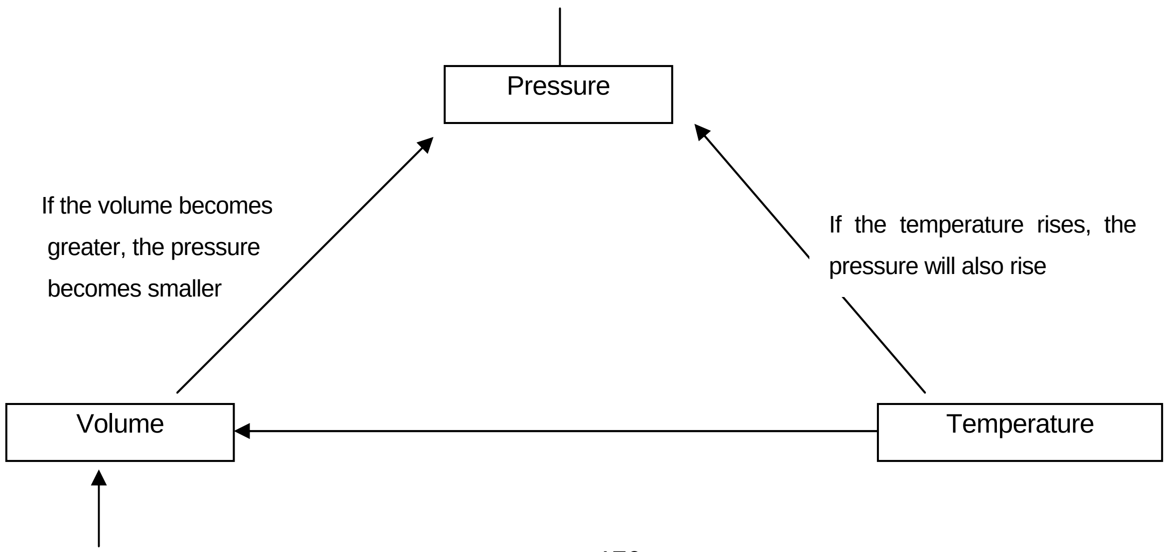
In this task you will get to work with these questions. You can find out what you do and what you do not yet understand. The task consists of two parts: A and B. The next pages describe how to proceed.

A: Construct a Concept Map

- In front of you lies a large piece of paper with several cards labeled with concepts. Organize the concepts and draw lines or arrows between the concepts that you think are related to each other.
- Near the lines/arrows write exactly what you think the concepts that you related have to do with one another. Try to do this as much as possible in the format of a regularity:

If … becomes greater/smaller, than … becomes greater/smaller

Below an example is given of an incomplete concept map about the topic “pressure”



B: Elaborate four relations[1]

1 Select four relations from your concept map. These relations must contain the following concepts.

1 Voltage - …

2 Current - …

3 Resistance - …

4 Energy - …

Thus, you select a relation between voltage and another concept, a relation between current and another concept, etcetera

2 Describe clearly and to the point an experiment with which you can prove the relation.

- Name the quantities/units that you are going to measure.
- Draw an experimental design, for example, with the electric circuits that have to be made.

3 Present the results that you expect in a diagram or a table. Do not forget to mention the quantities/units near the axes.

4 Think of an explanation for the relation. How do you explain the relation that you described and want to prove? Why is what you wrote near the line in the concept map so? Bear in mind that with electricity, the relations between quantities often have to do with the small particles that are called *electrons*.

The next pages give examples of the way the two relations from the concept map about pressure can be elaborated.[2]

[1] **Study 2**: The students were asked to elaborate *each* relationship of their concept map. Point 1 above was not included in the instruction. The instruction was: "For each relationship in the concept map, you describe clearly and to the point an experiment with which you can prove the relationship." Further the instruction was the same as in point 2 to 4 above.

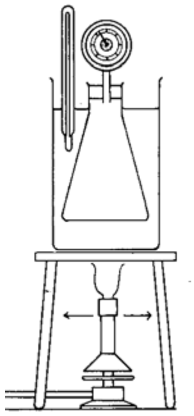
[2] Only one example is included here.

RELATION 2

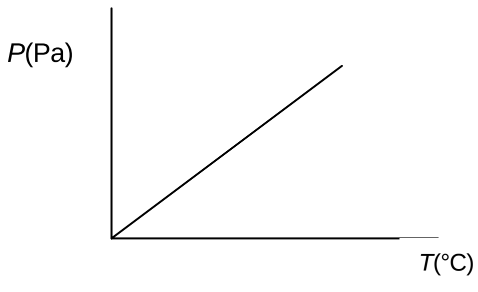
PROOF

- **Description of the experiment (with drawing of experimental design)**

A glass filled with air is placed in a larger glass filled with cold water.
The temperature of the water and the pressure of the air in the glass are measured.
The water is heated with a burner. The air pressure is measured several times while increasing temperatures (that are also measured).



- **Expected results (in a diagram or table)**



EXPLANATION FOR THE RELATION

Molecules move faster when the temperature of the air is increased. When the molecules move faster, they will bump more often and more powerfully against the sides: there is a higher pressure.

Procedure of the Task[1]

Step 1 Individual preparation

You have ***5 minutes*** to prepare individually for the task. Make a design for the concept map on the A4 in front of you. Draw lines between the concepts that you think are related. Start thinking about what you could write near the lines.

Step 2 Collaboration

Now you are going to make the concept map on the large paper. Exchange what you invented on your own design. Check whether or not you agree or if your designs can be complementary to one another. You must agree on the concept map that you make and it is also necessary that you both understand your concept map.

- You have ***20 minutes*** to construct the concept map.
- You have ***45 minutes*** to elaborate four relations.

Consultation of the textbook

By request, you can consult the chapter 'Electricity' in the textbook *Natuurkunde Overal*.
Ask for the textbook **only** when you cannot work it out on your own. It is the intention that you attempt, as much as possible, to make the task with the knowledge you have together.
When you want to consult the chapter, you have to ask the experimenter for the textbook. After you have found what you were looking for, and/or when you are going to work on something else, give the textbook back to the experimenter.

[1] **Study 2**: The part about the consultation was not included. In the condition with textbooks only the sentence "When you can not work it out on your own, you can consult the textbooks" was included. In this study the students had 25 minutes to construct the concept map and 50 minutes to elaborate the relationships.
Study 3: This is the instruction that was given in the condition in which the students had to ask for the textbook.

Procedure of the Task[1]

Step 1 Individual preparation

You have ***5 minutes*** to prepare individually for the task. Make a design for the concept map on the A4 in front of you. Draw lines between the concepts that you think are related. Start thinking about what you could write near the lines.

Step 2 Collaboration

Now you are going to make the concept map on the large paper. Exchange what you invented on your own design. Check whether or not you agree or if your designs can be complementary to one another. You must agree on the concept map that you make and it is also necessary that you both understand your concept map.

- You have ***20 minutes*** to construct the concept map.
- You have ***45 minutes*** to elaborate four relations.

Consultation of the textbook

It is the intention that you attempt, as much as possible, to make the task with the knowledge you have together. When you cannot work it out on your own, you can consult the chapter entitled “Electricity” in the textbook *Natuurkunde Overal*.

Each time you consult the textbook, you must note what you are going to use the textbook for. Note your question and the reason for this question.
After you consult the textbook, note whether or not you found what you were searching for.
You can simply do this on the checklist that lies on the textbook.

[1] **Study 3**: This is the instruction that was given in the condition in which the students were asked to fill out the checklist.

Appendix 1d Checklist for the consultation of the textbook[1]

1 Note what you are going to search for in the textbook in the form of a <u>question</u>.

2 Mark in the second column the reason behind your question:

- you don't know or understand something, for example: *What is the symbol of voltage*? Or: *What exactly is resistance?*
- you are not sure about something, for example: *Must V be near the x axis?*
- you disagree, for example: *Is voltage in volt or in ampere?*

3 After the consultation of the textbook, you mark in the third column whether or not your question is answered.

Question 1:	**Reason**: 0 do not know 0 uncertain 0 disagree	**Question answered?** 0 yes 0 no 0 partly
Question 2:	**Reason**: 0 do not know 0 uncertain 0 disagree	**Question answered?** 0 yes 0 no 0 partly
Question 3:	**Reason**: 0 do not know 0 uncertain 0 disagree	**Question answered?** 0 yes 0 no 0 partly
Question 4:	**Reason**: 0 do not know 0 uncertain 0 disagree	**Question answered?** 0 yes 0 no 0 partly
Question 5:	**Reason**: 0 do not know 0 uncertain 0 disagree	**Question answered?** 0 yes 0 no 0 partly
Question 6:	**Reason**: 0 do not know 0 uncertain 0 disagree	**Question answered?** 0 yes 0 no 0 partly
Question 7:	**Reason**: 0 do not know 0 uncertain 0 disagree	**Question answered?** 0 yes 0 no 0 partly
Question 8:	**Reason**: 0 do not know 0 uncertain 0 disagree	**Question answered?** 0 yes 0 no 0 partly

[1] **Study 3**: Checklist that was provided in the condition in which the students were asked to fill out the checklist each time that they consulted the textbook.

Appendix II Electricity Test

Name: …………………………………….
School: ……………………………………

What is the intention?
You are going to take a test about electricity. In this test you can show what you know and understand of this subject. The test consists of three units. Read carefully what you are asked to do in these units.
You have 40 minutes to take the test. Raise your hand when you are finished. The test will be picked up. Work quietly on another task.
Good luck!

Concept definition Unit

<u>What is the intention?</u>
Five[1] concepts are given on the next pages: voltage, current, electrons, electric energy and resistance. These concepts have to do with electricity.
Write down what you know about these concepts. Do this in the following ways:

1. Meaning
Try to define the meaning of the concept in your own words, or try to give the important features of the concept. In doing this you may also give an example that makes the meaning that you give clearer. Formulate your answer in the form of statements.

> For example, the concept *vibration* is given. When you only write down 'wave' it is not clear what you mean. Use complete sentences. For example:
> - vibration is moving through the air as a wave
> - a vibration has a certain frequency
> - A musical instrument produces vibrations that we hear as sound. When the vibration has a high frequency, we hear a high tone.

2. Magnitudes, units, symbols, formulas
Write down the magnitudes, units, symbols and formulas that you think belong to the concept.

3. Drawing
Make a drawing (for example, a circuit, model or diagram) to make the meaning of the concept clearer. When only a part of the electric circuit is relevant, mark this part with a circle or an arrow.

Try to show what you know of each concept in these three ways. When you have problems with one of these ways, you can leave this box empty.

[1] **Study 1**: The concept 'electric circuit' was also given.

VOLTAGE[1]		
meaning	magnitude/unit/symbol/formula	drawing
CURRENT (STRENGTH)		
meaning	magnitude/unit/symbol/formula	drawing

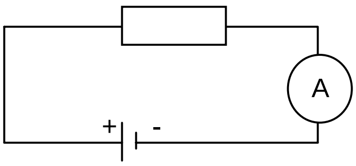
[1] In the unit of the actual test such a format was given for each concept.

Problem-solving Unit[1]

What is the intention?

Answer the questions below. Encircle the correct answer.

* Look at the circuit below.



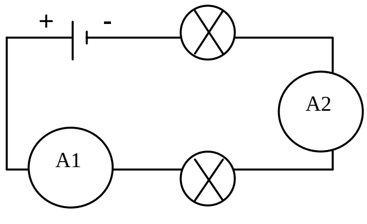
You make both the voltage and the resistance twice as large. Predict what will happen with the current strength.

A The current strength will increase
B The current strength will decrease
C The current strength will stay the same

* A bulb will shine brighter in a circuit of copper wires than in a circuit of iron wires. That is because:

A voltage goes more easily through copper
B copper contains more free electrons
C copper has no resistance at all

* Look at the circuit below. A1 and A2 are ammeters. Which statement is correct?



A A1 and A2 will read the same current strength
B A1 will read a larger current strength than A2
C A1 will read a smaller current strength than A2

[1] Some examples are given. The items in the post-test were partly the same as those in the pre-test. Others were designed as parallel items.

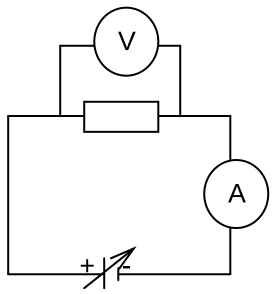
Study 1 and 2: This unit contained 6 items. Students also had to justify their answers.

Study 3: This unit contained 12 items that only asked the students to encircle the correct answer.

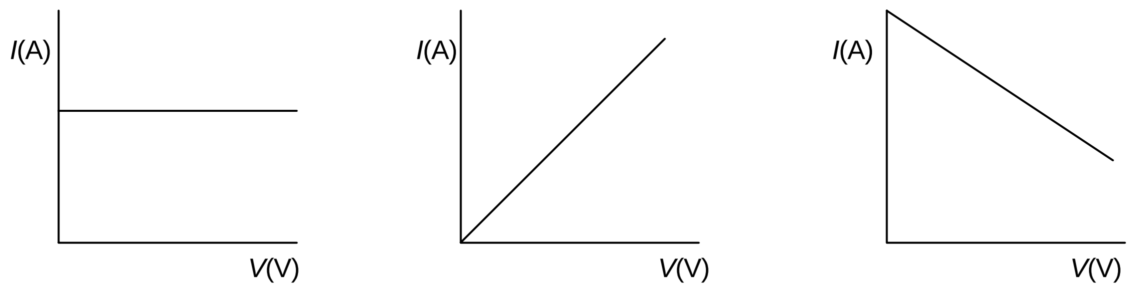
* Annet has a copper wire of 10 cm, but she wants to have a wire with a *smaller* resistance. Which wire will have a smaller resistance?

A A thicker wire of 10 cm
B A thinner wire of 10 cm
C A wire of the same thickness that has a length of 15 cm.

* Look at the circuit below.



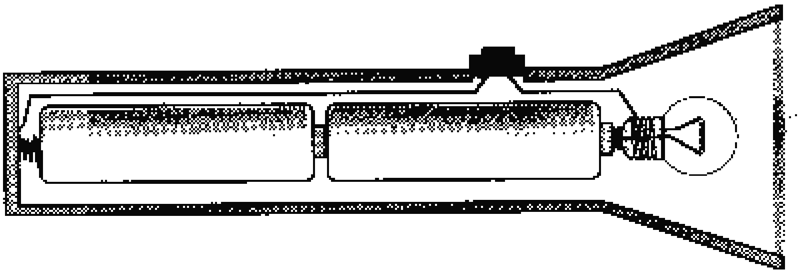
You increase the voltage. Which diagram gives an adequate representation of the relationship between the voltage and the current strength in this circuit?



A Diagram 1
B Diagram 2
C Diagram 3

Essay Question[1]

The shining of an electric torch has to do with electricity. How would you explain the shining of the electric torch with your knowledge of electricity? Try to give a *physical* explanation. Write your explanation as if it will appear in a textbook.



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[1] **Study 1 and 2**: The post-test included an Essay Question about a flat iron with the same format.

Study 3: This Essay Question was used in both the pre-test and the post-test.

Appendix III Attitude Towards Physics Questionnaire

Scale[1]:

completely agree	agree	I don't know	disagree	completely disagree
1	2	3	4	5

Questions:

1. Physics will not become my hobby.
2. In one way or another, I can't master physics.
3. I don't do anything more for physics than is necessary.
4. I am quite good at physics.
5. When we are doing physics, I am glad when the lesson is over.
6. I think that only in a few professions is physics of some use.
7. I refuse to spend much spare time on physics.
8. Our physics lessons are often fascinating and interesting.
9. Before a physics test, I am more nervous than before other tests.
10. During other subjects, I notice that physics is of some use to me.
11. Physics is important to get a job in the future.
12. During the physics lessons, I hardly ever feel nervous.
13. You can do very well without physics later on in your life.
14. I like physics.
15. In the future, I would like to have a job in which I can use physics.
16. I am not very interested in what is taught in the physics lessons.
17. In my spare time, I sometimes make an experiment that has something to do with physics.
18. Without physics, school would be much more fun.
19. I am totally fed up with physics.
20. Sometimes I do more homework for physics than we were assigned.
21. I believe physics is not of much use.
22. Most of the time I understand what is taught in the physics lessons.
23. In physics, I am more afraid to fail than in other subjects.
24. What you learn in the physics lessons is not of much use out of school.
25. I am certain about myself when I get my turn in physics.
26. During the physics lesson, the time goes by fast.
27. You can use physics for the most part later on.
28. I usually don't understand very much of our physics textbook.
29. Also in my spare time, I am sometimes working on things from the physics lessons.
30. For a lot of things that you come across everyday, physics is of some use.
31. Actually I would rather not take physics lessons.
32. I like to solve a physics problem myself.

[1] In the actual questionnaire the scale was presented after each item and a brief instruction was given.

A higher score was explained as a positive attitude towards physics. To calculate the 'attitude' score the scale on the items 4,8, 10, 11, 12, 14, 15, 17, 20, 22, 25, 26, 27, 29, 30, and 32 has to be reversed.

Appendix IVa Coding System: Coding of Communicative Functions

Transcription Notation

(…) the utterance is unintelligible

[ ] overlap in utterances (both students speak at the same time)

( ) nonverbal actions such as pointing, pasting, drawing and consultation of a textbook

(( )) remarks of the transcriber

Utterance: an utterance is distinguished from another utterance through a ‘perceptible’ pause, comma or point and has a singular communicative function. An utterance can consist of an exclamation, an unstructured string of words, a complete sentence or a sentence that is not finished.

Communicative function: the functional meaning of the utterance, the message or expectation that is communicated by the speaker.

The communicative function can be determined by means of the linguistic form of the utterance and its retrospective and prospective effect on the discourse.
The categories that are shown in the table below are based upon the coding scheme of Erkens (1997).

Category	Description and Examples
Informative	**Providing information**
Statement	Communication *These belong together: voltage and energy*
Evaluative/Argu-mentative	**Regarding previous information from a ‘meta’-level**
Argument	Logic extension reflecting reasoning
-continuation	'and' *(Current strength is resistance dependent) And voltage dependent*
-reason	'because' *(This doesn’t work) Because an electric circuit has to be closed*
-condition	'if', 'when' *(Current strength increases) When the material conducts better*
-consequent/conclusion	'then', 'thus' *(A voltage difference makes electrons move) then we have current*
-disjunctive	'or' *(Current strength depends on resistance) Or on voltage*
-counter	'but', 'no + explanation' *(A battery provides electrons) No it makes electrons move*

Evaluation	Personal opinion or judgment related to the task, one's own knowledge and understanding, one's own action(s) or to the action(s) of the partner *This is really difficult / I really don't know / You don't understand it*
Elicitative	**Asking for the other's (non)verbal response (questioning intonation)**
Question	Asking for information and checking
-disjunctive	Asking for a choice between two or more alternatives *Is that current or voltage?*
-verification	Checking own ideas or reasoning *An electron transports energy, doesn't it?*
-critical	Checking an utterance of another person *(A higher voltage results in less current strength) Less?*
-open	Asking for new information (features, meaning, examples, differences or similarities, reasons, consequences) *What is the difference between voltage and energy?*
Request for evaluation	Asking for the opinion or judgment of the other *Do you think this will be better?*
Request	Asking the other to pass an object or to repeat the utterance *Can you give me that pencil? / What did you say?*
Proposal	Suggestion for a common action or a task division *Let's draw an electric circuit / When you draw, I will write*
Responsive	**Reacting to an utterance**
Confirmation	Explicit support *Yes*
Acceptance[1]	Neutral support *Okay / Good / Mm mm*
Negation	Objection without explanation or an indignant repetition of what the other said *No / (Voltage is R) Voltage is R ((indignant))*
Repeat	repetition of the previous utterance *(The battery provides energy) Battery provides energy*
Directive	**Performing a (non) verbal instructing act to the other**
Order	*Stop drawing*
Off-task	**Not related to the task**
	How was your English test yesterday?

[1] In the second and third study acceptance were included in the subcategory 'confirmation'

Appendix IVb Coding System: Coding of Propositional Content

Proposition: utterance in which the student makes a statement about the meaning or a relation of one or more electricity concepts (see list below).
A proposition can be formulated by one student, but can also be co-constructed by contributions of two students. Also utterances in which indexical terms are used to refer to an electricity concept are coded as propositions. A proposition can have the form of a statement, an argument or a question.
The four proposition categories that are distinguished are described in the table below.
Electricity concepts: electric circuit, voltage, voltage source, current (strength), electrons, energy, electricity, resistance, the material type, length, cross-section area (or thickness), minus, plus.

Incorrect proposition: a statement about an electricity concept that is incorrect from a scientific point of view. All incorrect propositions are also coded in one of the four proposition types described in the table below.

Category	Description and Examples
Single Concept	Statement about one electricity concept *Electrons have a negative charge* *Current circulates* *Energy can be transformed into light*
Relation	Statement which relates two or more electricity concepts *Current strength is voltage and resistance dependent* *The electrons transport energy* *The longer the wire, the greater the resistance*
Concrete	Statement which relates one or more electricity concepts to a concrete phenomenon *A piece of curtain has more resistance than a copper wire* *The battery provides the voltage* *An ammeter is used to read the current strength*
Representation	Statement which relates one or more electricity concepts to another form of representation: magnitude, unit, symbol, formula, drawing, graph *Voltage is V* *You can draw a resistor as a block* *You have to put the resistance near the horizontal axis*
Incorrect	*Voltage is the number of electrons per second moving through a circuit* *A greater resistance results in less voltage* *Behind the ammeter there is less current strength than before the ammeter* *If the wire is thicker, there will be more resistance* *Current strength is in Volt*

Appendix IVc Coding System: Coding of Episodes

Episode: a meaningful sequence of utterances

To identify contingencies reflecting different types of elaborative talk, the transcripts are analyzed on an episodic level, making use of the coding on the utterance level. Because elaboration is likely to occur in question, conflict and reasoning episodes these episode types are distinguished in the coding scheme (see the table below). Elaborative episodes contain either collaborative elaboration or individual elaboration. On the content dimension the coding scheme focuses on reactions to incorrect propositions.

Episode Type	Categories
Question[1]	Answered -co-constructed elaborated answer -individual elaborated answer -short answer Not answered
Conflict	Elaborated -collaborative elaboration -individual elaboration Not elaborated
Reasoning	-collaborative reasoning -individual reasoning

[1] The distinction between co-constructed elaborated answers and individual elaborated answers was only made in the second and the third study. In the first study a category 'elaborative answers' included both individual and co-constructed elaborated answers.

Question Episode: episode that starts with a disjunctive, verification or open question about an electricity concept, and that includes the utterances that can be considered a response to the question.
A question episode ends when the following utterance cannot be related to the question and is related to another topic. When after a short intermezzo related to another topic or to procedural aspects, one or more utterances can be clearly related to the question, these utterances are also included in the question episode.
To avoid overlapping categories, questions that are part of a conflict or reasoning episode are excluded. For example, when the conclusion of a reasoning has the form of a question: *'Thus current strength depends on resistance?'*, this question is considered a part of the reasoning episode and not as the start of a question episode.

Co-constructed elaborated answer: an answer that contains more information than only yes, no, or an alternative, and that is constructed by contributions of two students.

Example:

A: but, what exactly is the resistance?	*question*
B: that means that something has difficulty going through	*statement*
B: then you used such a block in the circuit and the current strength decreased	*statement*
A: then the electrons were constrained	*argument continuation*
A: and had more difficulty going through	*argument continuation*

Individual elaborated answer: an answer that contains more information than only yes, no or an alternative, and that is given by only one student.

Example:

A: how can we use the concept electrons?	*open question*
B: they belong to energy	*statement*
B: because the electrons transport the energy	*argument reason*
B: the electrons get this energy in the battery	*argument continuation*
B: the larger the battery, the more energy	*argument continuation*

Short answer: 'yes', 'no', or an alternative.

Examples:

A: is voltage in Volt?	*question*
B: yes	*confirmation*
A: where does energy belong?	*question*
B: to electrons	*statement*

Not answered: no response to the question or a response in which the student states that (s)he does not know an answer.

Examples:

A: is it voltage or current strength?	*question*
B: the resistance belongs to the length	*statement*
A: what is the definition of energy?	*question*
B: I don't know	*evaluation*

Conflict Episode: episode that starts with a negation, a counter-argument (reacting on an utterance of the other student) or a critical question, and that includes the reaction to the uttered disagreement.

Only the conflicts that have to do with the meaning or relations of the electricity concepts are selected. A conflict episode ends when the following utterance cannot be related to the negation, counter argument or critical question and is related to another topic. Usually, the conflict ends with an agreement or a topic change. When after a short intermezzo related to another topic or to procedural aspects, one or more utterances can be clearly related to the conflict, these utterances are also included in the conflict episode.

Collaborative elaboration of a conflict: both students explain or justify their own idea and/or question the arguments given by the other.

Example:

A: I think that energy belongs to the battery	*statement*
B: but energy is lost in a resistor	*argument counter*
B: thus, energy belongs to resistance, the bulb	*argument conclusion*
A: but a battery contains energy	*argument counter*
B: it doesn't contain energy, it produces energy, doesn't it?	*verification question*
A: the electrons transport the energy from the battery to the bulb	*statement*
A: shall we draw a line from energy to the battery and to the bulb?	*proposal*
B: yes, that's okay	*confirmation*

Individual elaboration of a conflict: one student explains or justifies his or her idea.

Example:

A: the longer the wire, the greater the current strength	*statement*
B: no	*negation*
B: a longer wire means a greater resistance	*statement*
B: because the electrons must cover a longer distance	*argument reason*
B: thus a longer wire results in less current strength	*argument conclusion*
A: yes, you're right	*confirmation*

No elaboration of a conflict: the partner immediately accepts the negation or counter-argument, or the negation, counterargument or critical question is not responded to.

Examples:

A: voltage is ampere	*statement*
B: no that is current strength	*argument counter*
A: oh yes	*confirmation*
A: then I have the electrons (consults own design)	*statement*
B: the electrons first?	*critical question*
B: first comes the energy and then the electrons	*statement*
A: what does this mean, the cross-section?	*question*

Reasoning Episode: episode in which definitions, observations or hypotheses about electricity concepts (propositions) are related to each other, and that contains at least one utterance that is coded as an argument.
Reasoning that appears in the answering of a question or the elaboration of a conflict is not identified as a reasoning episode. A reasoning starts with the utterance that is further elaborated by means of an argument and ends with the last argument or verification question that is added to the reasoning. When after a short intermezzo related to another topic or to procedural aspects, one or more arguments or questions can be clearly related to the reasoning, these utterances are also included in the reasoning episode.

Collaborative reasoning: the reasoning is constructed by contributions of both students.

Example:

A: electrons have a negative [charge] (pastes)	*statement*
B: [have] a negative charge	*repeat*
A: [they are part of]	*argument continuation*
B: [they are part of]	*argument continuation*
A: atoms	
B: atoms	*repeat*
A: and the negative particles can move	*argument continuation*
B: consequently, there is a current strength	*argument conclusion*

Individual reasoning: the reasoning contains arguments of only one student.

Example:

A: wait, the electric circuit always needs energy (points)	*statement*
A: is provided by the electrons (points)	*argument continuation*
A: and these come from the voltage source	*argument continuation*
A: thus, both energy and electrons have to do with the voltage source	*argument conclusion*
B: yes (pastes concepts)	*confirmation*

Reaction to incorrect proposition: episode that starts with an incorrect proposition and that includes the response to the incorrect proposition. Incorrect propositions can be corrected, confirmed or neither corrected nor confirmed.

Correction of an incorrect proposition: the incorrect proposition is 'replaced' by a correct proposition. The correction can take place immediately after the verbalization of the incorrect proposition, but also later on in the discourse.

Example:

A: the bulb hinders the electrons	*statement*
A: thus less electrons will come back to the battery	*incorrect proposition*
A: then the current strength is lower	*argument consequent*
A: no, the current strength was always the same in a circuit, wasn't it?	*verification question*
B: yes	*confirmation*
B: because it is a serial circuit	*argument reason*
A: the electrons move slower through the circuit	*statement*
A: the electrons go back to the battery, but they lost their energy	*statement*

Confirmation of an incorrect proposition: the incorrect proposition is confirmed (for example with a 'yes' or a 'mm mm') or included in a reasoning.

Example:

A: voltage depends on the resistance	*incorrect proposition*
B: the greater the resistance, the smaller the voltage	*statement*
B: because the voltage has more difficulty going through the circuit	*argument reason*

No correction or confirmation: the incorrect proposition is not explicitly confirmed but also not corrected. The incorrect proposition is either not responded to or responded with *'I don't know'*.

Examples:

A: when you have a thick wire the resistance is high	*incorrect proposition*
B: the resistance is related to the current strength	*statement*
A: resistance is in ampère	*incorrect proposition*
B: I know nothing of all these quantities	*evaluation*
B: thus, don't ask me	*argument conclusion*

Appendix IVd Coding System: Coding of Textbook Use

The use of a textbook: one student or both students is/are reading text, looking at a picture, scanning rapidly over the text or turning over the pages.

Specification:
- line number(s) in the transcript
- the number of minutes/seconds the textbook is used
- the student(s) who consult(s) the textbook
- the textbook that is used (NO or SN)[1] and the pages that are consulted

The specifications and the coding of the textbook use in each dyad were mapped in a scheme as shown in the following example. The categories with which the textbook use is described are explained below.

Example

Line	Time	Student	Textbook	Verbali-zation	Situation	Result	Elaboration	Reading aloud	Product change
79-118	6.26	2	NO: index, p. 284, 105, 108	no	question	corres-ponding informa-tion	yes	no	yes (relation)
233	.30	1	NO: turns over the pages	yes	conflict	new in-formation	no	yes	no

Verbalization before the consultation of a textbook

Verbalization: the students verbalize their own ideas about the topic before they consult a textbook: they (try to) formulate a meaning, relationship, an experiment or explanation or they (try to) make a drawing on their own before they consult a textbook. When the students ask a question or disagree with each other, they try to answer the question or resolve the conflict first without the help of a textbook.

[1] **Study 2**: The students could consult two textbooks (NO and SN)
Study 3: The students could consult one textbook (NO)

Example

A: you would say that less resistance would mean a higher amperage

B: yes, when the voltage stays the same

A: when the voltage stays the same and R becomes less, I will increase

B: what was that formula?

B: you had two things, something multiplied by something is something multiplied with something

B: you know, I multiplied with R or something like that, V multiplied with R, and I multiplied with R (writes) or something like that had to be equal

A: no not R, it didn't contain an R twice

B: but it was something like that

A: [(turns over the pages in NO)]

B: [(turns over the pages in SN)]

No verbalization: the students do not verbalize their own ideas about the topic before they consult a textbook: they do not formulate a meaning, relationship, an experiment or explanation or do not make a drawing on their own before they consult a textbook. When the students ask a question or disagree with each other, they do not try to answer the question or resolve the conflict first without the help of a textbook.

Example

A: which one are we going to do?

A: number two?

B: that is voltage and energy

A: (turns over the pages in NO)

Situations in which a textbook is consulted

Question: a question is formulated immediately preceding the consultation of a textbook

Example

A: explanation

A: when the wire

A: what did we have?

B: the greater the length the greater the resistance

B: but why?

A: because they have to cover a longer distance?

B: maybe there is something in here (looks in NO)

Uncertainty: the talk of the student(s) reflects uncertainty about a proposition or a realization of a lack of knowledge/understanding. No explicit question is formulated.

Example

A: the material type changes the resistance

B: oh yes

A: and when the resistance becomes greater less electrons can go through, or something like that

B: [(turns over the pages in SN)]

A: [(turns over the pages in NO)]

Conflict: a conflict about a concept or a relation immediately precedes the consultation of a textbook

Example

A: the longer the wire

A: do you think that they can read this (writes)?

B: no the shorter the wire

A: no the longer

A: when it becomes longer, there is more resistance, isn't it?

A: yes it is (takes NO)

Partner is writing/drawing/reading/searching: the talk of the students gives no indication of the motive to consult the textbook, but the situation in which the textbook is consulted is one in which the partner is writing, drawing or consulting a textbook

Example

A: the larger the cross-section area, the more electrons can go through the wire

A: and the more energy

B: (writes)

A: and the energy that is supplied to the object

A: or, yes

B: [(writes)]

A: [(reads in SN)]

New part of the task: the talk of the students gives no indication of the motive to consult the textbook, but the situation in which the textbook is consulted is one in which a new part of the task is started. A new part of the task can be a new relation, a new experiment, a new table or diagram, or a new explanation.

Example

A: do we have that already, the relation between voltage and current strength?

B: no

B: (looks in SN)

Continuation: after a short interruption of the consultation of the textbook, the student continues searching or reading in the textbook without verbalizing what (s)he is looking for.

Example

A: what is the symbol of electrons?

A: released electrons

B: (takes SN) electrons

B: here, near the explanation, do we have to put the relation there?

…

B: [(erases in the diagram and writes)]

A: [(writes)]

A: (uses the index of SN and searches under the e for the word electron)

Confirmation: a student tries to confirm an idea or a proposal by information in the textbook (not in the context of uncertainty or a conflict)

Example

A: when V becomes greater, this will also become greater (points in the circuit)

A: that is that formula (points in NO)

Other: situations in which a textbook is consulted and that cannot be described through one of the above categories.

Result of the consultation of a textbook

No result: the student does not communicate information found in the textbook and/or does not change the group product with the help of the textbook. This may also be a result of an interruption of the consultation of the textbook due to an utterance of the partner which is reacted to.

Example

A: (uses the index of SN and searches under the e for the word electron)

B: oh

A: it is not in here

B: what?

A: I can't find it

Information that corresponds with the topic currently dealt with: the information that is found in the textbook and that is communicated or used to change the group product corresponds with the topic the students are dealing with. The information that is found corresponds with the current part of the task, confirms an idea or a proposal, helps with the answering of a question or with the resolution of a conflict.

Example

A: voltage, no current strength is I, isn't it?

B: I or U, I don't know

B: no U is energy

A: [(turns over the pages in NO)]

B: [(writes on own design)]

A: voltage is V (reads aloud from NO)

Information that does not correspond with the topic currently dealt with: the information that is found in the textbook and that is communicated or used to change the group product does not correspond with the topic the students are dealing with.

Example

A: next, voltage and current strength

A: (turns over the pages in SN)

A: oh, this is an experiment of resistance and the length of a wire (looks in SN)

A: we can use that

A: what did we have, the longer the wire the more resistance, isn't it?

Elaboration of the information found in the textbook

Elaboration: the information that is found in the textbook is elaborated: formulated in own words, discussed, included in a reasoning, questioned, or compared with own ideas.

Example

A: here, the longer and thinner the wire (reads aloud from SN)

B: that is resistance and the cross-section area

A: that a long thin wire resists the current more than a short and thick wire (reads aloud from SN)

A: thus, the larger and thinner the wire, the greater the resistance

B: thus the thicker the wire

A: the smaller the resistance

B: (writes)

A: and then we also have to put one over there (points)

No elaboration: the information that is found in the textbook is not elaborated

Example

A: oh, here it says (reads aloud from NO) the current in a wire is directly proportional to the voltage across the wire, as long as the resistance of the wire is constant

B: near current?

A: yes

B: directly proportional to the voltage
B: thus directly proportional
B: (writes)

Reading aloud from the textbook

Reading aloud: the student reads aloud the information in the textbook (almost) literally.

Example

A: yes, there is something about that in here
A: electric voltage has to do with energy and with charge, that is evident from the following (reads aloud from SN)
A: every charged particle has a charge that can be expressed in Coulomb (reads aloud from SN)

No reading aloud: the student does not read aloud the information in the textbook.

Example

A: (turns over the pages in NO)
B: what does it say about voltage, may I have a look?
A: yes, it only says that you have to carry out an experiment
A: it does not say what the relation is

Changing the group product as a result of textbook consultation

A change in the group product: the student(s) add(s) something in the group product (text or drawings) or change(s) something in the group product with the help of information found in the textbook.

Example

A: five constantan wires (points in NO) of the same thickness but with different lengths
B: oh yes
A: and then, measure the current strength, holding the voltage constant, in five constantan wires with different lengths (reads aloud from NO)
B: yes
A: (writes)
B: and three, we can do the same lengths but different cross-section areas
A: [(copies from NO)]
B: [then something is wrong here (takes the previous paper)]

No change in the group product: the student(s) do(es) not add something in the group product or change(s) something in the group product with the help of information found in the textbook.

Example

A:	iron conducts worse, greater resistance (reads table SN)
A:	copper has a smaller density (reads table in SN)
B:	yes, that is right
A:	and thus it has less resistance
A:	a larger density, more resistance (points in the concept map)
A:	less density, greater resistance
B:	okay
A:	I did it correct

Appendix V Publications related to the research

Van Boxtel, C. (1997). Begripsontwikkeling in interactie. In M. Meeuwesen & H. Houtkoop-Steenstra (Red.), *Sociale interactie in Nederland* (pp. 205-224). Utrecht: ISOR.

Van Boxtel, C., van der Linden, J., & Kanselaar, G. (1997). Collaborative construction of conceptual understanding. Interaction processes and learning outcomes emerging from a concept mapping and a poster task. *Journal of Interactive Learning Research, 3/4,* 341-361.

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Van Boxtel, C., van der Linden, J., & Kanselaar, G. (in press). Stimulating deep processing in a collaborative learning environment. To appear in H. Cowie, D. van der Aalsvoort & N. Mercer (Eds.), *Social interaction in learning and instruction: the meaning of discourse for the construction of knowledge*. Pergamon Press.

Van Boxtel, C., van der Linden, J., & Kanselaar, G. (accepted). Elaboration of conceptual knowledge in a collaborative learning environment. *Learning and Instruction*.

Van Boxtel, C., van der Linden, J., & Kanselaar, G. (submitted). Learning physics concepts through collaborative concept mapping. To appear in A. O'Donnell (Ed.), *Promoting thinking through peer learning. Special issue of Theory into Practice*.

Van Boxtel, C., van der Linden, J., & Kanselaar, G. (submitted). The use of textbooks as an extra tool during collaborative physics learning. *Journal of Experimental Education*.

ABOUT THE AUTHOR

Carla van Boxtel was born on 16 september 1970 in Uden (The Netherlands). She completed higher general secondary school at the Rivendell College in Uden. Then, she started to study History at Utrecht University. In 1991 she also started a study Educational Sciences at Utrecht University. In 1993 she graduated in Contemporary History and in 1994 in Educational Sciences. From 1995 to 2000 she worked as a Phd student at the department of Educational Sciences of Utrecht University. In this period, she also worked as a free-lance editor of a history textbook for secondary schools. At this moment, she is a part-time researcher at the department of Educational Sciences of Utrecht University and is doing research into computer supported collaborative learning within the domain of history. Besides, she continues her work as an editor of some textbooks and an educational Internetsite for secondary education.

OVER DE AUTEUR

Carla van Boxtel, geboren in Uden op 16 september 1970, verliep van 1982 tot 1988 het VWO op het Rivendell College te Uden. Zij ging daarna Geschiedenis studeren aan de Universiteit Utrecht. In 1991 begon ze daarnaast aan de studie Onderwijskunde, tevens aan de Universiteit van Utrecht. In 1993 studeerde ze af in de Contemporaine Geschiedenis en in 1994 behaalde zij het doctoraal diploma Onderwijskunde. Van 1995 tot 2000 was ze werkzaam als Assistent in Opleiding aan de Capaciteitsgroep Onderwijskunde van de Universiteit Utrecht. Daarnaast was ze in deze periode free-lance eindredacteur van een geschiedenismethode voor de basisvorming.

Op dit moment werkt ze part-time als post-doc aan de Capaciteitsgroep Onderwijskunde van de Universiteit Utrecht aan een onderzoek naar computerondersteund samenwerkend leren binnen het vak geschiedenis. Daarnaast werkt zij free-lance als eind- en site-redacteur aan een geschiedenismethode voor het voortgezet onderwijs.