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Ilkka Ratinen

Primary Student Teachers' Climate Change Conceptualization and Implementation on Inquiry-Based and Communicative Science Teaching

A Design Research

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ABSTRACT

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Climate change is one environmental hazard with social, environmental and economic consequences. There is still lack of knowledge how to instruct climate change for better understanding of it. This mixed method study based on design research with problem analysis and empirical and theoretical design solutions. The used design solutions seek domain knowledge about holistic, communicative and inquiry-based climate change education model based on sociocultural pedagogies. The study shows student teachers' deficient understanding of climate change and concludes how difficult it is to change student teachers' conceptual understanding of climate change. The study reveals the development of student teachers' beliefs towards the appropriate communicative inquiry-based science education as a slow process and it requires a lot of content knowledge and practical knowledge to develop, implement and evaluate complex phenomena-based learning. Domain theory reveals that although climate change is a complex and difficult phenomenon to learn and teach, versatile and recurrent communicative inquiry learning methods help to achieve better learning outcomes.

Keywords: design research, inquiry, communicative approach, practical knowledge

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PREFACE

I think that learning will never end. When I finished my first doctoral study in 2005 (Ratinen 2005) I honestly thought to do it never again. But, then I realized that my thinking of education is inadequate. I did not understand how people learn and how I should teach in order to students would achieve appropriate learning outcome. This study summarises one period of my research activity. Now I can argue that I understand *something* about how to teach science to primary student teachers. I mostly need to support students in their learning processes instead that I just teach them facts. After the first thesis I realized that systems thinking is necessary for solving environmental problems. After the present study I hope that I have understood what design research really means. On the future I will get those big ideas together. I'm thankful for all of my friends in the department of teacher education. Especially, I would like to thank Prof. Jouni Viiri and Prof. Helena Rasku-Puttonen for their support. Also PhD Sami Lehesvuori and teachers Otto Kulhomäki, Jousia Lappi and Tuukka Kokkonen have been important members in this design research team. Pero más importante que me gustaría dar las gracias a mi familia: Kirsi, Konsta, Nuutti, Greta y Tiitus. ¡Gracias y que perdóname!

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16.5.2016
Ilkka Ratinen

AUTHOR'S CONTRIBUTION

This design research was developed by the author and I have a main role in the planning, data collection, data analyses and writing of the sub-studies I-III. Viiri participated to the research planning of article II and he also commented the manuscript. Lehesvuori participated to the data triangulation of article II. Viiri attended to the research planning of article III and for commenting the manuscript. Lehesvuori and Kokkonen participated to the data triangulation of article III. Lehesvuori also commented the manuscript of article III.

LIST OF ORIGINAL PUBLICATIONS

I Ratinen, I. (2013). Student Class Teachers’ Conceptual Understanding of the Greenhouse Effect: A Mixed Method Study. International Journal of Science Education 35 (5-6), 929–955.

II Ratinen, I. Viiri, J., Lehesvuori, S. (2013). Primary School Student Teachers' Understanding of Climate Change: Comparing the Results Given by Concept Maps and Communication Analysis. Research in Science Education 43 (5), 1801–1823.

III Ratinen, I., Viiri, J. Lehesvuori, S. & Kokkonen, T. (2015). Primary student-teachers’ practical knowledge of inquiry-based science teaching and classroom communication of climate change. International Journal of Environmental and Science Education 10 (4), 561–582.

The process model used as a pedagogical basis for interactive inquiry-based teaching in sub-study II was developed in collaboration with the research team and reported in the following articles:

Lehesvuori, S., Ratinen I., Kulhomäki, O., Lappi, J., & Viiri. J. (2011). Enriching primary student-teachers’ conceptions about science teaching: Towards dialogic inquiry-based learning. Nordina 7 (2), 140–159.

Kulhomäki, O., Lappi, J., Ratinen, I., & Viiri, J. (2011). Luokanopettaja-opiskelijoiden intuitiivisia käsityksiä luonnontieteen opettamisesta. In K. Juuti, A. Kallioniemi, P. Seitamaa-Hakkarainen, L. Tainio, & A. Uitto. (eds.) Ainedidaktiikka moninaistuvassa maailmassa (pp. 146–163). Ainedidaktiikan symposium 2010. Helsingin yliopiston opettajankoulutuslaitoksen tutkimuksia 332. Opettajankoulutuslaitos, Helsinki.

Ratinen, I. (2012). Luokanopettajaksi opiskelevien kokemukset dialogisen tutkivan oppimisen toteutumisesta. In E. Yli-Panuna, K. Merenluoto, & A. Virta (Eds.), Koulu ja oppiaineiden monet kulttuurit. Ainedidaktinen symposiumi Turussa 11.2.2011 (pp. 71–85). Suomen ainedidaktisen tutkimusseuran julkaisuja. Ainedidaktisia tutkimuksia 3. Helsinki, Finland: Suomen ainedidaktinen tutkimusseura.

FIGURES

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1 INTRODUCTION

Climate change is a global environmental hazard, bringing with it huge social, environmental and economic consequences. We are now beginning to witness some of the consequences of climate change such as changes in weather patterns and the melting of polar ice (IPCC 2014). It seems evident that human beings need to study and implement both global and local solutions as means to adapting to climate change. How individuals understand and conceptualise the complexity of climate change plays a crucial role in attempts to reduce their own climatic impacts. Locally, climate change has become an issue for discussion in primary, secondary and upper secondary science classrooms, thus affecting the ability of future decision-makers to solve climate-related problems and to make appropriate and far-reaching decisions. Several European school curricula and policy documents (European Commission 2014), including those of Finland (POPS 2014; LOPS 2015), reveal the importance of developing students' decision-making skills on a scientific basis. Sharma (2011) considered science education an important element in societal responses to climate change. It follows that the way in which future teachers receive their teacher education is not irrelevant.

While climate change conditions are reported in the media on a daily basis, people's factual knowledge and conceptual understanding of the issue remain incomplete and are often misleading. Many studies have shown that student teachers know the basic facts about climate change, such as increasing Earth temperature, but that their knowledge is atomistic (Ekborg & Areskoug 2006; Hansen 2010). This is not specific only to student teachers; qualified teachers also have misconceptions and misunderstandings about climate change (Papadimitriou 2004; Miléř et al., 2012), and they probably pass their own ideas on to their pupils. Based on earlier studies (e.g. Boon 2010; Hansen 2010; Niebert & Gropengießer 2014), we know what people know about climate change, but we still lack knowledge of how to teach climate change in order to gain a better understanding of it. Studies (e.g. Jakobsson, Mäkitalo & Säljö 2009) have pointed out that in order to achieve an appropriate learning outcome, there is a need to study climate change by means of versatile methodologies such as interviews, surveys and writing tests. Similarly, Svihla and Linn (2012) maintained in their design research that middle school students can learn about climate change when the curriculum is carefully designed and teaching is based on visualisation in inquiry-based science lessons.

The study is based on the sociocultural approach to learning, which draws largely on the work of Vygotsky (1896–1934). It is not very much interested in the content of an individual's mind but on how knowledge is constructed in society, e.g. in a classroom as a social setting (Woolfolk 2012). The sociocultural viewpoint in classroom discussions on climate change describes learning as a social process and the origination of human intelligence in society or culture. Discussion is based on students' individual thinking and understanding of climate change. However, individuals' biological and psychological learning mechanisms, which are underlined by cognitive constructivism (e.g. Piaget, 1896–1980), are not the focus of this study.

In this study, climate change education is studied by means of design research. Climate change education is defined as an intentional inquiry-based and interactive teaching and learning process which improves students' scientific literacy regarding climate change. Therefore, this study focuses on the scientific principles of climate change with the aim of achieving more precise understanding of how to influence climate change learning through inquiry-based and communicative teaching. According to Lehtonen and Cantell (2015), Anderson (2012), and Fahey (2012), the aim of climate change education should, besides conceptual understanding, also be to affect personal change and societal transformation and thus a positive impact on the climate. The main objectives of climate change education, then, are to promote a common sustainable future and people's participation and skills to act towards this end from the societal and individual perspectives. Lehtonen and Cantell (2015) also recommended that climate change education pays attention to the emotions, behaviour and activities of the individual in relation to climate change (Lombardi & Sinatra 2013; Hufnagel 2015) and, as Ojala (2015) pointed out, teachers themselves need constructive strategies for coping with their emotions regarding climate change. Moreover, ethical education helps the learner to take an ethical stand on the issue of climate change and a multidisciplinary approach, such as combining art with science education, enables learners to better understand and explore their own views and feelings concerning climate change.

Despite the fact that design research (Gravemeijer & Cobb 2006; Svihla & Linn 2012) has established its place in educational research, it is a rare approach in climate change education research. Additionally, the focus of this study differs from those of previous studies as we seek to understand how to teach climate change using three theoretical and empirical design solutions. Design research enables the development of a pragmatic solution to climate change education but also helps in considering the theories behind it by systemically studying learning forms that support this successful solution. As Cobb et al. (2003) noted, design experiments can be included among the problems that students solve, the discourses that are encouraged, the participation that is established, the means that tools and related material provide and the practice that teachers can apply relations among these elements.

This design research consists of three sub-studies. Firstly, using problem analysis, it investigated student teachers' conceptualizations of climate change (sub-study I) whereby the knowledge gained was used as a content-based framework for the planning of a science education course. This course was the design object of the study. The study was framed as a theoretical design solution around the teaching of climate change and was based on the systems thinking of Bertalanffy (1972), who recognised three aspects of the systems approach. Systems science deals with the scientific exploration of systems and systems theory in the various sciences. Further, systems technology deals with applications in both computer operations and theoretical developments such as game theory. Finally, systems philosophy addresses the reorientation of thought and world-views resulting from the introduction of systems as a new scientific paradigm. Sub-study I draws on the latter in the empirical design solution, and systems thinking is conceived as the ability to recognise, describe and model complex aspects of reality as climate systems. In the present study, concept maps (Brandstädter, Harms, & Großschedl 2012) represent student teachers' conceptualisations of climate change, revealing their understanding of climate change as a system. The interactional graphs further expose how student teachers' knowledge is actualised in classroom communication. Together, these methods draw a more accurate picture of climate change education as a system. The important aspect of systems thinking is the ability to identify important elements of the climate system and the varied interdependency between these elements.

Secondly, a theoretical design solution was developed to teach climate change. A series of communicative inquiry-based teaching lessons were formed on the basis of the model developed by Lehesvuori et al. (2011). The model was further simplified in sub-study II, the focus of which was to reveal, using an empirical design solution, student teachers' pre- and post-conceptualisations of climate change (i.e. before and after they had participated in a series of four science lessons). In sub-study II, learning was considered as a process that includes sociocultural aspects and consisted of reviewing or relocating new information within students' existing models (see, e.g. Driver, Asoko, Leach, Mortimer & Scott 1994). Here, the scientific and social representation depends not only on the quality of the scientific information but also on how such information is presented, processed and applied collectively (Meira2006). The discussion in the inquiry-based science lessons was analysed on the grounds that learners' subject content knowledge was related to their ability to give appropriate scientific explanations (e.g. Childs & McNicholl 2007). Further, it was assumed that students' communication in the science classroom was more developed if they had internalised content knowledge about science.

We still lack understanding of how teachers' practical knowledge, i.e. their beliefs about the goals, values and principles of science education (Simmons et al., 1999; van Driel, Beijaard & Verloop 2001; Meijer, Verloop & Beijaard 2002; Meijer, Zanting & Beijaard 2002; Lotter, Harwood & Bonner 2007), influence their teaching on climate change in primary schools. This study (substudy III) addresses this deficit through four inquiry-based lessons about climate change that were developed by student teachers for four elementary school classes. Using a communicative approach, the last empirical design solution revealed how they conceptualised inquiry-based science teaching in their lesson planning and implementation.

This study summaries a cyclic design research project (Edelson 2002, 2006) and includes three empirical case studies. It seeks domain knowledge about holistic, communicative and inquiry-based climate change education models based on sociocultural pedagogies. The study concludes with a look at student teachers' understanding of climate change. It reveals the development of students' beliefs about the appropriate communicative inquiry-based science education. Finally, it presents domain theory relating to how to teach climate change in primary teacher education.

2 DESIGN RESEARCH

Over the last three decades, design research has evolved into an accepted paradigm of educational research (Collins 1992; Anderson & Shattuck 2012; Pernaa 2013). As a ubiquitous concept used as much for optimizing industrial processes as for developing teaching and learning sequences, Wang and Hannafin (2005, 6-7) define design research specifically in education as follows:

> …"a systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories."

The importance of design research is clear from its inclusion in various handbooks of education research (Schoenfeld 2006). Anderson and Shattuck (2012) define design research as a methodology that seeks to increase the impact, transfer and translation of education research into improved practices generalizable at the larger scale. In addition, it guides, informs, and improves both practice and research in educational contexts. According to Sandoval (2014), design research leads to both improvement in practice and to theoretical refinement. These improvements include design cycles, enactment, analysis, revision and attempts to link the processes of enactment to outcomes of interest.

In design research, theory-driven, creative and practicable solutions to learning and teaching problems are designed in an iterative process that is finally tested in a classroom situation. Design research aims to improve educational settings through systematic, flexible and iterative theoretical analysis, planning, design and implementation, which help create rules and theories for real-life situations (Wang & Hannafin 2005). A cyclical design research project typically combines qualitative and quantitative study methods (Sandoval & Bell 2004).

According to Edelson (2002; 2006), design research produces knowledge about design procedure, problem analysis and design solutions. The design procedure is the decision that seeks to provide an answer as to how to continue the design. In the present study, design procedure was developed as a cyclical process in which theoretical and empirical design solutions steered the design research in versatile ways.

Edelson (2002) has criticised educational research as lacking detailed guidance for teachers to organise teaching. As a result, he argues that it is necessary to construct a model, or a problem analysis, which can be used to investigate the nature of the design context. The aims of the analysis are to find out the needs and goals of the design. In the present study, the problem analysis focused on the elements that should be considered in climate change education. In other words, the problem analysis guided the present study by focusing on those design elements that can be expected to work in design solutions for teaching climate change and on how these issues can be handled in classrooms.

In design research, design solutions represent decisions about the design itself and solutions that are generated in the context of the design. In this study, three theoretical and empirical design solutions were constructed. The study explores the core ideas related to teaching climate change and the methods to be used from a theoretical perspective. The empirical design solutions seek to give student teachers an understanding of climate change and appropriate ways to teach it. Throughout this research project, the evaluation of prior design solutions (Phase 1 and 2 in Figure 1) helped the development of new design solutions, based on the topic studied earlier. Empirical design solutions were compared with the problem analysis, theoretical design solutions and the aims of the study (Edelson 2002). To understand the effects of theoretical and empirical solutions on climate change teaching, this study used the results of sub-studies I and II to reveal practical teacher knowledge in sub-study III.

Cobb et al. (2003) have pointed out that design research is carried out to develop theories as well as to produce empirical research. Design research develops theories about both the process of learning and the means designed to support that learning by developing either local instruction theories or theoretical frameworks that address more encompassing issues (Gravemeijer & Cobb 2006). According to Edelson (2002; 2006), three types of theories can be developed through design research: domain theory (*descriptive* knowledge about the problem to be solved through design), design frameworks and design methodologies. These three types of theories must be developed in every design research project, although, in practice, they may not be explicit, conscious or formally articulated.

There are two types of domain theory in design research: context and outcomes theory. According to Edelson (2002; 2006), context theory characterises the challenges and opportunities in a specific teaching and learning context, such as a description of the needs of certain students, the nature of the particular subject matter, or the organisation of an educational institution. Outcome theory describes answers to the desired outcome of the successful testing of the design solution (Edelson 2002; 2006). Throughout the design research process, the designers' knowledge of the requirements for a successful design solution continues to increase because outcome theory explains why a designer should choose particular elements for a design in one context and other elements in another. In this study, context theory relates to teaching climate change in primary school education and discusses challenges to its implementation in phenomena-based teaching. In this study, inquiry-based learning is a parallel concept with phenomena-based learning. Hence, inquiry is a means for phenomena-based learning, wherein learners identify and address certain questions, such as how to minimize their own climate impact, and then design and carry out investigations on the topic and communicate their results. In addition, the study generates outcome theory and discusses the elements that are associated with successful climate change education.

In this study, the design framework is a generalised description of the design solution. This provides information for other researchers dealing with similar problems to design similar solutions for their own topics and contexts. Design methodology provides procedural guidelines that support successful design solutions.

3 DESIGN PROCEDURE

This study adds to knowledge about the design process of teaching climate change. Figure 1 represents the cyclical design procedure as a whole. It begins with a theoretical problem analysis of the climate change concept. The problem analysis leads through three design solutions to a domain theory. Three design solutions are needed since, for instance, the student teachers' conceptualization of climate change alone provides an sufficient basis for a design solution for teaching about climate change. Besides teacher students' ideas, we need understanding about how these ideas incorporate into classroom teaching in order to from a domain theory. The theoretical background to the design solutions is described in Chapter Six, with the empirical design solutions outlined in Chapter Eight. The methodologies used in empirical design solutions are content analysis, survey and statistical analysis, concept mapping, communication analysis, and stimulated recall interviews.

Based on the design solutions, a domain theory was developed for this study. Each design solution generated a number of aspects to be considered in climate change education. A context theory was developed in Phase 1 (Figure 1), i.e., the challenges to teaching climate change as a systemic phenomenon. An outcome theory was generated in Phase 2, i.e., the elements of successful climate change education.

The demand for this design research arose from a need to develop inquiry-based science teaching and learning aspects for science education courses. Climate change was chosen as a topic because of its multidisciplinary nature and its importance in today's world. The problem analysis examined the way that student teachers conceptualise climate change and developed design solutions for teaching climate change using systems thinking (sub-study I). This has been a lengthy process, with the first results published in 2008 (Ratinen 2008). In the first sub-study, student teachers' ideas were explored in three different science education courses over a three-year period. In that study, the way that student teachers conceptualise climate change was statistically analysed to illustrate their general knowledge of climate change.

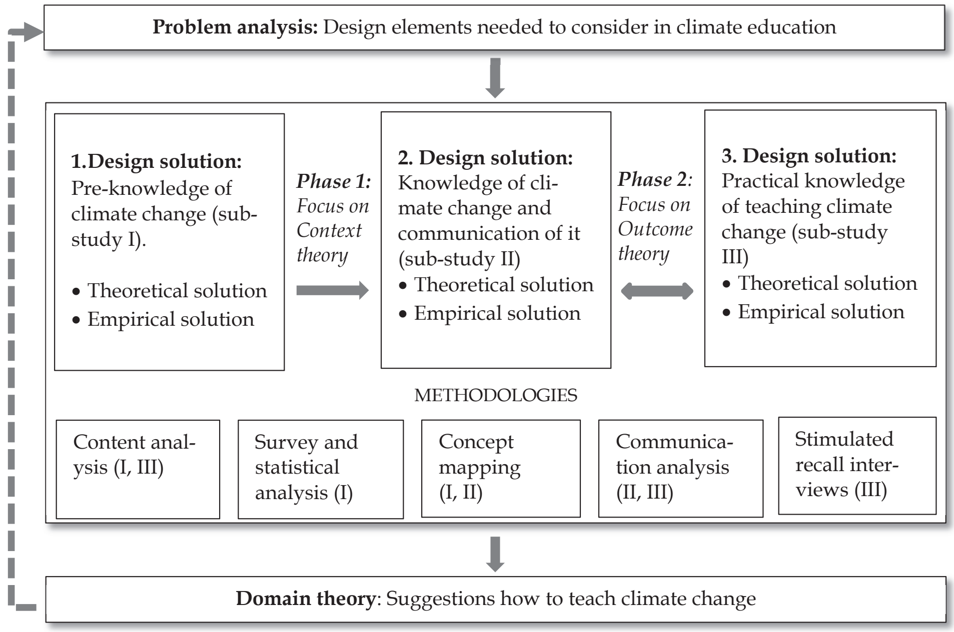


FIGURE 1 Schematic representation on design procedure (modified after Edelson, 2002; 2006).

An inquiry-based process model was developed during an S-TEAM project funded by the European Union (Lehesvuori et al. 2011; Kulhomäki, Lappi, Ratinen & Viiri 2011; Ratinen 2012). The process model provided a pedagogical basis for the first development phase of the design procedure. The model was included in an interactive inquiry-based teaching model of climate change. Course teaching was also based on a systems thinking model, developed using ideas from the previous problem analysis. The outcomes of this development phase comprised concept mapping and the communicative approach used in sub-study II.

The second development phase of the design procedure consisted of an interactive inquiry-based science teaching model for teaching climate change in primary schools. This was a cyclical phase where student teachers developed the project. They studied the principles of communicative inquiry-based science teaching and then implemented the ideas they had learned in the real primary school environment. Finally, they evaluated how successful they had been in delivering instruction. A core element of the science education course was that students study the teaching of one science topic in relation to climate change (polar bears, the greenhouse effect, the life cycle of porridge, climate change and temperature zones – for more information, refer to sub-study III) for the duration of one academic year. Most science education course content supports this study project. The students' study project includes content analysis, finding out pupils' ideas about the topic, and identifying, selecting or creating the most appropriate presentations and teaching strategies represented in sub-study III. Here, we followed the model of educational reconstruction (Duit, Komorek & Wilbers 1997; Duit, Gropengießer & Kattmann 2005). Finally, we explored the student teachers' practical knowledge and how they conceptualised inquiry-based science teaching in their lesson planning and implementation of climate change teaching (sub-study III). The case study method was selected in sub-studies II and III because it makes possible a deeper analysis of a particular group in the context of climate change.

4 RESEARCH AIMS

As described in the introduction, a lack of understanding persists as to how learners construct their knowledge of climate change through instruction. The main aim of the present study was to use design solutions to develop a domain theory for climate change instruction. The domain theory seeks to find examples for teaching climate change. It also seeks to examine student teachers' practical knowledge of purposeful, communicative inquiry-based science teaching.

In this design research, the design principles are not intended as recipes for success, but to help others select and apply the most appropriate substantive and procedural knowledge to design climate change education and develop tasks to support that end. This study consists of the following research aims and design solutions:

- Design solution 1: How do primary student teachers conceptualise climate change (sub-study I)?
- Design solution 2: How does teaching based on the process model affect primary school student teachers' understanding of climate change as shown by communication analysis and pre- and post-concept maps (sub-study II)?
- Design solution 3: How can primary school student teachers' practical knowledge of the communicative and inquiry-based teaching of climate change be implemented in the primary school science classroom (sub-study III)?

5 PROBLEM ANALYSIS OF CLIMATE CHANGE CONCEPTUALISATION

Problem analysis identifies the needs and goals that represent design issues for teaching climate change (Figure 1). The problem analysis presented in this chapter is based on a theoretical analysis of how people conceptualise climate change. The chapter also describes the design elements that need to be considered in climate change education.

Despite the fact that the issue of climate change has a daily presence in the media, people's factual knowledge and their conceptual understanding of climate change is often incomplete and confused. Many people regard the greenhouse effect merely as an environmental problem and not as a phenomenon that regulates the earth's climate and keeps its temperature relatively stable, thus making life on the planet possible.

Many researchers have found that learners know the basic facts about climate change, such as the increasing temperature of the earth, but that their knowledge is atomised and distorted (Boyes & Stanisstreet 1997; Meira 2006; Johnson et al. 2008; Ratinen 2008; Jakobsson, Mäkitalo & Säljö 2009; Taber & Taylor 2009; Boon 2010; Hansen 2010; Bell, Matkins & Gansneder 2011; Liarakou, Athanasiadis & Gavrilakis 2011; Ratinen 2013; Ratinen, Viiri & Lehesvuori 2013; Reinfried & Tempelmann 2014; Niebert & Gropengießer 2014). It is not only students but also teachers who have misconceptions and misunderstandings about climate change (e.g., Papadimitriou 2004; Miléř, Hollan, Válek & Sládek 2012). In addition, teachers probably pass on their own ideas to their pupils. Hermans (2015) points out that although teachers understand climate change as a system, their understanding can be incorrect.

Many studies (Table 1) show that it is common to confuse the greenhouse effect and climate change with the depletion of the ozone layer. Scientifically, the connection between climate change and ozone depletion is not strong (IPCC 2014). The problems of distinguishing between the greenhouse effect and ozone depletion may be due to problems in distinguishing infrared (IR) from ultraviolet (UV) radiation or even radiation from thermal energy (Boyes & Stanisstreet 1997; Hermans 2015). Many primary school children think that the environment is deteriorating, that plants and animals are being infected by pollution, and that the air is becoming dirty, thereby preventing heat from being re-radiated thus making the climate hotter (Koulaidis & Christidou 1999). Jeffries, Stanisstreet and Boyes (2001) found that students had a greater number of misconceptions in more recent studies than in studies made 10 years earlier. Groves and Pugh (2002) found that students held on to their misconceptions as to the cause of climate change even after instruction. According to Andersson and Wallin (2000), students cannot distinguish the greenhouse gases correctly and, for example, believe that chlorofluorocarbons (CFCs) are responsible for climate change because they destroy ozone and help enlarge the ozone hole that allows UV rays to reach the earth.

With regard to environmental education, it is interesting that many people link climate change with the results of human action such as littering (Nevanpää 2005). Indeed, studies of student beliefs about global environmental problems indicate that they do not fully understand the fundamental societal changes (relating to the economy, business activities, infrastructure, social institutions, and the environment) that would occur as a result of a drastic reduction in carbon dioxide (CO_2) emissions (Anderson & Wallin 2000; Hermans 2015). In addition, students failed to adequately connect climate change to their own behaviours (Hermans 2015). Lester, Ma and Lambert (2006) point out that pupils with scientifically correct knowledge of climate change tend to be more active with regard to opposing climate change. Their finding that pupils gained better science knowledge after instruction show the importance of education in this field.

TABLE 1 Students’ conceptualizations of the greenhouse effect and climate change.

Conception	Research
Climate change is not understood as a change of radiation balance.	Koulaidis & Christidou 1999; Anderson & Wallin 2000; Nevanpää 2005; Shepardson, Niyogi, Choi & Charusombat 2011; Niebert & Gropengießer 2014; Hermans 2015
Climate change is causally related to ozone depletion.	Boyes & Stanisstreet 1997; Koulaidis & Christidou 1999; Ekborg & Areskoug 2006; Jeffries, Stanisstreet, & Boyes 2001; Papadimitriou 2004; Nevanpää 2005; Hermans 2015
Climate change is confused with other phenomena.	Boyes & Stanisstreet 1997; Anderson & Wallin 2000; Shepardson, Niyogi, Choi & Charusombat 2011
Every environmentally harmful action causes climate change.	Gowda, Fox, & Magelky 1997; Fisher, 1998; Papadimitriou 2004; Nevanpää, 2005
Greenhouse gases are understood insufficiently.	Fisher 1998; Koulaidis & Christidou 1999; Anderson & Wallin 2000; Ekborg & Areskoug 2006; Papadimitriou 2004; Shepardson, Niyogi, Choi & Charusombat 2011
The influence of climate change on ecology and society is not understood.	Fisher 1998; Anderson & Wallin 2000; Nevanpää 2005; Hermans 2015

6 THEORETICAL DESIGN SOLUTIONS

Design solutions seek to provide answers to the kinds of questions raised in the context of the design. This section outlines theories used in empirical design solutions and explores student teachers' existing knowledge of climate change (Figure 1, Design solution 1). For more details, refer to sub-study I and Ratinen (2008). The systems thinking model of climate change education is presented in order to illustrate the scientific context behind the design of the science education course.

The design research also consists of a theoretical design solution as to how to gather information for design research. The section describes the main theories of communicative inquiry-based science teaching and practical teaching knowledge. For more information, refer to sub-studies II and III. Empirical design solutions are described in Chapter Eight.

6.1 Theoretical design solution 1: systems thinking in climate change education

Sociocultural aspects should be considered as part of educational systems thinking (Jacobson & Wilensky 2006; Ratinen, Viiri & Lehesvuori 2013). Complex systems such as climate change can be taught in the sociocultural context via three central dimensions: (1) network thinking using concept maps, for example; (2) thinking with models such as illustrative models of climate change; and (3) system-compatible actions such as teaching about the impact of incoming radiation on the earth's systems (see more about the dimensions in Ossimitz 2000). Ben-Zvi Assaraf and Orion (2005; 2010) identified eight characteristic aspects of systems-level thinking: (1) identifying the components and processes of a system; (2) identifying processes that create relationships between system components; (3) constructing a framework of relationships; (4) drawing general conclusions; (5) understanding that a given relationship can impact other relationships; (6) knowing that there can be hidden dimensions that affect the system; (7) understanding the cyclical nature of systems; and (8) recognising that systems can change over time. These aspects of systems-level thinking were considered when devising lesson plans for the current study. Ben-Zvi Assaraf and Orion (2010) have pointed out that although systems thinking is regarded as a high-order thinking skill, it can be developed even in primary schools, at least to a certain extent. Evagorou et al. (2009) have pointed out that primary school children have the potential to develop systems thinking skills by using simulations.

Climate change as the accelerated greenhouse effect (Figure 2) represents a serious problem where the combined effect of the abiotic and biotic environment is often difficult to recognise (Davies 2004). Scientifically, climate change is caused by elevated levels of greenhouse gases, which contribute to the additional absorption and emission of long-wave radiation in the surface troposphere system.

We can understand the ontology of climate change by understanding the relationships between climate system components. In this study, the systems thinking model of climate change is represented by seven scientific processes (sub-study I). When categorising the responses of the present study's respondents, the identification of these key processes was used to discern different levels of understanding and to help plan the scientific teaching of climate change. The following processes were described.

Model processes

P1: Wave model. The earth receives energy from the sun mainly in the form of visible light. Reflected short-wave radiation is distinguished from emitted long-wave radiation.

P2: Particle model. Photon energy is directly proportional to wave frequency, where a wave consists of discrete packets of energy called photons. The particle model describes how photons are emitted and absorbed by charged particles.

P3: Black body radiation. The earth emits energy into space in the form of IR radiation.

Molecular processes

P4: The atmosphere has different abilities to absorb radiation. The atmosphere absorbs IR radiation using photons, which cause vibration and rotation of the greenhouse gas molecules. Thus, radiation is converted into heat energy. The molecules of the greenhouse gases are able to vibrate because of their symmetry. These vibrations create a transient dipole moment. As a result, greenhouse gases can absorb and emit IR radiation.

Figurative processes

P5: Incoming and outgoing radiation may be influenced in different ways by the atmosphere.

P6: Different gases in the atmosphere have different abilities to absorb electromagnetic radiation at different wavelengths. Ozone is not a greenhouse gas in the stratosphere (UV absorption) but it accelerates the greenhouse effect in the lower troposphere.

P7: The increasing concentration of gases in the atmosphere may be affected by positive radiative forces.

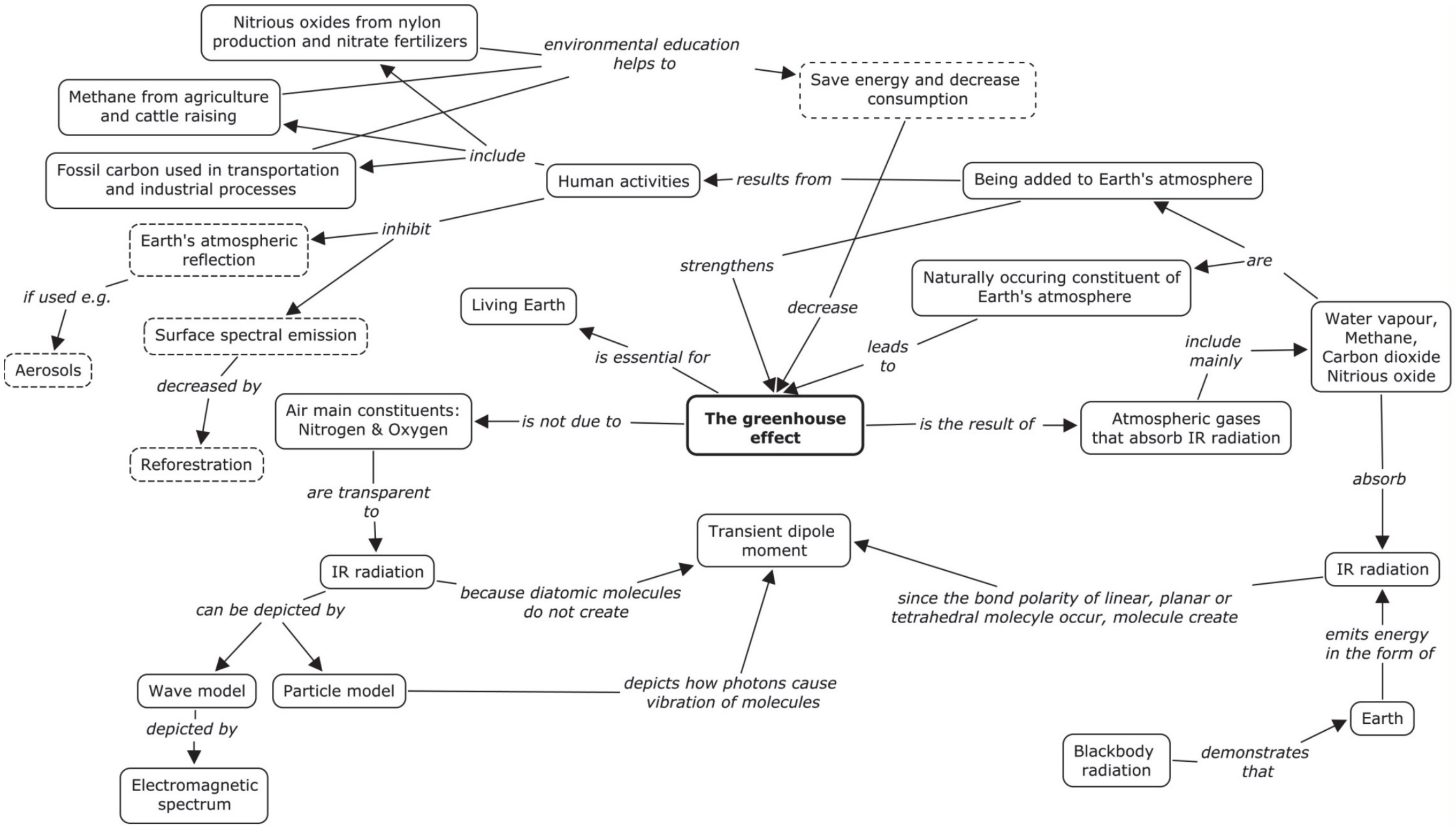


FIGURE 2 Simplified concept map related to the greenhouse effect. Boxes drawn by dash line depict some solutions for the mitigation of climate change

Accordingly, climate change is not caused by the physical and chemical features of the sun's IR radiation and greenhouse gases but by the way these features interact. In this study, concept mapping refers to the technique of schematically illustrating the students' systemic knowledge of the elements of the greenhouse effect and the interdependencies between these elements in order to facilitate meaningful learning (Novak 1990; Novak & Cañas 2008). The technique stems largely from Ausubel's Theory of Meaningful Learning (Ausubel, Novak & Hanesian 1978).

6.2 Theoretical design solution 2: communicative inquiry-based teaching and learning

Tiberghien, Vince and Gaidiox (2009) have pointed out how important it is to distinguish between general philosophical theories and the theories that do real work. There are many factors that influence learning, such as different types of classroom activity, the duration of each activity and the various possibilities of class organisation. In design research, communication analysis can produce more detailed knowledge about learning particular topics. In addition, sociocultural theory can be enriched with specific theories such as theories about using models in science education (Tiberghien, Vince & Gaidiox 2009).

Although inquiry-based learning can provide a very suitable context for various forms of communications, the danger remains that the approach will not be applied as intended. Too often, the teacher may be excessively concerned with supplying the right content and so fail to incorporate the pupils' views into the classroom discourse. To avoid such shortcomings, teachers must be aware of the different aspects of the communicative approach (Mortimer & Scott 2003; Lehesvuori et al. 2013), especially the dialogic dimension, which takes pupils' views into account and works with them, free of any evaluative tone.

The basic principle driving inquiry-based learning is that this approach can more effectively prepare pupils for future challenges and supports a better understanding of science and the general conduct of science (Lederman, Antink & Bartos 2014). Therefore, it can be postulated that inquiry also supports systems thinking development.

Based on the theories of Akkus, Gunelb and Handc (2007) and Minner, Levy and Century (2010), pupils participating in inquiry-based teaching have been shown to achieve better learning outcomes than those in traditional courses. A controversial argument related to inquiry-based learning from Abrahams and Millar (2008) and Hodson (2014) has suggested that doing experiments alone does not lead to better learning outcomes. In order to support pupils' learning, teachers must be more aware of the different phases (e.g., Bybee et al. 2006, 5E) and aspects of inquiry-based learning. Furtak, Seidel, Iverson and Briggs (2012) point out that pupils who participate in inquiry-based teaching with teacher-led activities have larger effect sizes than those with student-led conditions. In addition, there is no single way to carry out inquiry, but it may entail different levels of openness, as Banchi and Bell (2008, 27) have suggested:

- *Confirmation inquiry* is useful when a teacher's goal is to reinforce a previously introduced idea; students are provided with a question and procedure for confirming or reinforcing a previously learned idea or practicing the specific skills of data collection and recording.
- In *structured inquiry*, the question and procedure are posed by the teacher, but students generate an explanation, supported by the evidence they have collected.
- In *guided inquiry*, the teacher provides students with only the research question, and students design the method to test both the question and any resulting explanations.
- At the highest level of openness, *open inquiry*, students have an opportunity to act like scientists: deriving questions, designing and carrying out investigations, and communicating their results.

Inquiry-based science education can use different levels of openness and these levels can be studied within Mortimer and Scott's (2003) communicative framework. This accommodates both dialogic and authoritative approaches in the science classroom. Classroom discourse consists of four categories, generated from the combination of two dimensions: interactive/non-interactive and authoritative/dialogic (for more details, see sub-study II). Within these categories, the communicative approach addresses both the everyday understanding or prior knowledge of learners and the authoritative view of science. The interactive/non-interactive dimension indicates the different ways in which teachers can use communication, whether through whole-class discussions, question/answer sessions or lecturing. Here, the closing down phase is potentially very important; for instance, if discussions are opened up by a dialogic approach, in which learners are given the opportunity to work with different ideas, discussions should also at some point be closed down by advancing an authoritative view.

In summary, communicative inquiry-based science teaching and learning holds that it is important for pupils to consider their own ideas and arguments alongside experimental exercises, and that teachers must be sensitive in collecting pupils' ideas at the appropriate moment and guiding students at other moments by providing relevant information.

The process model (Table 2) developed in design phase 1 combines the ideas of both inquiry-based teaching and communication analysis, accommodating all levels of openness of inquiry. The *initiation phase* includes probing pupils' preconceptions. Although preconceptions might at this point be viewed as misconceptions, pupils should be given the opportunity to express them. Using inquiry-based teaching, the teacher can reveal these (mis)conceptions by employing a dialogic approach and opening up problems to inquiry. At a later stage, the views can be further reflected on, using the results of the executed inquiry.

The *practice phase* includes planning, executing and reflecting on the results. Hypotheses are made and tested, and results are discussed among peers. The role of the teacher should be more that of tutor than director, thus laying the groundwork for meaningful planning and inquiries. Although pupils are expected to do the thinking, the teacher can still raise questions that further guide pupils' work and thinking. It should be emphasised that, in this phase, the teacher should particularly encourage pupil-pupil interaction. The *reviewing phase* is essential to achieving educational goals. Although more authoritative communication is emphasised in this phase, preconceptions and misconceptions should be reviewed against scientific results and theories to make explicit the connections between views (e.g. everyday views and the scientific view) and possible gaps in previous thinking. Since different ideas are still being considered, the dialogic approach remains, but the authoritative approach should still be implemented when drawing final conclusions about the content and about the procedure itself. For meaningful learning of science (Scott & Ametller 2007), when problems are opened up (dialogic approach) they should subsequently be closed down (authoritative approach).

TABLE 2 A process model for planning an inquiry-based learning sequence, showing the learners' action and the classroom communication appropriate to each phase.

	Inquiry-based learning [1)]	**Communicative approach** [2)]
Initiation phase	Learners are engaged by scientifically oriented questions. Learners give priority to evidence.	Opening-up phase: Dialogic and interactive Dialogic and non-interactive
Practise phase	Learners formulate explanations from evidence.	(Emphasis on pupil-pupil interaction)
Reviewing phase	Learners evaluate their explanations in light of alternative explanations. Learners communicate and justify their proposed explanations.	Closing-down phase: Dialogic and non-interactive Authoritative and interactive/non-interactive

Notes. 1) NRC (2000); 2) Mortimer & Scott (2003); Scott & Ametller (2007); Lehesvuori et al. (2011).

The process model was used in this study to analyse the extent to which inquiry-based teaching and the communicative approach were successfully implemented in a science education course and in four primary school classes.

This study was informed by the sociocultural approach, which is important in communicative inquiry-based teaching and learning (Mortimer &

Scott 2003). Inquiry-based teaching has become increasingly popular in science teaching and professional development programmes (e.g., Luera & Otto 2005; Akerson & Hanuscin 2007; Hodson 2014; Feng & McComas 2015), especially following the outlining of these approaches by the U.S. National Science Educational Standards in 2000 and 2014 (National Research Council 2000; 2014). One limitation of these programmes is that they tend to neglect the dialogic aspect of inquiry-based science teaching. In addition, professional development programmes often fail to access student teachers' pre-existing needs for professional development (Chval, Abell, Pareja, Musikul & Ritzka 2008). The guidelines for inquiry-based approaches are in many ways related to dialogic teaching but the descriptions involved are often uninformative. A deeper understanding of complex interactions is needed in inquiry-based science teaching (Oliveira 2009).

6.3 Theoretical design solution 3: teacher's practical knowledge

In this study, the teacher's practical knowledge (i.e., their beliefs about the goals, values and principles of the science education of climate change) constitutes a framework for design-based study (sub-study III). It is important to know more about student teachers' practical knowledge because a lack of understanding persists with regard to how teachers integrate knowledge from different sources, such as inquiry-based teaching and the communicative approach, into the conceptual frameworks that guide their actions in practice.

Teacher growth is a process of the construction of various knowledge types: content knowledge, pedagogical content knowledge and practical knowledge. According to Shulman (1987), content knowledge represents teachers' understanding of the subject matter taught, whereas pedagogical content knowledge is the knowledge needed to make the subject matter accessible to students. It is known that insufficient content knowledge leads to inappropriate teaching practices (e.g., Gruenewald 2004). In their studies of student teachers' content and pedagogical content knowledge, Käpylä, Asunta and Heikkinen (2009) and Kleickmann et al. (2013) found a close relationship between the two. More recently, Alonzo, Kobarg and Seidel (2012) have studied teachers' pedagogical content knowledge by using video analysis and have pointed out that teachers with strong content knowledge need additional knowledge to translate content knowledge into a form useful for teaching.

In contrast to these studies, the present study does not address the knowledge needed by a teacher as an advisory script for how to implement a classroom session or lesson plan and, in consequence, no detailed analyses of student teacher content or pedagogical content knowledge of climate change are offered here. Instead, this study focuses on the practical knowledge (Table 3) that guides teacher actions in the classroom, where their beliefs about the goals, values and principles of education play a very important role (Simmons et al. 1999; van Driel, Beijaard & Verloop 2001; Meijer, Verloop & Beijaard 2002;

Meijer, Zanting, & Beijaard 2002; Lotter, Harwood, & Bonner 2007). Connelly, Clandinin and He (1997) have pointed out that a teacher's practical knowledge resides in the teacher's past experience (their own school history), in the teacher's present mind and body (e.g., based on their level of educational achievement) and in their future plans and actions. In this sense, even novice student teachers without lengthy teaching experience have some practical knowledge, based on their own history.

This study focuses on teacher beliefs (Lotter, Harwood & Bonner 2007). According to Hollingsworth (1989) and Pajares (1992), teacher beliefs often include information about students, learning, and instructional strategies. For instance, teachers may believe that they need to transmit knowledge to passive students so that those students will be better prepared for tests. Otherwise, teachers may have particular beliefs about inquiry-based teaching strategies such as lab work, as the results of this study will reveal.

Practical knowledge includes elements of formal knowledge within the teaching context (Table 3). In the present study, such elements are derived from the participating student teachers' lesson plans for using inquiry-based science education and communication in the classroom. For novice science teachers, their practical knowledge often consists of elements that are not integrated (van Driel, Beijaard & Verloop 2001). This lack of integration is often evident in novice teachers' teaching, for instance, in the differences between their personal beliefs about science teaching and their own actual classroom practice (e.g., Simmons et al. 1999).

TABLE 3 Description of practical knowledge. Type I-III are modified from Meijer, Verloop and Beijaard (2002) and Schepens, Aelterman, and Van Keer (2007).

Practical knowledge type	**Description**	**Student teachers' *beliefs* in their lesson plans**
Type I	Focus on teaching strategies and content	• The goal was to use dialogic teaching. • Values and principles of inquiry-based teaching were included partly in the lesson plan. • Three-part structure of the process model was included incompletely in the lesson plan.
Type II	Focus on individual learners	• The goal was to use collaborative learning. • Values and principles of inquiry-based teaching were included in the lesson plan. • The inquiry itself remained incomplete within the three-part structure of the model.
Type III	Focus on inquiry-based teaching	• The goal was to use diverse communication, and inquiry-based teaching methods were quite well known. • Values and principles of inquiry-based teaching were included in the lesson plan. Three-part structure of the model was well included in the lesson plan.

7 RESEARCH METHODS FOR EMPIRICAL DESIGN SOLUTIONS

The methods (Figure 1) used in this study are described in more detail in Table 4. As a mixed methods study, both quantitative and qualitative methods were used. In sub-study I, statistical generalisations were made of the way that student teachers conceptualise climate change. Those generalisations, together with the findings of theoretical literature (problem analysis), form the basis of teaching in sub-studies II and III, which are qualitative in nature. Methods selection based on research questions. Both quantitative and qualitative methods were familiar for the researchers.

TABLE 4 Research methods classified by Sub-studies.

Sub-study	**Source**	**Methods**	**References**
I	Open questionnaire (n=275) Survey (n=275)	Mixed methods: QUAL->QUAN QUAL: concept mapping QUAN: KW-ANOVA, PCA, Pearsson's *r*, Cohen's *d*	Novak 1990; Novak & Cañas 2008; Creswell & Plano Clark 2005; Cohen 1988
II	Essays and drawings (n=20) Video recorded science class (tot. 12 h), (n=4)	Concept mapping Communication analysis	Novak 1990; Novak & Cañas 2008; Mortimer & Scott 2003
III	Lesson plans (n=4) Video recorded class (tot. 8 h), (n=4) Group interviews (n=4)	Content analysis Communication analysis Stimulated recall interview	Neuendorf 2001 Mortimer & Scott 2003; Lehesvuori ym. 2013 O'Brien 1993

7.1 Design and data analysis in design solution 1

In order to obtain data for design solution 1, a mixed methods approach was used. Three groups (2003, 2004, 2005) (n=275) of second-year Finnish primary school student teachers were asked to complete an open-ended and closed-form questionnaire (Appendix 1). As the recent studies reveal, learners' conceptualization of climate change has remained largely unchanged for more than twenty years (Hansen 2010; Dawson 2014). A study by Jeffries, Stanisstreet and Boyes (2001) was used to design the closed-form questionnaire; nine questions were added to probe students' environmental attitudes. In their study, Jeffries, Stanisstreet and Boyes repeated the procedures of previous surveys, thus increasing the reliability and validity of the study. The closed-form questionnaire took the form of statements to which the students were asked to respond by circling the appropriate word: 'Right', 'Probably right', 'Difficult to say', 'Probably wrong' and 'Wrong'. The items were arranged in three sections: real and possible consequences of an exacerbation of the greenhouse effect, real and possible causes, and real and possible cures.

The questionnaire was administered during initial science classes and no data were collected before that course. The mechanism of the greenhouse effect was taught after the questionnaires had been completed. Students completed the questions as individuals, but their anonymity was guaranteed. In the present mixed method study, the qualitative questionnaire was collected before the quantitative questionnaire (QUAL->QUAN). An embedded design was used in which the QUAN data set provides a supportive role in the study based on the QUAL data (see Creswell & Plano Clark 2005). Students' responses in the QUAL data sets were based on their writings and therefore their ability to write a coherent story about the greenhouse effect may have affected the results. However, embedded QUAN data sets played a supplemental role for a more valid interpretation of the results.

The open-ended questionnaire (QUAL) helped to give insight into the respondents' thinking by obtaining their spontaneous responses without imposing answers, as occurs when using a closed-form questionnaire (QUAN). The latter type, however, enables us to scrutinise relationships between different students.

Differences between the responses of male and female students, and differences that depended on students' scholastic achievements were analysed using KW-ANOVA because these factors had an effect on the way students conceptualise the greenhouse effect. Principal components analysis (PCA) was used to combine students' environmental attitudes and their responses to the questionnaire items about the possible consequences, causes and cures of the greenhouse effect.

Pearson's product moment correlation coefficient (r) was used in the analysis of the impacts of environmental attitudes on the students' knowledge of the greenhouse effect. The original Likert scale (0–5) variables were processed by PCA before the analysis of *r*, transforming them into component scores on an interval scale.

The present study reports effect sizes along with the differences in responses by gender. The effect size index *d* was derived by dividing the mean difference by the standard deviation. According to Cohen's rough characterisation (Cohen 1988), d=0.2 indicates a small effect size. In contrast, d=0.5 is deemed to be a medium effect size and d=0.8, a large effect size.

7.2 Design and data analysis in design solutions 2

Sub-study II focuses on one group of second-year primary school student teachers (2010), (n=20). The pre and post-essays helped to gain insight into the respondents' thinking about climate change because the students were able to give spontaneous responses. The open-ended question was as follows: 'What does climate change mean?' Students had about 45 minutes to complete their responses. The data-based analysis examined the respondents' answers as follows: first, they were read through, and then they were classified into concept categories. Next, two concepts maps were drawn up by the researchers (one before and one after the teaching), based on the concept categories. Two researchers compared the final concept maps, and the content of the concept maps was qualitatively analysed to make sure that they were similar.

The science sessions were video recorded, which allowed us to analyse the communication that took place during the sessions. Design solution 2 presents an analysis of both the teachers' and the students' contributions to classroom communication. The video recordings were analysed and systemically coded with the Atlas.Ti software into the four categories used by Mortimer and Scott (2003).

Interactive dialogic communication reveals the students' own understanding (both scientific and non-scientific). Where students were able to take part in authoritative interactive communication, this indicates an understanding of the scientific concepts. The closing down phases of the communication were also analysed. Scott and Ametller (2007) stress that meaningful science teaching should include both dialogic and authoritative aspects.

Two researchers coded the session independently and then compared episodes (κ=0.66, p<0.001). In this sub-study, an episode was considered to be a teaching sequence where it included a coherent entity when communication exchanges and classroom activities were considered in their context. Coded categories were compared to the main ideas of the science lesson plans. This enabled an analysis of how teacher demonstrations, working in groups with peers, whole-class questioning, and carrying out practical activities worked to achieve the teaching purpose of the sessions. The descriptive analysis of teacher and student activity is presented as explanatory episodes (see Childs & McNicholl 2007). Selected explanatory episodes indicate the ways in which the teacher used the discourse to develop suitable scientific explanations about climate change with the students.

7.3 Design and data analysis in design solutions 3

The purpose of sub-study III was to illuminate student teachers' practical knowledge of planning, implementing and evaluating the lesson on climate change. This illustrated their own thinking and understanding of inquiry-based science teaching. Versatile methodologies were used, including lesson plan analysis, communication analysis and stimulated recall interviews.

Sub-study III focuses on the same second-year primary school student teachers (training session was in 2011) (n=20) as in sub-study II. The students consisted of four groups and their lesson plans (n=4) were checked against the participating student teachers' ideas of the process model of inquiry-based teaching and their beliefs. Differences between lesson plans and actual instruction were noted. Lesson plans generally focus on the pedagogical knowledge and decisions of the teacher (Jacobs, Martin & Otieno 2008). In this study, interpretative content analysis (Neuendorf 2001) was used to see how the student teachers' goals, values and teaching principles (in their lesson plans) embodied their own practical knowledge of primary school science teaching.

In order to analyse the lesson plans, categories were derived from combinations of types of practical knowledge. The coding was based on practical knowledge types from Meijer, Verloop and Beijaard (2002).

The video-recorded lessons (n=4) were systematically coded into the four communicative approach categories developed by Mortimer and Scott (2003). Based on the video analysis, a communication graph was generated and each of the lessons was mapped, providing a visual representation of the lessons through their patterns of interaction. The communication analysis aims to present, in a readily accessible format, the implementation of the process model including the different teachers' and pupils' interactions and periods of inquiry during the lessons.

Classroom communication analysis began by selecting episodes consisting of teacher-student exchanges, constituting a meso-level analysis of classroom discourse (Tiberghien & Malkoun 2008; Lehesvuori et al. 2013). The meso-scale approach was selected to create an overview of communications during a 90-minute teaching sequence. Episodes were first selected on the basis of activity type, topic and changes in communication. Changes in communicative approach were considered when making decisions about the episodes; the end of an episode (and the beginning of another) was considered to occur when there were changes in activity, topic or communication. After that, the dominant communicative approach was selected for each episode, enabling scrutiny of whether structures resembling inquiry-based teaching (opening up/inquiry/closing down) could be identified. The communicative approaches adopted by the teacher towards the end of the lesson indicated the closing-down phase, with increased emphasis on the scientific view. Cohen's kappa value was not calculated but three researchers independently coded the communications used in the classes and then compared the coding and discussed possible differences to arrive at a common view. Mapping the interaction patterns of the lessons provides an outside observer's overall picture of classroom talk, which can be used for analysis of the student teachers' practical knowledge in real-life teaching situations.

Stimulated recall group interviews (e.g., Schepens, Aelterman & Van Keer 2007), (n = 4) were used to gather the student teachers' own evaluations of their written lesson plans and their implementation of the inquiry-based lesson. Video clips of various communicative-approach episodes during the implemented lessons were played back to stimulate retrieval of any thoughts the participants had during the writing of their lesson plans and the actual teaching.

While communication analysis revealed researchers' interpretations of the implemented classes, the stimulated interviews, analysed by content analysis, clarified in greater depth student teachers' own thinking about inquiry-based teaching and classroom communication. This triangulation method also improved the study's validity. According to Meijer, Verloop and Beijaard (2002), multi-method triangulation is a worthwhile procedure for the enhancement of the internal validity of qualitative studies, especially with a complex topic such as teachers' practical knowledge. The level of openness in inquiry was analysed by reference to Banchi and Bell's (2008) categories.

8 EMPIRICAL DESIGN SOLUTIONS

This study's design solutions include both theoretical and empirical elements (Figure 1). In this chapter, we present empirical design solutions for student teachers' conceptualisation of climate change (more detailed results are given in sub-studies I-III). Their communication in a science education course on climate change is analysed using the communicative approach. The student teachers' understanding both before and after the science course is revealed by concept maps. Finally, the student teachers' practical knowledge is studied in the context of teaching climate change in primary schools.

8.1 Empirical design solution 1: primary student teachers' conceptualisation of climate change

The first empirical design solution revealed that the primary school student teachers' knowledge of the greenhouse effect and climate change were unreliable. From the systems thinking point of view, their conceptualisation of the greenhouse effect is more at the figurative level than the model or molecular level. Relatively few students understand correctly the nature of solar radiation and its mechanism in the greenhouse effect. The results indicate that students have insufficiently conceptualised the wave and particle model and, in particular, the transient dipole moment of greenhouse gases. In the other words, students did not have a good understanding of the mechanism of the greenhouse effect caused by greenhouse gases, water vapour, carbon dioxide, methane, low-level ozone and nitrous oxide. The open-ended questionnaire indicates that students' understanding of atmospheric processes is incomplete because some of them also associated pollution with the greenhouse effect. The closed-form questionnaire revealed the students' understanding of atmospheric gases from a different point of view. Namely, fewer than half of the students knew that ground level ozone acts as a greenhouse gas. There was no mention of ground level ozone in the students' replies to the open-ended questionnaire. Eighty percent of the students imagined that there was a link between the greenhouse effect and skin cancer, and they had an incorrect model of climate warming, which involved excess penetration of solar radiation into the earth, maybe via holes in the ozone layer. Students incorrectly relate the greenhouse effect to ozone layer depletion and their misconceptions are related to a lack of scientific knowledge (Figure 3).

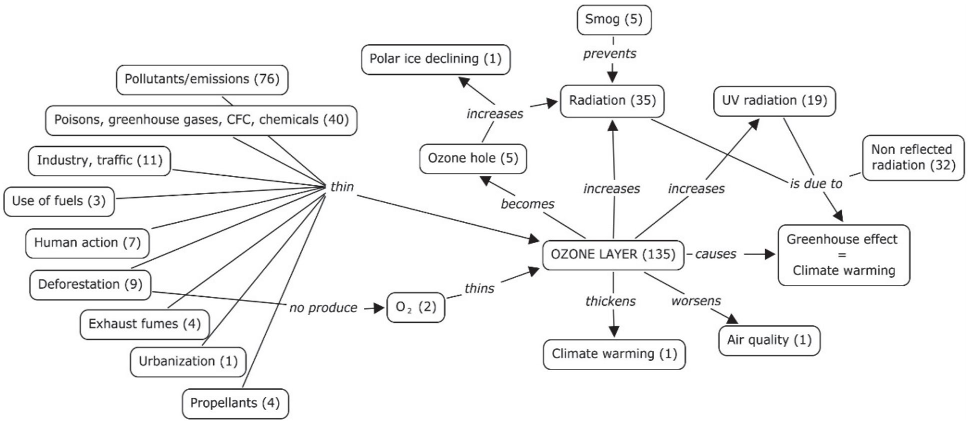


FIGURE 3 Ozone layer depletion is causally related to the greenhouse effect. Concept map based on student teachers' responses to the open questionnaire. Number in parentheses = the number of students' mentions.

Qualitative analysis indicated that IR radiation was not usually mentioned in connection with the greenhouse effect. Instead, according to the quantitative analysis, UV radiation was confused with thermal radiation. There is a strong possibility that students had not grasped the three first levels of systems thinking (identifying the components and processes of a system, identifying processes that create relationships between system components, and building up a framework of relationships) in their studies in upper secondary school. Therefore, the basis for a holistic understanding of the greenhouse effect was lacking.

The first design solution helped to develop a context theory, which was examined in the second empirical design solution. As a result of this solution, the design of the science education course was based on the system's viewpoint of climate change.

8.2 Empirical design solution 2: student teachers' understanding of climate change revealed by communication analysis and pre- and post-concept maps

In the science education course, versatile teaching methods were used to construct systematic knowledge of climate change. Nevertheless, the findings from the second empirical design solution suggest that primary school student teachers' knowledge of climate change remained inadequate, even after four inquiry-based science sessions (Figure 4). Conceptual understanding of climate change increased, though it remained incomplete.

The important role of the sun's radiation in causing the greenhouse effect by greenhouse gases and in accelerating climate change, which was taught in the physics session, can be clearly seen in Figure 4 (circled with a line of dashes). The greenhouse gases are presented in detail in the post-concept map, and the gases were associated with the mechanism of climate change, especially in the chemistry session (in the square in Figure 4). In Figure 4 there are many biological concepts (circled with a solid line); however, the disturbance of oxygen and carbon circulation due to using fossil fuels no longer featured in the students' responses.

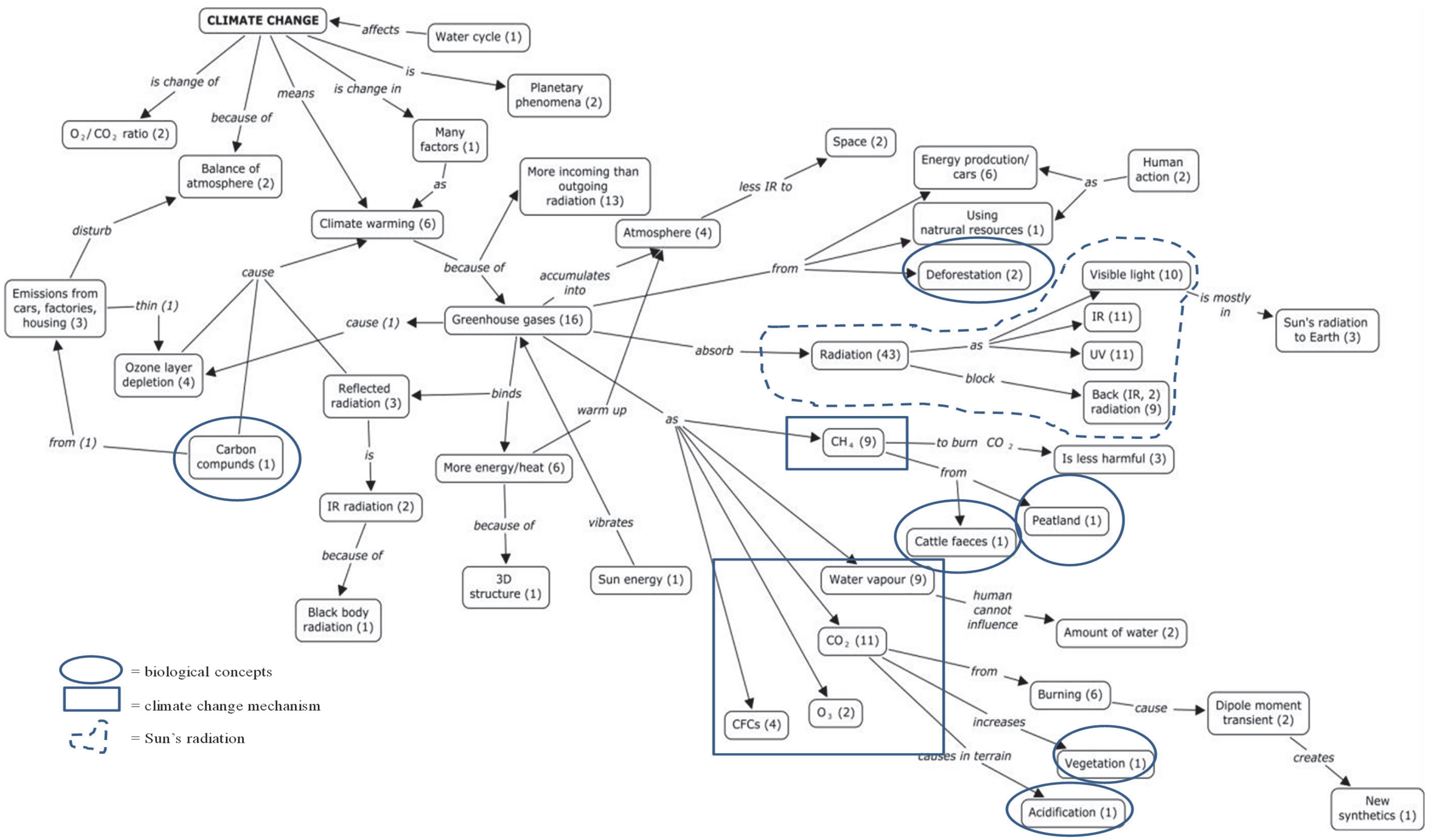


FIGURE 4 The concept map constructed according to students' post-conceptions of climate change. The numbers in parentheses indicate the number of students.

It is evident that the students' thinking has begun to move towards the idea of systems thinking about climate change, even if they are still uncertain about many things. Nevertheless, students' thinking was more coherent after the four dialogic inquiry-based sessions. Overall, it could be expected that students' thinking would be more coherent. However, as the number of concepts indicates, the level of students' conceptualisation of climate change varied considerably.

Design solution 2 reveals that the students would probably have been better able to participate in the discussion at the end of the geography session than they were before. Students' post-conceptions (especially those expressed after physics and chemistry sessions) were not evident in discussion activities when the physico-chemical basis of climate change was studied using the communicative approach and reviewed at the end of the geography session.

Design solution 2 indicates an interconnection between discussion and knowledge: without relevant knowledge, students do not have the confidence to initiate discussion, and if there is no discussion, teachers cannot find out exactly what learners know and how they think. Otherwise, students' fear of giving the wrong answer may paralyse the discussion.

The results from the second design solution helped to develop the outcome theory but because there were still a lack knowledge as to how to teach climate change in primary school, the third design solution was generated.

8.3 Empirical design solution 3: primary student teachers' practical knowledge of communicative and inquiry-based teaching

As student teacher discussions were weak and their knowledge of climate change remained inadequate after the science education course, they were given a task to plan and implement climate change lessons in primary schools (four classes: A, B, C and D). The experiments used in the primary school were studied and piloted in the course. The purpose was to teach the student teachers the principles of communicative inquiry-based science teaching. On that basis, design solution 3 brings a new perspective to the methodological discussion of the student teachers' practical knowledge with regard to climate change education. Their practical knowledge is revealed by their planning and implementation of the communicative and inquiry-based approach in primary school science classrooms (Table 5).

Design solution 3 reveals the multi-dimensionality of science teaching by comparing the results of lesson plan analysis, communication analysis and stimulated recall interviews. The lesson plan analysis gave a picture that student teachers' beliefs seem to be relatively coherent in relation to the elements of inquiry-based teaching (See Lehesvuori et al. 2011). They planned to use relevant inquiry-based learn by doing experiments, such as melting ice, and model-based experimental demonstrations to illustrate the greenhouse effect.

TABLE 5 Student teachers' practical knowledge revealed from their lesson plans and lesson realization.

Class	Student teacher's practical knowledge due to communication analysis		
	I (f)	II (f)	III (f)
Class A; Polar bear	4	6	3
Class B; The greenhouse effect	5	4	1
Class C; The life cycle of porridge	7	5	0
Class D; Climate change and temperature zones	5	5	1
Sum of types	21	20	5

Notes. (I = Focus on own teaching and concentration on subject matter. II = Focus on pupils as individual learners. III = Basic understanding of inquiry-based science in lesson plan and its implementation).

To summarise the results of communication analysis, the main differences between lesson plans and lesson implementations were:

- Class A: Student teachers did not dialogically open up the lesson, thereby ignoring pupils' pre-existing knowledge.
- Class B: The opening-up phase was closed before the experiment. The student teachers did not review pupils' ideas according to the scientific point of view.
- Class C: There was no opening-up and no dialogic closing down. The student teachers did not explain the experiments.
- Class D: Pupils did not advance their own thinking, and their perspectives were ignored when the student teachers compared and linked pupils' concepts to the scientific point of view.

Communication analysis revealed that dialogic teaching was achieved in Type I practical knowledge (authoritative closing down). The values and principles of inquiry-based teaching were ignored in the lesson. In addition, the process model was not fully internalised. In Type II practical knowledge, pupils did not share their ideas, and the values and principles of inquiry-based teaching remained deficient in the experiment. The inquiry itself remained incomplete within the process model. In Type III practical knowledge, dialogic and inquiry-based teaching were achieved quite well. The values and principles of inquiry-based teaching in the class and lesson were critically reflected. Overall, the process model was successfully achieved in the class.

Student teachers' practical knowledge remained relatively incoherent. Their practical knowledge also varied significantly, with extremes represented by the teachers of Classes A and C. The student teachers of Class A demonstrated an above-average ability to plan, implement and critically evaluate an inquiry-based science lesson. In contrast, student teachers in Class C did not refer to the process model at all. Student teachers' readiness to apply dialogic communication in their teaching also varied significantly. Those classified as Type III (i.e., having a basic understanding of inquiry-based science in lesson planning and its implementation in actual classroom communications) performed relatively poorly in all four classes. This means that although student teachers knew the appropriate teaching strategies, even for dialogic teaching, they did not know how these should be enacted in the classroom.

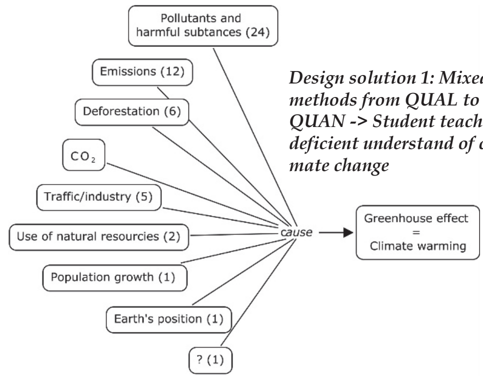
9 DISCUSSION

Design research contributes to three types of outputs: design principles, curricular products and professional development of the participants involved (McKenney, Nieveen & van den Akker 2006). This study emphasises the third design principle and seeks to show how climate change can be taught successfully in primary schools using versatile design methodology (Figure 5). The research reveals how difficult it is for primary school student teachers to change the way they conceptualise climate change. It also shows that learning how to use appropriate communicative inquiry-based science education is a slow process, which requires considerable resources in terms of teaching development, implementation and evaluation. Design principles are not intended as recipes for success, but to help others select and apply the most appropriate, substantive and procedural knowledge for climate change education design and development.

9.1 Main outcome of the design solutions

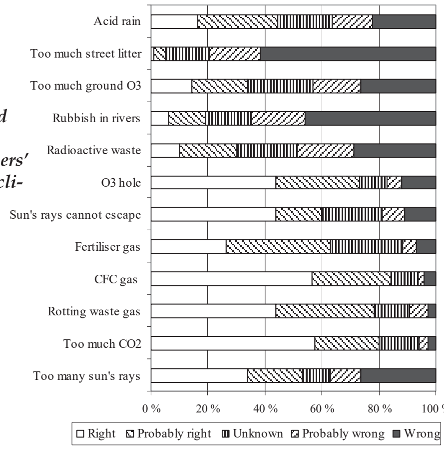
This study brings a new critical insight to support development of the phenomenon-based learning of climate change. The main results can be summarised as follows: (1) primary school student teachers' initial conceptualisation of climate change as a natural scientific phenomenon was insufficient; (2) student teachers' conceptualisation of climate change remained deficient after the science education course; and (3) student teachers did not succeed in gaining practical expertise (i.e., the ability to use an appropriate communicative inquiry-based method). Although included in the student teachers' lesson plans, they were unable to put the principles of dialogic and inquiry-based learning to use in a practical classroom setting.

Using the mixed methods approach (Figure 5), empirical design solution 1 shows how student teachers misunderstood the scientific basis of climate change. The results are similar to those found by Papadimitriou (2004), Ekborg



The simplified causal relationship of the greenhouse effect (n = 24). Number in parenstudy = the number of students' mentions.

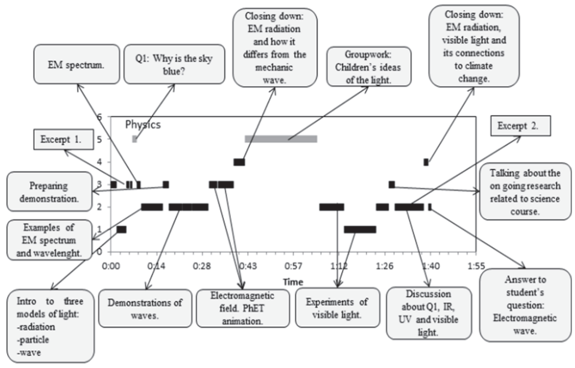
Design solution 1: Mixed methods from QUAL to QUAN -> Student teachers' deficient understand of climate change



Distribution of students' responses on the causes of the greenhouse effect. Conceptual Distinction that the Thinning Atmosphere is the Reason for the Greenhouse Effect.

PHASE 1

Design solution 2: Detailed description of communication. QUAL -> Student teachers' deficient knowledge to join to scientific discussion.

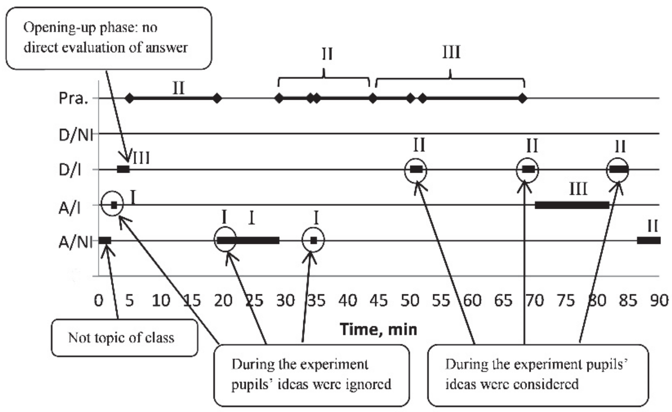


Communication in the physics session. 1=I/A; 2=I/D; 3=NI/A; 4=NI/D and 5=Inquiry.

Excerpt 2 I/D, (01:33:30–01:35:55)

16. *Teacher*: Why is the sky blue?
17. *Student*: [*Wait time (Chin, 2004).*]
18. *Teacher*: Why are there different colours in the sky?
19. *Student3*: It [colour] depends how the light refracts.
20. *Teacher*: Yes. What colour is (the sky) on the Moon?
21. *Student4*: It is black.
22. *Teacher*: Why is the sky black on the Moon?
23. *Student5*: There is nothing which refracts light. There isn't any atmosphere.
24. *Teacher*: Yes, there isn't any atmosphere on the Moon. But what is the air? What are the elements of the air, mainly? What [element] is there most of?
25. *Student3*: Oxygen.
26. *Teacher*: Oxygen is the second. What is there more of?
27. *Student3*: Hydrogen.
28. *Teacher*: [*Teacher did not hear the student's answer.*]
29. *Teacher*: N – i.e., nitrogen.
30. *Teacher*: So, there are nitrogen and oxygen molecules in the atmosphere, and they refract [scatter] light like, we can imagine, the dust particle [shows data projector and former demonstration] did, and because the wavelength of blue is shorter, we see the sky as blue.

PHASE 2



Design solution 3: Detailed analysis of practical knowledge. QUAL-> Combined lesson plan analysis, communication analysis and stimulated recall interviews revealed Student teachers' deficient skills to teach climate change in the elementary school.

Lesson diagram. (A/NI = Authoritative and non-interactive, A/I = Authoritative and interactive, D/I = Dialogic and interactive, D/NI = Dialogic and non-interactive, Pra. = Practising phase; I = Focus on own teaching and concentration on subject matter. II = Focus on pupils as individual learners. III = Basic understanding of inquiry-based science in lesson plan and its implementation).

FIGURE 6 Exemplary design methodology.

and Areskoug (2006), Boon (2010) and Hermans (2014). It appears that student teachers' understanding was very basic. They did not understand climate change as a system where the earth receives radiation from the sun and itself emits energy at the lower frequencies of thermal radiation. Their academic success at upper secondary school did not have a significant impact on their understanding of climate change as a complex phenomenon.

Design solution 2 indicates an interconnection between discussion and knowledge. Without relevant knowledge, students do not have the confidence to initiate discussion and, where there is no discussion, student teachers cannot know exactly what learners know and how they think (Mortimer & Scott 2003; Childs & McNicholl 2007; Chin 2007; Smart & Marshall 2013). The science education course was designed to use versatile inquiry-based teaching methods and considered climate change from different points of views. The pedagogical idea of the course was to familiarize student teachers with a multidisciplinary approach to climate change. A constructivist vision of science education was emphasized in order to promote deeper understanding of climate change, instead of knowledge transmission. The physics and chemistry sessions provided the scientific basis of climate change, the biology session was more applied, and the geography session brought the themes together. The student teachers focused progressively on scientific phenomena related to climate change and we assumed that through retrospective design solution 3, student teachers would have been better prepared to teach climate change. However, the use of inquiry-based science lessons in the primary school context did not work as taught through the process model in the science education course. Dialogic aspects were also ignored in practice. Despite the fact that the science education course included a series of appropriate experiments (demonstrations and lab work) together with observations (how to learn science) and study projects (how to plan, implement and evaluate climate science teaching in primary school), it nevertheless did not give students an adequate basis to teach climate change appropriately in the primary school context. Student teachers did not ask open questions or construct knowledge together with their pupils. The scientific experiments that they used with regard to climate change remained vague and the results were not explained by closed-down discussion as, for example, in the 5E model (Bybee et al. 2006).

Achieving understanding of complex scientific concepts and mechanisms requires considerable time and effort, and as for example Janssen, Westbroek, Doyle and van Driel (2013) and Kennedy (2005) pointed out, innovations in schools can set up unrealistic demands on teachers. Janssen et al. (2013) argued that teachers' practical work requires *instrumentality* (procedures), *congruence* (local fit), and reasonable *cost* (limited time and resources). The importance of the goal of teaching science and heuristics in coping with complex situations was emphasized in the science education course of this study. However, it is possible that student teachers' did not apply those ideas to climate change education. Kennedy (2005) stated that the teacher training programme with the greatest influence on teachers' practices provided teachers' new ideas about how students learn, especially how they learn complicated ideas and difficult content, as well as concrete pedagogical strategies consistent with these ideas. The science education course in this study was quite complicated, including many tasks and pedagogical supports, and thus there were many opportunities for error.

Overall, this design research shows that although student teachers knew the appropriate inquiry-based teaching strategies even for dialogic teaching (as in Lehesvuori et al. 2011), they did not know how to enact these strategies in the classroom. The results are significant because the science education course clearly did not provide the student teachers with a learning experience where sociocultural learning theories could be achieved in the real primary school classroom environment. The theoretical and practical contributions taken from the main findings were presented as domain theory and discussed in relation to the design methodology (Figure 5). The first design solution followed the first design phase, which focused on the generation of a context theory for teaching climate change. After the first design phase, a science education course was created using versatile methodologies. The second design phase (part of a cyclical process) generated a suggested outcome theory for teaching climate change.

9.2 Design methodology

Research into inquiry-based teaching (e.g., the 5E model, Bybee et al. 2006) has normally been carried out by interviews and surveys, and writing field notes (Lotter, Harwood & Bonner 2007; Abrahams & Millar 2008, Minner, Levy & Century 2010; Furtak, Seidel, Ivarson & Briggs 2012; Feng & McComas 2015). Teacher's practical knowledge has also been examined in many studies (e.g., Connelly, Clandinin & He 1997; Simmons et al. 1999; van Driel, Beijaard & Verloop 2001; Meijer, Verloop & Beijaard 2002; Meijer, Zanting & Beijaard 2002; Lotter, Harwood & Bonner 2007).

This design research brings a new design methodology perspective to the methodological discussion of teacher's practical knowledge and the use of communicative inquiry-based methods in science classes. This study reveals the multi-dimensionality of practical knowledge by comparing the results of lesson plan analysis, communication analysis and stimulated recall interviews. The *lesson plan analysis* showed that student teachers' beliefs are relatively coherent in relation to the elements of inquiry-based teaching. They planned to use relevant inquiry-based learn by doing experiments (Johnson et al. 2008), such as melting ice, and model-based experimental demonstrations to illustrate the greenhouse effect (Reinfried & Tempelmann 2014).

The *communication analysis* makes explicit the kind of practical knowledge student teachers used in the real classroom environment. These findings contradict the picture given by the lesson plan analysis. The teaching was not in line with the student teachers' lesson plans. The experiments they used remained vague, because interaction with pupils did not foster pupil thinking. The student teachers planned to teach the principles of climate change dialogically, but they ignored pupils' existing knowledge. In addition, the closing-down component (see Ratinen, Viiri & Lehesvuori 2013) of the classes reveals a lack of coherence in the student teachers' practical knowledge as they did not clearly close down the lesson or review the main points of the climate change class. For example, the results of the measurement of electricity consumption in relation to the amount of greenhouse gases were ignored.

Based on the findings of the present study, communication analysis and interactional graphics can be applied in teacher education while student teachers study science pedagogy and observe classroom practice. As a formative assessment tool, the interactional graphics show educators how their teaching impacts students' scientific thinking, including their misconceptions. Dialogic conversation makes science teaching more meaningful and purposeful for the students (Lehesvuori et al. 2013). When student teachers follow the observations made in the class, in which individual notes are taken in an assigned form, student groups can negotiate a communication graphic of the observed lesson. This encourages them to engage fully with the different interactional options and what they mean for their practical knowledge. This supports student teachers in lesson planning and in the successful achievement of inquiry-based teaching in practice.

The *stimulated recall interview* reinforced the impression that the student teachers intended to use both inquiry-based teaching methods and experiments and to consider their pupils' own ideas and arguments. But they did not do as they planned. These results agree with those of Childs and McNicholl (2007). In their study, student teachers discussed primary science teaching as teaching without formulae, with a stronger focus on phenomena and explanations. Otherwise, the results are similar with the findings of Meijer, Zanting and Beijaard (2002) in which student teachers looked beyond the how and into the why of teaching in their recall interviews.

9.3 Domain theory

In this study, the outcome from problem analysis and theoretical and empirical design solutions can be presented as a domain theory. A domain theory is the generalisation of a portion of problem analysis (Edelson 2002; 2006) and it offers *descriptive knowledge* about the problem to be solved through design. Misconceptions about climate change are well known in many age groups. But there is still lack of knowledge about the kind of teaching and learning that can lead to appropriate learning outcomes. To avoid this shortcoming, the present study aimed to develop a domain theory about how to teach climate change along with practical knowledge of purposeful communicative inquiry-based science teaching, with particular reference to primary school science education. Table 6 describes the main ideas taken from the design solutions to the domain theory.

TABLE 6 Main elements of domain theory taken from the design solutions.

Main outcome of the design solutions (ds)	Domain theory
Ds 1: Climate change is not understood as a system.	Context theory: Knowledge of climate change is constructed hierarchically and it is a very difficult phenomenon to learn. New knowledge about climate change is needed to anchor the concepts learners already know. Outcome theory: Help learners to construct climate change as *a change* in the climate system: visible light from the sun is transformed to infrared radiation when emitted from the earth. Teaching of climate change should focus on the process of climate change not only the individual elements.
Ds 2: Without relevant knowledge, teachers won't have the confidence to discuss climate change in science class.	Outcome theory: Inquiry helps to construct new information piece by piece and enables scientific discussion about climate change during the learning process. Need to link the conceptual problems to hands-on experiments.
Ds 3: Scientific phenomena of climate change are difficult to understand in science class.	Outcome theory: The openness of inquiry should be considered carefully. Open inquiry should not be used for topics with which learners are not familiar. For teachers, leaning how to use inquiry methods in their science classes is a lengthy process.
Ds 4: Closed questions are more common in science classes than open questions. The principles of communicative inquiry-based science teaching are not internalised.	Outcome theory: Open questions increase the cognitive level of questioning and facilitate a more student-centred discourse.
Ds 5: The climate change experiments remain detached from the context.	Outcome theory: Teacher as co-inquirer and relevant communication with pupils helps the use of purposeful experiments to foster pupils' scientific thinking.
Ds 6: Closing-down elements are rare in science classes indicating that pupils' everyday thinking will not be replaced by scientific thinking.	Outcome theory: The communication graphic tool describes where closing-down elements are ignored. Construction of knowledge does not relate to the main points of the climate change class.
Ds 7: Dialogic talk, when used, helped pupils to construct their knowledge.	Outcome theory: Dialogic conversation makes science classes more meaningful and purposeful.

9.3.1 Context theory

Context theory characterises the challenges and opportunities that we encounter in climate change education. According to the findings, phenomenon-based inquiry learning should be carried out deliberately, at least when dealing with complex phenomena such as climate change. The idea is interesting in the light of systems thinking. In the learning process, systems thinking means the construction of knowledge that begins with our observation and recognition of events and objects through concepts we already own. We learn by constructing a network of concepts and adding to them (Ausubel, Novak & Hanesian 1978). In our thinking, knowledge is constructed hierarchically as a system; new information is meaningful to the extent that it can be related and anchored to concepts that are already known.

As we know, teaching climate change is difficult for teachers and researchers because it is an issue that is characterised by controversy, uncertainly, interdisciplinary issues and complexity. In addition, teachers need to understand the natural and man-induced factors affecting the climate, their potential consequences, and ways to mitigate climate change (Lambert et al. 2012). Learners find it difficult to understand climate change because abstract processes and concepts are involved, such as the electromagnetic spectrum, wavelength, and the absorption and re-emission of electromagnetic energy. The fact that climate change is such a difficult phenomenon to teach is probably the main reason that inquiry-based learning and teaching modules are not used in primary school classes. Wieringa, Janssen and Van Driel (2009) found that complex contexts would not help teachers work toward the outcomes they intended. However, Hestness et al. (2011) found potential positive impacts on student teachers' understanding of content related to global climate change, their confidence in teaching, and their awareness of resources to support their future science instruction. These results cannot be compared with those in the present study because their teaching focused on the consequences rather than the causes of climate change. However, there is evidence that it is more learningful to concentrate on the consequences of climate change in primary schools.

When the science education course introduced other scientific topics such as winter ecology, human biology and mechanics in physics, student teachers learned the principles of communicative inquiry-based teaching and learning, as pointed out by Lehesvuori et al. (2011). Therefore, it is possible that the content of the science education course in this design research was too demanding for the primary school student teachers.

9.3.2 Outcome theory

Next, we examine aspects of outcome theory and its role in developing a new design framework to teach climate change in primary school science teaching. First, inquiry-based teaching should be used in the teaching of climate change. Without inquiry, students cannot gain relevant concepts for their knowledge construction. The process of inquiry helps them construct the information, piece by piece, and the teacher's role is to help the student in his/her learning process. Science teaching, also phenomenon based, should be based on core science ideas and the learners' understanding of them. Without this, there is no clear learning goal in teaching (see e.g., Hodson 2014).

In systems thinking, it is important to construct knowledge as *a change* in a particular system (Tapper & Ratinen 2015). In climate change education, the change takes place when system elements such as greenhouse gases interact with thermal radiation. Teachers and learners need to understand that the visible light of the sun is absorbed by the earth, but then re-radiated as thermal radiation to the atmosphere. Greenhouse gases absorb thermal radiation and cause a new emergent phenomenon, the greenhouse effect. Teachers and learners should understand that the greenhouse effect is not in itself wicked, but that its acceleration is. Without this basic understanding, it is impossible to plan teaching in a way that can help learners understand, for example, the impact of their own consumption habits on climate change.

Phenomenon-based teaching and learning sequences (on a subject such as climate change) should be closely based on learners' preconceptions; the knowledge acquisition process should be seen as an active construction process by the individual within a certain social and material setting. It seems to be evident that teaching climate change requires a relatively simple and guided (see Banchi & Bell 2008) inquiry if the teaching purpose is to include students in active discussion and well-constructed knowledge structuring. Hansen (2010) recommends linking the conceptual problems to hands-on experiences. According to the present study, inquiry-based teaching should be considered carefully, on a step by step and case basis. If the learners are not accustomed to inquiry-based learning and teaching, it is possible that practical work will not work as planned (Abrahams & Millar 2008). When very open inquiry is used for learners who are not familiar with inquiry-based learning and teaching, learning outcomes are less successful than in teacher-guided inquiry, as Furtak, Seidel, Ivarson and Briggs (2012) summarised in their meta-analysis.

Secondly, the active construction process seems to be a coherent approach in an inquiry-based learning and teaching module, especially when attention is paid to the forms of communication. Hestness et al. (2011) have emphasised the importance in science teacher education of providing opportunities for student teachers to increase their understanding of the relevant content and of helping student teachers become familiar with appropriate curricular resources, as well as engaging in on-going discussion and being able to evaluate developing views and perspectives related to climate change. Shea, Mouza and Drewes (2016) pointed out that pedagogical supports and place-based relevance exercises support learning about climate change science in meaningful ways that promote deeper understanding of Earth's changing climate. The principles of inquiry have become increasingly popular in science classrooms, with the student recognised as an active inquirer and the teacher as co-inquirer. However, inquiry-based science methods often remain vague both in the way they are described and applied (Oliveira 2010). Smith and Marshall (2013) and Chin (2007) have pointed out that giving students the opportunity to utilise and strengthen both written and oral expression of their reasoning and justification processes provides a foundation for the effective communication of scientific ideas. When teachers monitor their questioning strategies in a mindful way, they are able to set goals for increasing the cognitive level of questioning and facilitate a more student-centred discourse in their classrooms (Smith & Marshall 2013).

Thirdly, as communication analysis revealed, learners should be active and motivated to join discussions. When students are involved in communication, it allows the teacher to gauge their thinking and understanding as well as help develop inquiry-based teaching sessions. The use of interactive dialogic communication to gather students' ideas coupled with authoritative expert-guided teaching is needed for students to develop their scientific thinking adequately. In addition, in pre-service primary school teacher education, it is better to ask questions based on *processes* (e.g., how the greenhouse gases act on the atmosphere) because students' knowledge of the greenhouse effect reveals their difficulty in understanding the complexity of the processes involved. Boon (2010) discusses a constructivist approach, which requires teaching to be built on the learner's existing knowledge of the greenhouse effect and their existing frames of reference.

Fourthly, Lambert et al. (2012) argue the need for valid and reliable instruments to measure the knowledge of climate change so that effective curricular and instructional implementation can be measured. The present findings support the view that combined communication analysis and concept mapping probably help the teacher to develop more instructive teaching and learning sequences. We will never completely understand how learners learn. However, in addition to the methods applied in previous studies (e.g., field notes, interviews, journal writing), future studies should also use methods more closely related to actual classroom teaching. These could include graphical analysis based on videos of lessons.

Next, the systemic level (figurative, molecular or model) of teaching in climate change education should be considered carefully for the different ages of learners, to avoid errors. Primary school pupils should start with the simplified fact that people introduce greenhouse gases into the climate system and the atmosphere, thereby making the climate warmer. After this, they should think about how greenhouse gas emissions could be reduced.

Finally, from the philosophical point of view, sociocultural learning theory postulates that knowledge is relative (relativism), i.e., there is no absolute truth (cf. naïve realism), but only an interpretation of reality. This theory is suitable for science teaching, but often knowledge as an absolute fact, the law and the theory of science get confused in science teaching in schools (Lederman 2006). In the present study, student teachers detected the correct facts from pupils' responses and climate change was presented as a fact but it was not modelled as a phenomenon.

As a summary of outcome theory, sociocultural learning is situated learning where learners take part in activities directly relevant to the application of learning. In other words, learners make the experiments together, observe the measurements, analyse data, and explain and evaluate the results in the social interaction. The knowledge is not just the pupils' or teacher's (intrapsychological); it is shared and experienced knowledge (interpsychological) that can be revealed by communication analysis. Climate change education for primary school student teachers should include versatile and recurrent communicative inquiry-based learning methods. It is important to activate synergic integration between qualitative experiments (e.g., pupils' misconceptions of light), theoretical systematisations, quantitative experiments (on, e.g., the properties of visible light), and explicative models. When using versatile evaluation methods such as communication analysis teachers can obtain useful process skill data from the pupils' learning process.

9.4 Limitations and transferability

The guidelines for conducting educational design research by Edelson (2006) were considered to be a part of theory development: (1) it should be research driven; (2) systematic documentation of the design is carried out throughout the project; (3) formative evaluation is essential in design research because it can identify weaknesses in the problem analysis, design solution or design procedure; and (4) it should identify appropriate generalisations in the form of domain theories, design frameworks and design methodologies. The following paragraphs show how these principles were considered in the present study.

As design research should be research driven, validity issues should be applied to the results. Models and theories in this design framework were based on cyclical design and the testing and evaluation of the research. This design research project produced transferable and authentically tested educational solutions through well documented cyclical phases, as outlined in Chapter 3. The validity of this study can be divided into four classes (Yin 2009). *Construct validity* means that the researcher is able to establish the correct operational measures for the concepts being studied. This was done here by selecting the specific research problems to be studied in design research. The variables to be studied were selected with the help of the theoretical literature by extensively analysing educational research material.

In this study, design phases were systematically documented in the substudies. The theoretical problem analysis represents well-known and significant educational theories of systems thinking, namely, the communicative approach and inquiry-based science teaching based on the sociocultural theory of teaching and the teacher's practical knowledge. Theoretical problem analysis of learners' conceptualisation of climate change was based on the extensive literature review.

Formative evaluation was used to develop a cyclical process to make the design study more coherent. Problem analysis leads to the design solution for teaching climate change from the systems thinking point of view. In that design solution, it is necessary to understand that that earth receives the sun's radiation and itself emits energy at the lower frequencies of thermal radiation. In that complex atmospheric system, the accelerated growth of greenhouse gases absorbs thermal radiation and makes the earth warmer. This fact has been recognised in numerous studies (see problem analysis) and it should be taken into account in teaching design. As a result, the construct validity of this design research can be said to be valid. As the methods used in this study are selected and formulated on the basis of the theoretical problem analysis, it is assumed that the methods used in the design solutions are able to assess the main domains of the selected criteria.

Internal validity is also a notable concept in design research. We were able to achieve internal validity here because the factors which are taken into account in construct validity describe internal validity even better. In this study, internal validity was increased by using methodological triangulation on the qualitative and quantitative research tools. Besides the methodological and researcher triangulation used in sub-studies II and III, the multiple levels of analysis were drawn from the mixed methods used in sub-study I.

Generalisation of the present study as *external validity* can be established by the domain with which the findings of the design research can be associated. External validity can be increased by research design, but it was still a considerable problem in sub-studies II and III, in which the group of participants was relatively small, making quantitative generalisation of the results impossible. However, the design of the teaching concepts via extensive literature analysis and mixed methods analysis in sub-study I, the collaborative planning of the primary school science classes and the testing of the concepts in actual primary school classes partly answer the challenge of testability and generalisation. Overall, the results also seem to corroborate previously published educational research.

As the data were checked and every calculation and analysis reproduced, the *reliability* of this study, i.e., demonstrating that the operations and data used in it can be repeated with the same results, should be good. In other words, reliability is the degree to which the assessment tools produce stable and consistent results. In this study, triangulation of data sources and data collection methods was used, as well as researcher triangulation. Another researcher independently conducted a similar analysis of all of the data in order to validate the results.

9.5 Ethics

Ethical issues are important in educational research. This study followed the ethical guidelines of the Finnish Advisory Board on Research Integrity (Tenk 2015). Data was collected following the responsible conduct of research. Student teachers were informed that all the collected data were confidential and used only for the present study. Before the primary school science classroom was video recorded, pupils' parents signed consent forms, which is an essential part of ethical practice in science education research. Consent forms allow respondents to decide which parts of their data can be used for the purposes of the study, and whether they require anonymity and removal of the pupil's facial image. The data were stored securely.

During the data analysis, we followed the guidelines presented in Wasserman (2013). Data analysers were familiar with the database because it was based on previous research. In addition, the researcher presented his data to colleagues and others proof-read early drafts of the work to uncover possible analytical mistakes. In science ethics, it is important to carry out research carefully and to ensure that results are accurate. In this study, for example, Spearman's correlation was ignored in the first sub-study because the coefficient remained less than 0.3.

The researcher of the present study developed the content of the science education course and also acted as the teacher during the course. However, that did not lead to any bias as researcher triangulation was used for the data analysis. The study did not affect students' performance in the science education course because there were no noticeable differences when compared with groups that did not participate in the present study or that were involved in the same course earlier.

The course contents were designed to give student- teachers the skills and knowledge necessary to use inquiry-based teaching in their future teaching. As a result, the teaching module included a series of appropriate experiments (demonstrations and lab work) together with observations (how to learn science) that could give students a solid background from which to develop their understanding and preparedness to teach not only climate change but other scientific topics by inquiry-based methods. Other groups participating in the science education course had similar learning outcomes.

Similarly, instruction in the primary school followed the current national core curriculum when pupils participated in the inquiry-based science teaching classes.

The research was carried out and the results were reported in compliance with scientific community practice. General diligence, accuracy and ethical guidelines were considered throughout the present study. In addition, the appropriate consideration of other researchers' work and respect for the transparency of science were taken into account.

9.6 Future research

The core question is how to teach climate change to primary school student teachers so that they are better able to guide their pupils' learning process. Based on the present design solutions, there is no one answer to this question and we do not have a simple solution to make climate change education perfect. In this study, domain theory suggests that real scientific experiments, together with enriched communication between teacher and learners helps learners conceptualise climate change. More iteration cycles of design research are required to improve validity. Tiberghien, Vince & Gaidiox (2009) have pointed out that a transition from grand theories to specific theory is required, together with the evolution of research studies and new research trends on design. Accordingly, an idea for future research would be to iterate the design research cycle (Figure 1) in order to obtain more knowledge on how design principles and curricular products should be developed so that leaners achieve better learning outcomes. In that design research, a new cyclical learning process should be designed based on the earlier learning process. The influence of repeated iterations on learning should then be explored.

In order to get a detailed understanding of learning processes with regard to climate change, a larger data set would probably help to make a clearer illustration and to generalise how learners construct their understanding. Communication and discussion in the classroom would probably constitute discursive patterns that could then be used in science classes in general. These patterns might reveal learners' misconceptions about core scientific core ideas, for instance, that photosynthesis means capturing radiation from the sun and that energy cannot be destroyed but can be converted to less useful forms.

As we know, the climate summit in Paris in 2015 has resulted in a global agreement for a sustainable global solution to solve the climate crisis. Geoengineering (i.e., solar radiation management and carbon dioxide removal techniques) has also been suggested as a solution to the problem (Cairns 2014). Both approaches entail a large number of ethical issues. From this point of view, it would be interesting to study the ideas of citizens and students, among others, about mitigation to climate change or geoengineering. One of the core issues in climate change discussion is who finally decides how climate change can be prevented. At the same time, the different solutions should be discussed at schools and in teacher education.

Climate change is a man-made failure within the climate system (IPCC 2014) and as a result it is possible that man may also be able to solve the problem. Future research may look at the development of design research for studying the system competence associated with climate change problem solving. Systems competence (thinking) refers to the ability to recognise a complex component of reality in the associated organisation and its behaviour as a system, and to act accordingly in a manner appropriate for the system (Rempfler 2012). Rempfler and Uphues (2012) state that these three dimensions should be taken into account in design research. There is still much work to be done in climate change education. One example concerns how to use animations and simulations (Evagorou 2009; Svihla & Linn 2012) in climate change teaching at the school level and how to teach decision makers and citizens to work towards improving the climate.

YHTEENVETO

Tässä kehittämistutkimuksessa laadittiin syklinen teoreettis-empiirinen malli (Edelson 2002, 2006), jonka avulla tutkittiin Jyväskylän yliopiston opettajankoulutuslaitoksen luonnontieteen pedagogiikan kurssin vaikutusta luokanopettajien ilmastonmuutoskäsityksiin ja tapoihin oppia ja opettaa ilmastonmuutosta vuorovaikutteisen tutkivan oppimisen avulla. Tutkimus koostuu kolmesta julkaistusta kansainvälisestä artikkelista ja niiden yhteenvedosta.

Ilmastonmuutos on yksi koko ihmiskuntaa koskettavista ilkeistä ongelmista, jonka ratkaisemiseksi tai siihen sopeutumiseksi tarvitaan monen tieteenalan panosta. Kasvatustieteessä ilmastonmuutosta on tutkittu sen käsitteellisen ymmärryksen kautta monen ikäisten ihmisten osalta. Sen sijaan sitä, miten ilmastonmuutosta tulisi opettaa, jotta ilmastonmuutoksen käsitteellinen muutos olisi luonnontieteellisten käsityksen kanssa yhdenmukaista, on huomattavan vähäistä. Kehittämistutkimus tarjoaa keinon vastata tähän puutteelliseen tietoon, sillä sen avulla kehitetään tunnistettuihin (ongelma-analyysin kautta) tarpeisiin ja ongelmiin toimivia ratkaisuja.

Käytännössä kehittämistutkimuksessa toteutetaan aiempaan tutkimustietoon perustuvia interventioita todellisissa opetus- ja oppimistilanteissa. Tutkimuksen kehittämistuotoksien avulla laadittiin ilmastonmuutoskasvatukseen liittyviä kontekstisidonnaisia teorioita (context theory) sekä haluttuun lopputulokseen pääsemistä kuvailevia teorioita (outcome theory), (tässä työssä vuorovaikutteinen tutkiva oppiminen). Näiden teorioiden avulla tavoitteena on ymmärtää paremmin, miten oppiminen tietyssä tilanteessa tapahtuu, ja rakentaa sen perusteella yleistä teoriaa oppimisesta (domain theory). Menetelmän vahvuutena pidetään sitä, että tutkimuksesta syntyy sekä käytännön tarpeeseen kehitetty konkreettinen kehittämistuotos, kuten opetuskokonaisuus tai kurssi. Samalla voidaan kehittää teoriaa, kuten tässä työssä esimerkiksi vuorovaikutusanalyysin teoriaa, kehitetyn tuotoksen ja kehittämisprosessin olemuksen näkökulmista käsin. Ideaalitapauksessa prosessissa kehitetyt pienen mittakaavan ratkaisut, tapaustutkimukset, saadaan ajan mittaan yleistettyä osaksi suuremman käyttäjäkunnan toimintaa, kuten esimerkiksi tarkoituksenmukaista luonnontieteen opetusta luokanopettajakoulutuksessa.

Kehittämistutkimuksen ensimmäisessä vaiheessa, ongelma-analyysissä, selvitettiin oppijoiden käsityksiä ilmastonmuutoksesta (I artikkeli). Ensimmäisessä artikkelissa paljastuvien opiskelijoiden käsitysten perusteella kehitettiin ja testattiin tutkivan oppimisen mallia (Lehesvuori et al., 2011; Kulhomäki, Lappi, Ratinen & Viiri 2011; Ratinen 2012), jossa myös hyödynnettiin ongelma-analyysin pohjalta kehitettyä systeemisen oppimisen mallia. Näiden mallien perusteella suunniteltiin opetusinterventio luokanopettajaopiskelijoille, jossa ilmastonmuutos opiskeltiin neljän tieteenalan, fysiikan, kemian, biologian ja maantieteen esimerkkien avulla (II artikkeli). Luonnontieteen pedagogiikan kurssiin kuului myös opintoprojekti, jossa luokanopettajaopiskelijat suunnittelivat, toteuttivat ja arvioivat (stimuloidun haastattelun avulla) opetuskokonaisuuden alakoulun kuudennelle luokalle opetuksellisen rekonstruktiomallin avulla (Duit, Komorek,Wilbers 1997; Duit, Gropengießer, Kattmann 2005), (III artikkeli). Artikkeleiden päätulokset, kehittämistuotokset voidaan tiivistää seuraavasti:

- Artikkeli I: Luokanopettajaopiskelijoiden ilmastonmuutoskäsitykset ovat luonnontieteelliseltä perustaltaan puutteelliset.
- Artikkeli II: Luokanopettajaopiskelijoiden käsitykset ilmastonmuutoksesta eivät juuri kehittyneet luonnontieteelliseltä perustaltaan tutkivan ja vuorovaikutteisen opetusjakson aikana, joka näkyi opetuksen aikana vähäisenä osallistumisena dialogiseen opetuskeskusteluun ja käsitekarttojen vähäisenä laadullisena muutoksena.
- Artikkeli III: Luokanopettajaopiskelijoiden uskomukset tutkivasta ja vuorovaikutteisesta luonnontieteen opetuksesta realisoituivat puutteellisesti alakoulun luonnontieteen opetuksessa. Dialogia ja tutkivan oppimisen periaatteet eivät toteutuneet suunnitellulla tavalla.

Huolimatta siitä, että luokanopettajat eivät merkittävällä tavalla oppineet ilmastonmuutosta luonnontieteen pedagogisella kurssilla eikä heidän opetus toteutunut suunnitellusti, kehittämistutkimus auttaa teoriaa luomalla ymmärtämään, kuinka ilmastonmuutosta voisi opettaa opettajankoulutuksessa.

Kehittämistutkimus paljastaa, kuinka tiukassa luokanopettajaopiskelijoiden ilmastonmuutosta koskeva käsitteellinen muutos on ja toisaalta sen, että opiskelijoiden uskomusten kehittyminen kohti tarkoituksenmukaista tutkivaa ja vuorovaikutteista luonnontieteen opetusta on hidas prosessi ja vaatii paljon niin opetuksen kehittämiseltä, toteutukselta kuin arvioinnilta. Kehittämistutkimuksessa kehittyneellä teorialla on merkitystä ilmastonmuutosopetuksen toteutuksessa. Tutkimus tuo uutta kriittistä tietoa ilmiöpohjaisten oppimiskokonaisuuksien (erityisesti ilmastonmuutos) ja tutkivan opettamisen kehittämisen tueksi tulevien opetussuunnitelmien mukaiseen opetukseen. Luonnontieteen opetus täytyy perustua, vaikka se olisi ilmiöpohjaista, vallitseviin luonnontieteellisiin peruskäsityksiin ja niiden ymmärtämiseen. Jos peruskäsitteet eivät ole hallussa, oppiminen ja opetus ajautuvat puuhapedagogiikan puolelle ilman, että niissä on selkeää tavoitetta ja ydinajatusta (ks. Hodson 2014).

Tutkivan oppimisen (mm. 5E-malli, Bybee et al. 2006) toimivuus opetustilanteissa ja sen vaikutus opetustuloksiin on perinteisesti perustunut laadullisiin haastattelu- ja määrällisiin tilastollisia yleistyksiä tuottaviin tutkimuksiin (Lotter, Harwood & Bonner 2007; Abrahams & Millar 2008, Minner, Levy & Century 2010; Furtak, Seidel, Ivarson & Briggs 2012; Feng & McComas 2015). Tutkimukset eivät ole tuottaneet kovinkaan syvällistä tietoa opettajien käytännöllisestä tiedosta eli uskomuksista, kuinka esimerkiksi tutkivaan oppimista kannattaisi hyödyntää opetuksessa. Vuorovaikutteisen tutkivan oppimisen analyysissä, jossa tutkitaan opettavan aiheen ympärillä käytyä luokkahuonekeskustelua (ks. Lehesvuori et al. 2013) saadaan yksityiskohtaista tietoa siitä, millaisia käsityksiä opettajalla ja oppilaalla on opetettavasta ilmiöstä ja siitä, kuinka opettaja orkesteroi luokkahuoneessa tapahtuvaa keskustelua. Luonnontieteen opetuksessa tärkeän käsitteenmuodostuksen perustana, esimerkiksi rekonstruktiomallin mukaisessa opetuksessa, ovat oppilaiden ennakkokäsitykset. Ne ovat tärkeässä asemassa erityisesti opetuksen suunnittelussa ja sen alkuvaiheessa. Luokkahuonevuorovaikutusanalyysi tarjoaa hyvät mahdollisuudet nähdä, millaisen opetuksen avaamisvaiheen opettaja luo oppitunnin alussa ja toisaalta, miten opettaja sulkee opetuksen. Sosiokulttuurisen luonnontieteen opetuksen tulisi perustua yhteisölliseen oppimiseen, jossa oppijoiden ennakkokäsityksen huomioon ottamisella rakennetaan yhdessä luonnontieteen luoteeseen sopivaa tiedonkäsitystä. Jos oppijat ovat tiedonrakentamisessa alkuvaiheessa harhapoluilla, heidät täytyy oppimisprosessin alkuvaiheessa tai viimeistään lopussa ohjata ajattelemaan luonnontieteellisesti oikealla tavalla.

Ilmastonmuutosopetuksessa systeemiajattelun mukaisen tiedonkäsityksen (Tapper & Ratinen 2015) avulla oppijoille on tärkeää opettaa ilmastosysteemissä tapahtuvaa muutosta, joka tapahtuu systeemissä olevien elementtien vuorovaikutuksen avulla. Opettajien täytyy ymmärtää, että auringon näkyvä valo absorboituu maapallolle, mutta säteilee osittain takaisin maanpinnalta lämpösäteilynä ja mahdollistaa kasvihuonekaasujen avulla uuden emergenttisen elämän kannalta välttämättömän kasvihuoneilmiön. Opettajien ja oppijoiden tulisi ymmärtää, että kasvihuoneilmiö sinällään ei ole ilkeä ongelma vaan sen voimistuminen. Ilman tätä perusymmärrystä opetusta on mahdotonta suunnitella siten, että oppijat osaisivat miettiä ilmastokasvatuksen yhteydessä muun muassa omien kulutustottumusten vaikutusta ilmastonmuutokseen tai opettajien esimerkiksi muodostaa kantaa ajankohtaiseen biotalousbuumiin. Tässä kehittämistutkimuksessa tuli esille, että luokanopettajaopiskelijoiden puutteellisen ilmastonmuutoksen ymmärryksen kehittämisen myötä he eivät pääsääntöisesti kyenneet toteuttamaan opetusta, jossa vuorovaikutteinen tutkiva oppiminen olisi toteutettu kurssilla opetettujen periaatteiden valossa.

Tämän tutkimusten kehittämisratkaisuiden perusteella luonnontieteen opetuksessa kannattaa kiinnittää erityinen huomio tutkivan oppimisen avoimuuteen (Banchi & Bell 2008). On todennäköistä, että kehittämisratkaisut tuottavat puutteellisen oppimisprosessin myös muillakin kuin luokanopettajaopiskelijoilla seuraavien perustelujen tukemana. Ensiksi ensimmäisen artikkelin mukaan luokanopettajaopiskelijat ovat erittäin hyvin menestyneet koulussa. Heidän kouluosaaminen ei kuitenkaan neljännen artikkelin mukaan jalostu osana luonnontieteen pedagogisia opintoja (opetus kuvataan III artikkelissa) taidoiksi rakentaa kovinkaan laadukkaita tutkivan oppimisen opetuskokonaisuuksia. Todennäköinen syy löytyy tosiasiasta, että ilmastonmuutos on heille hyvin vaikea opetettava ilmiö ja aihealue. Toiseksi toisen artikkelin mukaan luokanopettajaopiskelijat eivät kyenneet kunnolla osallistumaan dialogiseen opetuskeskusteluun. Keskustelu on vaikeaa myös muille oppijoille esimerkiksi alakoulussa, sillä oppijoilla on vaikea ymmärtää ilmastonmuutos luonnontieteellisesti oikein. Luokanopettajaopiskelijat oppivat ilmastonmuutoksen puutteellisesti, joka heijastui systeemisesti abstrakteimmilla ajatteluntasoilla fysikaalis-kemiallisissa prosesseissa. Näiden syiden vuoksi tutkivassa opetuksessa täytyy erityisen tarkkaan ottaa huomioon oppilaiden ennakkotiedot. Tämän tutkimusten tulosten perusteella luonnontieteen pedagoginen kurssi oli sisällöllisesti liian vaativa luokanopettajaopiskelijoille ja heillä oli suuria vaikeuksia suunnitella ilmastonmuutosopetusta avoimen tutkivan oppimisen avulla (opintoprojekti).

Tutkimuksen mukaan ilmiöpohjaista tutkivaa oppimista on toteutettava harkitusti ainakin silloin, kun kyseessä on monimutkainen ilmiö, kuten ilmastomuutos. Ajatus on systeemiajattelun valossa kutkuttava. Oppimisen kannalta systeemiajattelulla tarkoitetaan prosessia, jossa oppilaan tietorakenteessa ylimpänä ovat tiettyyn tiedon alaan kuuluvat ylätason käsitteet, seuraavana välitason käsitteet ja alimpana alatason käsitteet (Ausubel, Novak & Hanesian 1978) eli oppilaan tiedot ovat järjestyneet aivoihin systeemiajattelun tapaisesti hierarkkisessa muodossa. Jos oppija ei ole ymmärtänyt esimerkiksi ilmastonmuutokseen liittyviä alakäsitteitä, kuten kasvihuonekaasuja oikein, ei hän kykene ymmärtämään ilmiötä kokonaisuudessakaan luonnontieteellisesti oikein. Päinvastoin hän saattaa esimerkiksi sotkea kasvihuonekaasut mekaaniseksi esteeksi lämmön karkaamiselle, mihin syntyvä (otsoni)aukko päästää lävitse enemmän auringon säteilyä lämmittäen samalla ilmastoa. Ihmisen ilmastoystävällisen käyttäytymisen kannalta vielä hankalampaa on, että jos hän mieltää kaikki saasteet ilmastonmuutoksen aiheuttajaksi, joka saattaa johtaa ilmastonmuutoksen torjunnan kannata merkityksettömiin toimenpiteisiin, kuten roskien keräämiseen. Ilmastonmuutoksen torjumisen opettamisen voi tiivistää systeemiajattelun ideaan, että kokonaisuus on enemmän kuin osiensa summa: yksi ihminen ei juuri ilmastoa muuta tai sitä pelasta, mutta miljoonat ihmiset näin kykenevät tekemään.

Ilmastokasvatuksessa tulisi tämän tutkimuksen perusteella miettiä, millä systeemisellä tasolla ilmastonmuutosta on järkevää opettaa eri ikäisille oppilaille ilman virhekäsityksen syntyä. Tämän tutkimuksen perusteella alakouluissa tapahtuneiden interventioiden valossa alakoululaisille kannattaa lähteä liikkeelle toteamuksesta, että ihmiset tuottavat kasvihuonekaasuja, joiden määrän kasvu ilmakehässä lämmittää ilmastoa. Ja sitten vasta miettiä sitä, miten kasvihuonekaasujen syntyä voitaisiin pienentää.

Sosiokulttuurisessa luonnontieteen opetuksessa (mm. Woolvolk 2012) mukaan kasvihuoneilmiö puidaan ja rakennetaan uudeksi tietorakenteeksi oppijoiden välisen sosiaalisen vuorovaikutuksen avulla. Mutta jos tässä vuorovaikutuksessa oppijat operoivat virheellisillä käsitteillä, ei tapahdu oppimista. Tämän vuoksi vuorovaikutusanalyysilla saatava tieto on merkittävä keino muiden tutkimusmenetelmien lisäksi ymmärtää oppijoiden tiedonrakentamisprosessia sosiaalisen vuorovaikutusprosessissa. Tämän kehittämistutkimuksen perusteella näyttää siltä, etteivät opettajaksi opiskelevat kykene ohjaamaan oppilaita luonnontieteellisesti oikeaan ajatteluun, vaan esimerkiksi opetuskeskusteluissa haetaan oikeaa vastausta. Tieteenfilosofisesti tarkasteltuna sosiokulttuurisessa oppimiskäsityksessä on näkemyksenä, että tieto on suhteellista (relativismi), eli absoluuttista totuutta (vrt. naiivi realismi) ei ole vaan se on tulkintaa todellisuudesta. Teoria sopii hyvin myös luonnontieteen opettamiseen, mutta valitettavan usein absoluuttinen tieto, laki ja teoria sotkeutuvat luonnontieteen kouluopetuksessa (Lederman 2006). Miten ilmastonmuutos tulisi sitten luokanopettajaopiskelijoille ”opettaa”, jotta oppimista tapahtuisi ja he kykenisivät paremmin myös ohjaamaan oppilaiden oppimisprosessia?

Tämän kehittämistutkimuksen lopputulema on, että sosiokulttuurinen oppiminen on tiedon etsimistä ja käsittelyä osana sosiaalista vuorovaikutusta. Tällöin tieto ei ole oppijoilla eikä opettajalla, vaan siinä sosiaalisessa vuoropuhelussa, jota oppimisympäristössä käydään. Tältä perustukselta ilmastonmuutosopetus kannattaa luokanopettajakoulutuksessa toteuttaa monipuolisia tutkivan oppimisen menetelmiä (esim. avoimen tutkivan oppimisen malli hiilidioksidin vaikutuksesta lämpötilan nousuun) hyödyntämällä ja rohkaisemalla opiskelijat monipuoliseen vuorovaikutukseen oppimisprosessin aikana. Tällä tavalla saadaan tärkeää tietoa opiskelijoiden prosessitaidoista, jotka kertovat heidän ymmärryksen kehittymisestä. Ja kun opiskelijoille kehittyy taidot arvioida myös omaa pedagogiikkaa, on todennäköistä, että he kykenevät opettamaan myös oppilailta monipuolisesti, vuorovaikutteisesti ja erilaiset oppijat huomioon ottaen.

APPENDIX 1. QUESTIONNAIRE FOR SUB-STUDY 1

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ILKKA RATINEN

The purpose of this questionnaire is to collect student teachers' conceptualizations of the greenhouse effect. The study aims to create a model for science education in school. In this model, the greenhouse effect serves as an example topic. All survey data will be treated confidentially.

HOW TO ANSWER

First answer the open questions, and then the multiple-choice questions. Due to the nature of the study PLEASE DO NOT LOOK AT THE MULTIPLE-CHOICE QUESTIONS BEFORE ANSWERING THE OPEN QUESTIONS OR CHANGE YOUR RESPONSES TO THE OPEN QUESTIONS AFTER COMPLETING THE MULTIPLE-CHOICE SECTION.

OPEN QUESTIONS

1. What do you think the greenhouse effect is?

2. What is the cause of the greenhouse effect?

3. What kinds of consequences does the greenhouse effect have?

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ILKKA RATINEN

QUESTIONNAIRE

Circle the number that most closely matches your opinion about the following claims.

	Totally agree	Quite agree	Difficult to say	Quite disagree	Totally disagree
a) I do not support protection of the environment if other people do not protect it.	1	2	3	4	5
b) People have to change their life-style completely in order to save nature.	1	2	3	4	5
c) I cannot do much to prevent the deteriorating state of the environment.	1	2	3	4	5
d) I am ready to compromise my own welfare for the better future of the environment.	1	2	3	4	5
e) The state of the environment is so good that is not worth paying attention to.	1	2	3	4	5
f) Science and technology can solve environmental problems.	1	2	3	4	5
g) A built landscape is more beautiful than a natural landscape.	1	2	3	4	5
h) Nature would have to be protected even if it does not increase welfare.	1	2	3	4	5
i) Ordinary people cannot affect the state of the environment.	1	2	3	4	5
j) I do not care about the destruction of nature	1	2	3	4	5

4. If the greenhouse effect increases then (circle the correct answer)

	True	Probably true	Difficult to say	Probably wrong	Wrong
a) Earth will get hotter	1	2	3	4	5
b) more earthquakes	1	2	3	4	5
c) more flooding	1	2	3	4	5
d) more river fish poisoned	1	2	3	4	5
e) more food poisoning	1	2	3	4	5
f) more skin cancer	1	2	3	4	5
g) changes in Earth's climate	1	2	3	4	5
h) more deserts	1	2	3	4	5
i) more heart attacks	1	2	3	4	5
j) more crop diseases	1	2	3	4	5
k) sea level will rise	1	2	3	4	5
l) polar ice melting	1	2	3	4	5
m) biodiversity will decrease	1	2	3	4	5

5. The greenhouse effect is increasing because of (circle the correct answer)

	True	Probably true	Difficult to say	Probably wrong	Wrong
a) rubbish in rivers	1	2	3	4	5
b) too much solar radiation	1	2	3	4	5
c) too much CO_2	1	2	3	4	5
d) too much ground ozone	1	2	3	4	5
e) too much street rubbish	1	2	3	4	5
f) rotting waste gas	1	2	3	4	5
g) radioactive waste	1	2	3	4	5
h) acid rain	1	2	3	4	5
i) CFC gases from spray cans	1	2	3	4	5
j) fertilizer gases	1	2	3	4	5
k) ozone holes	1	2	3	4	5
l) Sun's rays cannot escape	1	2	3	4	5

6. The greenhouse effect will decrease if we (circle the correct answer)

		True	Probably true	Difficult to say	Probably wrong	Wrong
a)	eat healthy food	1	2	3	4	5
b)	use unleaded fuel	1	2	3	4	5
c)	clean our beaches	1	2	3	4	5
d)	use nuclear power not coal	1	2	3	4	5
e)	ban nuclear weapons	1	2	3	4	5
f)	plant new trees	1	2	3	4	5
g)	use more wind power	1	2	3	4	5
h)	use more recycled paper	1	2	3	4	5
i)	protect rare species	1	2	3	4	5
j)	save energy	1	2	3	4	5
k)	use cars less	1	2	3	4	5

7. My knowledge of the greenhouse effect (circle the correct answer)

		A lot	Something	A little	Nothing at all
a)	I know about the greenhouse effect.	1	2	3	4
b)	I learnt about the greenhouse effect at school.	1	2	3	4
c)	I learnt about the greenhouse effect from TV.	1	2	3	4
d)	I learnt about the greenhouse effect from the radio.	1	2	3	4
e)	I learnt about the greenhouse effect from the press.	1	2	3	4
f)	I learnt about the greenhouse effect from my own studies.	1	2	3	4

8. Background information (circle the correct answer)

a) Sex 1 female 2 male

b) Year of birth ____

c) Matriculation examination grade 1 L 2 E 3 M 4 C 5 B 6 A

d) Geography grade, 5 6 7 8 9 10

biology grade, 5 6 7 8 9 10

chemistry grade and 5 6 7 8 9 10

physics grade in high school diploma 5 6 7 8 9 10

THANK YOU!

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ORIGINAL PAPERS

I

PRIMARY STUDENT-TEACHERS' CONCEPTUAL UNDERSTANDING OF THE GREENHOUSE EFFECT: A MIXED METHOD STUDY

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RESEARCH REPORT

Primary Student-Teachers' Conceptual Understanding of the Greenhouse Effect: A mixed method study

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The greenhouse effect is a reasonably complex scientific phenomenon which can be used as a model to examine students' conceptual understanding in science. Primary student-teachers' understanding of global environmental problems, such as climate change and ozone depletion, indicates that they have many misconceptions. The present mixed method study examines Finnish primary student-teachers' understanding of the greenhouse effect based on the results obtained via open-ended and closed-form questionnaires. The open-ended questionnaire considers primary student-teachers' spontaneous ideas about the greenhouse effect depicted by concept maps. The present study also uses statistical analysis to reveal respondents' conceptualization of the greenhouse effect. The concept maps and statistical analysis reveal that the primary student-teachers' factual knowledge and their conceptual understanding of the greenhouse effect are incomplete and even misleading. In the light of the results of the present study, proposals for modifying the instruction of climate change in science, especially in geography, are presented.

Keywords: *The Greenhouse effect; Mixed method; Concept mapping; Systems thinking; Primary student-teachers*

Introduction

Climate change as a global environmental hazard has often been presented in the media. Climate change has huge social, environmental and economic consequences. Nowadays, we are beginning to see some of the consequences of climate warming such as changes in weather patterns and the melting of the polar ice (IPCC, 2007).

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It seems evident that humans need to research and implement both global and local solutions in order to adapt to climate change. Globally, different nations have different interests for participating in the shared community effort on behalf of the climate: some nations participate under the pressure to create a better future, and others escape their responsibility. How individual people understand and conceptualize complex climate warming plays a crucial role when they try to decrease their own impacts on climate. Locally, climate change has become an issue for discussion in the primary, secondary and upper secondary science classroom, which affects the abilities of future decision-makers to solve the problems and to make appropriate and far-reaching decisions. Several European school curricula and policy documents, including those of Finland, reveal the importance of developing students' decision-making skills based on science. It follows that the way future teachers receive their teacher education is not irrelevant.

A leading objective of Finnish education policy is to achieve as high a level of education and competence as possible for the whole population (FNBE, 2009). About 35% of pupils continue on to upper secondary education when they leave comprehensive school. Finnish teachers are highly qualified and committed, and a Master's degree is a basic requirement. Teacher education also includes teaching practice. As the teaching profession enjoys high popularity in Finland, universities are in a position to select the most motivated and talented applicants.

At the University of Jyväskylä, the core of the science education programme for primary student-teachers comprises a student study of the teaching of a single science topic for the duration of one academic year. The majority of the teaching provided supports this project. The project includes content analysis, determining students' ideas about the topic, finding, selecting or creating the most appropriate presentations and teaching strategies, and drawing up a practical teaching plan. The questionnaires used in the present study were conducted prior to the project. Nevertheless, the present study provided the impetus for several primary student-teachers to conduct their own studies of the teaching of climate change.

In Finnish schools, the greenhouse effect is mainly taught in geography classes. Geography as a holistic science offers many opportunities also in education to participate in community climate efforts. According to previous studies (Nevanpää, 2005), traditional instruction has not achieved results that indicate pupils' understanding of climate change. There is still a need for more information about pupils' conceptual change during teaching.

The present study leans on systems thinking and concept mapping, which are widely used in science teaching. von Bertalanffy (1972) recognized three aspects of the systems approach. First, systems science deals with the scientific exploration of systems and systems theory in the various sciences. Secondly, systems technology deals with applications in both computer operations and theoretical developments such as game theory. Thirdly, systems philosophy addresses the reorientation of thought and worldview resulting from the introduction of systems as a new scientific paradigm. The present study draws on the latter, and systems thinking is conceived as the ability to recognize, describe and model complex aspects of reality as climatic systems. The important aspect of systems thinking is the ability to identify important elements of the climatic system and the varied interdependency between these elements. According to Ossimitz (2000), systems thinking incorporates four central dimensions: (1) network thinking, (2) dynamic thinking, (3) thinking in models, and (4) system-compatible action. Ben-Zvi Assaraf and Orion (2005) identified eight characteristic aspects of systems-level thinking: (1) identifying the components and processes of a system, (2) identifying processes that create relationships between system components, (3) constructing a framework of relationship, (4) drawing general conclusions, (5) understanding that a given relationship can impact other relationships, (6) knowing that there can be hidden dimensions that affect the system, (7) understanding the cyclical nature of systems, and (8) recognizing that systems can change over time.

In this study, concept mapping refers to the technique of schematically illustrating students' knowledge of the elements of the greenhouse effect and the interdependencies between these elements in order to facilitate meaningful learning (Novak, 1990; Novak & Cañas, 2008). The technique stems largely from Ausubel's *Theory of Meaningful Learning* (Ausubel, Novak, & Hanesian, 1978). According to this theory, concept mapping can also be the most important tool to systematize and describe the learners' prior knowledge. Concepts can consist of briefly presented forms of human experiment and the nodal points between the abstract and the concrete (Novak & Cañas, 2008). In the present study, the conceptualization of the greenhouse effect is divided into three major entities: figurative, model and molecular (Lin & Hu, 2003), which were used to form a category framework for the understanding of the greenhouse effect.

The present study is focused on finding answers to the following questions:

- How do primary student-teachers conceptualize the greenhouse effect?
- What are their ideas about the consequences of and solutions to climate warming?
- How do their environmental attitudes, gender and scholastic achievement affect their conceptualization of the greenhouse effect?

A review of the research questions is presented at the end of the study in order to develop the instruction of the greenhouse effect and climate warming in geography.

Previous Research on the Conceptualization of the Greenhouse Effect

The present study examines primary student-teachers' understanding of the greenhouse effect. Despite the fact that climate change is daily presented in the media, people's factual knowledge and their conceptual understanding of climate warming and the greenhouse effect are incomplete and often misleading (Rickinson, 2001). Many people regard the greenhouse effect merely as an environmental problem and not necessary as the phenomenon that regulates the Earth's climate and keeps its temperature relatively stable, thus making life on the planet possible (Figure 1). Scientifically, the mechanism of the greenhouse effect is caused by specific atmospheric gases, mainly water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), low-level

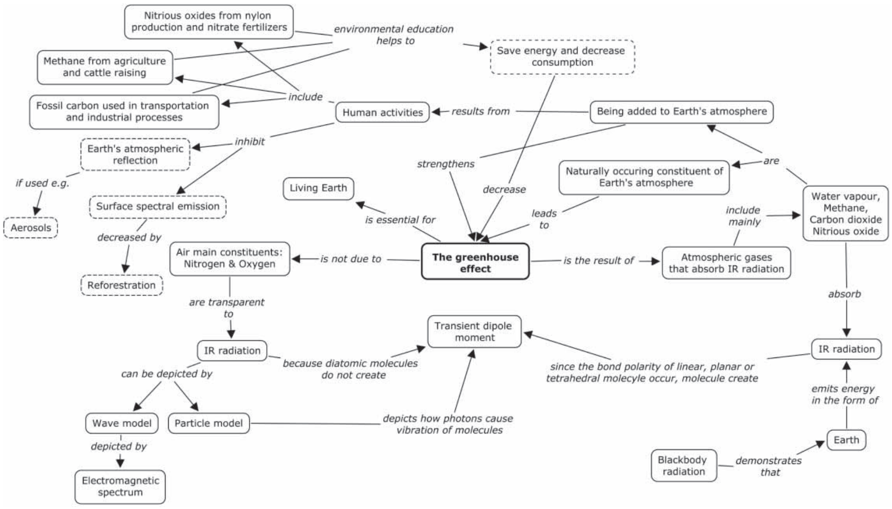

Figure 1. Simplified concept map related to the greenhouse effect. Boxes drawn by dash line depict some solutions for the mitigation of climate warming

ozone (O_3) and nitrous oxide (N_2O). The anthropogenic greenhouse effect, that is, climate warming, means that the Earth is now absorbing 0.85 ± 0.15 W/m^2 more energy from the Sun than it is emitting to space (simulation period 1880–2003) (Hansen et al., 2005). Climate warming is caused by elevated levels of greenhouse gases, which contribute to additional absorption and emission of long-wave radiation in the surface-troposphere system.

Many researchers have found that student-teachers know the basic facts about climate warming, such as the increasing temperature of the Earth, but their knowledge is atomistic (Ratinen, 2008). It is not only students but also teachers who have misconceptions and misunderstandings about climate warming (Papadimitriou, 2004), and they probably pass their own ideas on to pupils.

Many studies (Table 1) show that it is common to confuse the greenhouse effect with the depletion of the ozone layer. Scientifically, the connection between climate warming and ozone depletion is not strong (IPCC, 2007). However, reduced ozone causes less solar radiation absorption in the stratosphere, thus cooling the stratosphere. As a result, the cooler stratosphere emits less long-wave radiation to the troposphere, thus, in turn, cooling the troposphere (-0.15 ± 0.10 W/m^2). The problems of distinguishing between the greenhouse effect and ozone depletion may be due to problems in distinguishing IR radiation from UV radiation or even radiation from thermal energy (Boyes & Stanisstreet, 1997). Moreover, primary-school pupils think that the environment deteriorates, plants and animals are infected by pollution and the air becomes dirty, which prevents heat from re-radiating and, therefore, the climate is hotter (Koulaidis & Christidou, 1999). Jeffries, Stanisstreet, and Boyes

Table 1. Students' conceptualizations of the greenhouse effect and climate change

Conception	Research
Climate change is not understood as a change of radiation balance	Koulaidis and Christidou (1999), Andersson and Wallin (2000), Nevanpää (2005)
Climate change is causally related to ozone depletion	Boyes and Stanisstreet (1997), Koulaidis and Christidou (1999), Ekborg and Areskoug (2006), Jeffries et al. (2001), Papadimitriou (2004), Nevanpää (2005)
Climate change is confused with other phenomena	Boyes and Stanisstreet (1997), Andersson and Wallin (2000)
Every environmentally harmful action causes climate change	Gowda, Fox, and Magelky (1997), Fisher (1998), Papadimitriou (2004), Nevanpää (2005)
Greenhouse gases are understood insufficiently	Fisher (1998), Koulaidis and Christidou (1999), Andersson and Wallin (2000), Ekborg and Areskoug (2006), Papadimitriou (2004)
The influence of climate change on ecology and society is not understood	Fisher (1998), Andersson and Wallin (2000), Nevanpää (2005)

(2001) found that more students held misconceptions in their later study than in the study which they made 10 years earlier. Groves and Pugh (2002) found that students held on to their misconceptions of the cause of climate warming even after instruction. According to Andersson and Wallin (2000), students cannot distinguish the greenhouse gases correctly and, for example, they believe that chlorofluorocarbons (CFCs) are responsible for the climate warming, because they destroy ozone and create the ozone hole that allows UV rays to reach the Earth.

With regard to environmental education, it is interesting that many people link climate warming with the results of human action such as littering (Nevanpää, 2005). Indeed, studies of students' understanding of global environmental problem indicate that the students do not fully understand what fundamental societal changes (economy, business activities, infrastructure, social institutions and the environment) would occur as a result of a drastic reduction in CO_2 emission (Andersson & Wallin, 2000).

Recently, students' views on global warming and their beliefs about actions taken to decrease global warming and their willingness to act have been an important research area (Boyes, Skamp, & Stanisstreet, 2009). Their study indicates that altering beliefs about the usefulness of one's own action is not expected to produce noticeable changes in behaviour. Lester, Ma, Lee, and Lambert (2006) pointed out that pupils having a scientifically correct content knowledge of global warming tend to express activism towards global warming more frequently. Their finding that pupils gained better science knowledge after instruction showed the importance of education.

Based on earlier studies (Table 1), seven scientific processes are developed and presented in this study. In the categorization of the responses of the present study's respondents, the identification of these key processes was used to discern different levels of understanding. The following concept categories were used:

Model

P1: Wave model. The Earth system receives energy from the Sun mainly in the form of visible light. Reflected short-wave radiation is distinguished from emitted long-wave radiation.
P2: Particle model. Photon energy is directly proportional to the wave frequency and a wave consists of discrete packets of energy called photons. The particle model describes how photons are emitted and absorbed by charged particles.
P3: Black body radiation. The Earth emits energy into space in the form of infrared radiation.

Molecular

P4: The atmosphere has different abilities to absorb radiation. The atmosphere absorbs infrared radiation by photons, which causes vibration and rotation of the greenhouse gas molecules. Thus, radiation is converted into heat energy. The molecules of the greenhouse gases can vibrate because of their symmetry. These vibrations create a transient dipole moment. Therefore, greenhouse gases can absorb and emit infrared radiation.

Figurative

P5: Incoming and outgoing radiation may be influenced in different ways by the atmosphere.
P6: Different gases in the atmosphere have different abilities to absorb electromagnetic radiation at different wavelengths. Ozone in not a greenhouse gas in the stratosphere (UV absorption), but it accelerates the greenhouse effect in the lower troposphere.
P7: The increasing concentration of gases in the atmosphere may be affected by positive radiative force.

Mixed Methods and Procedures

Three groups ($n = 275$) of second-year primary student-teachers at the University of Jyväskylä, Finland, were asked to complete an open-ended and a closed-form questionnaire. The student respondents had successfully completed their upper secondary-school studies (Table 2) but had not studied science at university level

Table 2. Respondents' background information

Variable	Frequency	%	*M*	SD
Respondents	275	–	–	–
Women	217	79	–	–
Men	58	21	–	–
Age	275	–	23.80	4.48
Matriculation examination mark	275	–	Magma cum laude approbatur	
Geography mark	270	–	8.74	0.82
Biology mark	275	–	8.58	0.93
Physics mark	258	–	8.01	1.28
Chemistry mark	262	–	8.03	1.33

prior to the questionnaires. The present study scrutinizes how participants' scholastic achievements affect their conceptualization of the greenhouse effect.

The questionnaires were administered during initial science classes and no data were collected prior to the course. The greenhouse effect mechanism was taught subsequent to the questionnaires. Students completed the questions as individuals, but their anonymity was guaranteed. In the present mixed method study, the qualitative questionnaire was collected before the quantitative questionnaire (QUAL-> QUAN). The embedded design was used, in which the QUAN data set plays a supportive role in the study based on the QUAL data (Creswell & Plano Clark, 2005). Students' responses of the QUAL data sets were based on their writings, and therefore, their skills of writing a coherent story about the greenhouse effect may be affected by the results. However, embedded QUAN data sets played a supplemental role for the more validate interpretation of the results.

The open-ended questionnaire (QUAL) helped to gain more insight into the respondents' thinking by obtaining their spontaneous responses without imposing answers, as that occurring when using a closed-form questionnaire (QUAN). The latter type, however, enables us to scrutinize relationships between different students.

The open-ended questions asked were as follows: 'What does the greenhouse effect mean?' and 'What is the greenhouse effect caused by?' In the theory-based analysis of the open-ended questionnaire, respondents' answers were first read and then classified into main categories and concept categories. Secondly, concept maps based on the concept categories were drawn up. In addition, the frequencies of students' concepts were calculated.

The study done by Jeffries et al. (2001) was utilized to design the closed-form questionnaire and nine questions were also added to probe students' environmental attitudes. Their study repeated the previous surveys' procedures, thus increasing the reliability and validity of the study. In addition, some questions used to investigate students' knowledge about the greenhouse effect were revised in the present study. The closed-form questionnaire also asked about the extent to which students thought they had learned about global warming from different sources (school, television, newspapers and magazines, radio and education). The background information collected by the questionnaire included gender, date of birth, matriculation examination marks and the marks awarded for geography, biology, physics and chemistry in the upper secondary-school diploma. The closed-form questionnaire took the form of statements to which the students were asked to respond by circling the appropriate word: 'right', 'probably right', 'difficult to say', 'probably wrong' and 'wrong'. The items were arranged in three sections: real and possible consequences of an exacerbation of the greenhouse effect, real and possible causes, and real and possible cures. The first section contained eight, the second section six and the third section five scientifically acceptable statements. In addition, the first and third sections contained five and the second section six scientifically unorthodox statements interspersed at random. The final page of the questionnaire asked students to record how much they thought they knew and how much they thought they had learned from different sources. In order to compare percentages, the two positive responses ('right' and 'probably right') were combined to provide a measure of the proportion who agreed with an idea. Similarly, to indicate those who disagreed with an idea, the other two responses ('probably wrong' and 'wrong') were combined.

Differences between the responses of male and female students and between students' scholastic achievements were analysed using KW-ANOVA, as these factors can influence their conceptualization of the greenhouse effect (Jeffries et al., 2001). Principal component analysis (PCA) was used to combine students' environmental attitudes and their responses to the questionnaire items about possible consequences, causes and cures of the greenhouse effect. Three principal components were extracted from the data on environmental attitudes and four from the students' opinions of the greenhouse effect. All principal components were varimax rotated and, therefore, independent. The principal components calculated from the attitude statements explained 48% of the total variance and 40% of the students' opinions of the greenhouse effect. The basic idea of PCA is to seek common variation among the many variables and from interpretative groups of variables.

Pearson's product moment correlation coefficient (r) was used in the analysis of the impacts of environmental attitudes on the students' knowledge of the greenhouse effect. The original Likert scale variables were processed by PCA prior to the analysis of r, thus transforming them into component scores on an interval scale. The correlations are not, however, presented as they are negligible (<0.239). Therefore, although the correlations were statistically significant, they were educationally insignificant.

The study presents the effect sizes, as well as differences in responses by gender. As the statistical tests were studied by KW-ANOVA, the differences in responses by science studies (five groups) and matriculation examination (five groups) were unable to be calculated. The effect size index d was derived by dividing the mean difference by the standard deviation. According to Cohen's rough characterization (Cohen, 1988), $d = 0.2$ indicates a small effect size. In contrast, $d = 0.5$ is deemed as a medium effect size and $d = 0.8$ as a large effect size.

Mixed Analysis of Students' Concepts of the Real and Possible Causes of the Greenhouse Effect

The present study indicates that 4% of the respondents wrote in their answers that the greenhouse effect is not the same as climate warming. According to these 12 primary student-teachers, the Earth is a planet with life because the greenhouse effect keeps the temperature relatively stable and makes life on the Earth possible. In their replies, the students suggested that the environmental problem results from the enhanced greenhouse effect, caused by emissions of man-made greenhouse gases. However, their answers to P2 and P7 were not very detailed even if the students had successfully passed their science classes (Table 2). In the closed-form questionnaire, almost every student (99.6%) agreed with the statement that if the greenhouse effect grows, the climate will change and the Earth will get hotter (94%). This shows that primary student-teachers' conceptualization of the greenhouse effect is inadequate, but they are able to choose scientifically relevant statements in the questionnaire, thus underlining the importance of the use of a mixed method approach with respect to complex issues such as the greenhouse effect.

According to Papadimitriou (2004), many primary student-teachers confuse the greenhouse effect with climate change, and 51% view the greenhouse effect as being the cause of climate change. Nevanpää (2005) noted the same for students. In Swedish studies, 10% of ninth-grade students regarded the greenhouse effect as a natural phenomenon (Andersson & Wallin, 2000). Among Finnish primary student-teachers, the conceptual confusion of these two phenomena is probably caused by the media, where climate change has been the concept discussed and not the greenhouse effect (Lyytimäki, 2007). Papadimitriou (2004) supposes that primary student-teachers have experience of short-term weather patterns from TV, which has supported their beliefs about climate change.

Greenhouse Gases as a Source of the Greenhouse Effect

Relatively few primary student-teachers (12%) had conceptualized in their responses that the greenhouse effect and climate warming were caused by specific atmospheric gases such as carbon dioxide, methane and CFCs (Figure 2). The quantitative analysis indicated that many of the students (84%) presumed CFCs to be greenhouse gases (Figure 3). The result is similar to that obtained by Jeffries et al. (2001), but Papadimitriou (2004) pointed out that only 7% of primary student-teachers associated aerosols and sprays with the cause of climate change.

In the present study, over 79% of primary student-teachers thought that (methane) gas from rotting waste contributed to climate change, but rather fewer (37%) thought this to be true of nitrogen oxide gases derived from fertilizers. Mixed method analysis reveals that primary student-teachers have a fairly good understanding of greenhouse

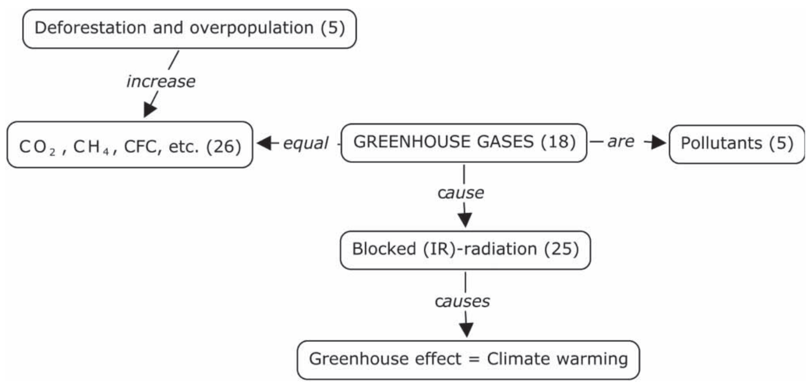

Figure 2 Greenhouse gases cause the greenhouse effect ($n = 32$). Number given in the parentheses indicates the number of students' mentions

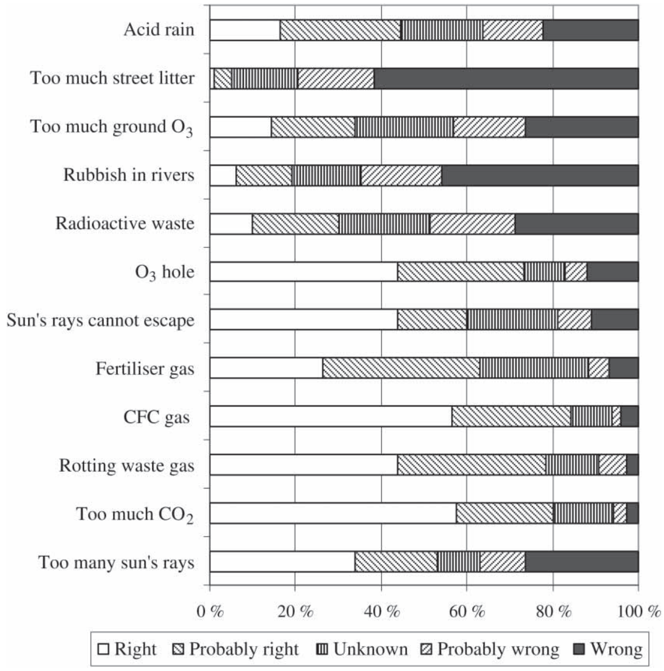

Figure 3. Distribution of students' responses on the causes of the greenhouse effect. Conceptual distinction that the thinning atmosphere is the reason for the greenhouse effect

gases trapping more terrestrial radiation near the ground, but they do not understand the particle model (P2) and UV absorption of greenhouse gases (P4). Therefore, on the basis of respondents' answers, their understanding of atmospheric processes is incomplete. According to Nevanpää (2005), pupils may assume that carbon dioxide as such has a warming potential. In the present study, this kind of misconception did not occur. Pollutants, however, were also regarded as greenhouse gases (Figure 2).

According to five primary student-teachers (2%), the greenhouse effect and climate warming are caused by the thinning atmosphere, which means that these students have not conceptualized the greenhouse effect in a scientifically precise manner (P1–P7) (Figure 4). Generally, students expressed the view that pollutants, emissions, industry and natural devastation thin the atmosphere. Based on earlier studies, the students may logically think that the decreasing of the 'protective layer' of the atmosphere makes the atmosphere hotter (Christidou & Koulaidis, 1996; Nevanpää, 2005). Koulaidis and Christidou (1999) pointed out that primary-school pupils thought that living things are infected by air pollution and that this pollution destroys the atmosphere and makes the climate hotter. The primary student-teachers involved in the present study inquiry have likely misunderstood the atmosphere as being a homogenized structure where the ozone layer is an essential and life-protecting atmospheric component because it absorbs incoming UV radiation.

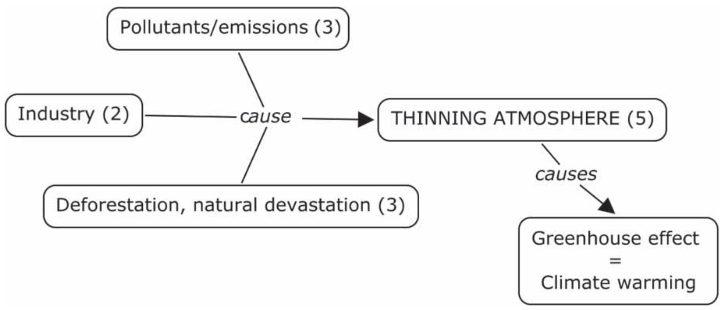

Figure 4. The thinning atmosphere causes the greenhouse effect (n = 5). Number in parenthesis = the number of students' mentions

Disturbed Radiative Forcing is the Reason for the Greenhouse Effect

Relatively few primary student-teachers (10%) wrote that disturbed radiative forcing causes the greenhouse effect and climate warming (Figure 5). In the closed-form questionnaire of the present study, however, considerably more students (60%) associated the statement about the entrapment of the Sun's rays with climate warming (Figure 3). In the study done by Jeffries et al. (2001), more than 80% of the students stated that global warming occurs because the Sun's rays cannot escape.

Because the results analyzed on the basis of qualitative and quantitative questionnaires clearly differ, it is useful to examine students' responses further. Students who belong to this concept category emphasized that the Sun's rays cannot escape, but they did not make the conceptual distinction between sunlight and terrestrial radiation clear in their responses. Therefore, respondents did not understand the mechanism of black body radiation (P3) and the enhanced greenhouse effect caused by greenhouse gases (P4). Figure 5 indicates clearly the way pollutants and emissions

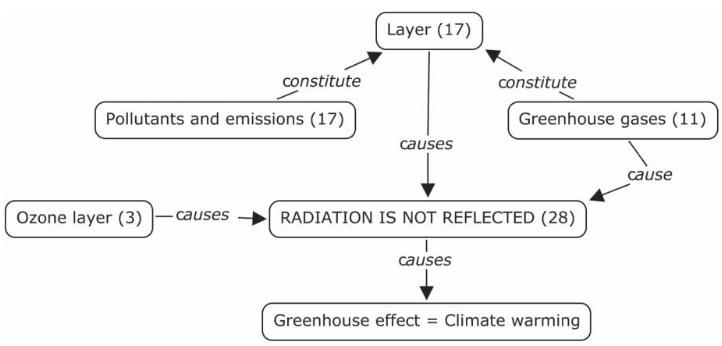

Figure 5. Disturbed radiative forcing causes the greenhouse effect (n = 28). Number given in the parentheses indicates the number of students' mentions

constitute a layer which prevents radiation from reflecting out into the atmosphere. This kind of misconception is fairly common among students (Koulaidis & Christidou, 1999; Papadimitriou, 2004). In fact, atmospheric aerosols increase albedo (Kuusisto & Käyhkö, 2004). Similarly, rather few students associated the ozone layer with the decreasing of terrestrial radiation (compare Figure 9). Although many students correctly identified the mechanism of climate warming, many (53%) also chose the wrong mechanism, when more of the Sun's rays penetrate the Earth system (Figure 3).

The Greenhouse Effect is the Result of Simple Causality

Compared with earlier studies (Andersson & Wallin, 2000; Nevanpää, 2005), in the present study, rather few (9%) primary student-teachers simplified the greenhouse effect to merely the causes and consequences of climate warming (Figure 6). Nevertheless, quite many students associated acid rain (44%) and radioactive waste (30%) with the greenhouse effect (Figure 3). Students in this category, for example, associated pollutants, emissions and deforestation with global warming, but they did not understand climate warming as a broad scientific process. Myers, Boyes, and Stanisstreet (1999) found that school students' statements, giving pollution as the cause of the greenhouse effect or global warming, are more common among older students. Myers et al. (1999) suggested that the older the students are, the more aware they are of global, but very abstract, phenomena. It is possible that the respondents in the

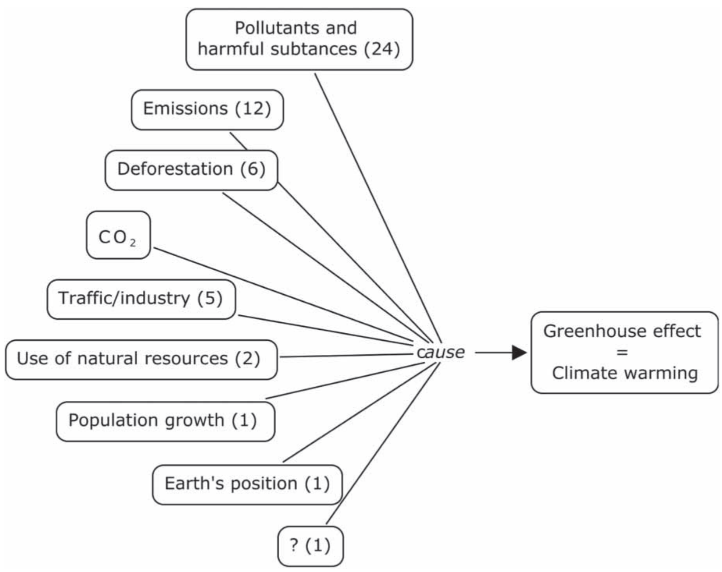

Figure 6. The simplified causal relationship of the greenhouse effect ($n = 24$). Number given in the parentheses indicates the number of students' mentions

present study have studied climate warming at school, and also from secondary sources such as the media, but their understanding has not attained the level of model or molecular. It is also possible that climate warming is largely a matter of belief (Papadimitriou, 2004). All in all, climate warming is a complex issue with many negative and positive feedback mechanisms, which makes it challenging to learn.

The Greenhouse Effect is Depicted by Non-scientific Statements

Primary student-teachers' responses revealed that rather few of them (4%) associated illogical issues with the greenhouse effect and climate warming (Figure 7). Papadimitriou (2004) found that very few (7%) primary student-teachers spontaneously associate waste disposal or radioactive waste with the greenhouse effect. The quantitative questionnaire of the present study also indicates that students did not make an erroneous connection, on the one hand, between street littering (79%) and rubbish in rivers (65%) (Figure 3) and, on the other hand, between climate change (99.6%) and global warming (94) (Table 3). Instead, the students causally associated radioactive waste (30%) and acid rain (44%) with climate warming. According to Jeffries et al. (2001), students may suppose both radioactive waste

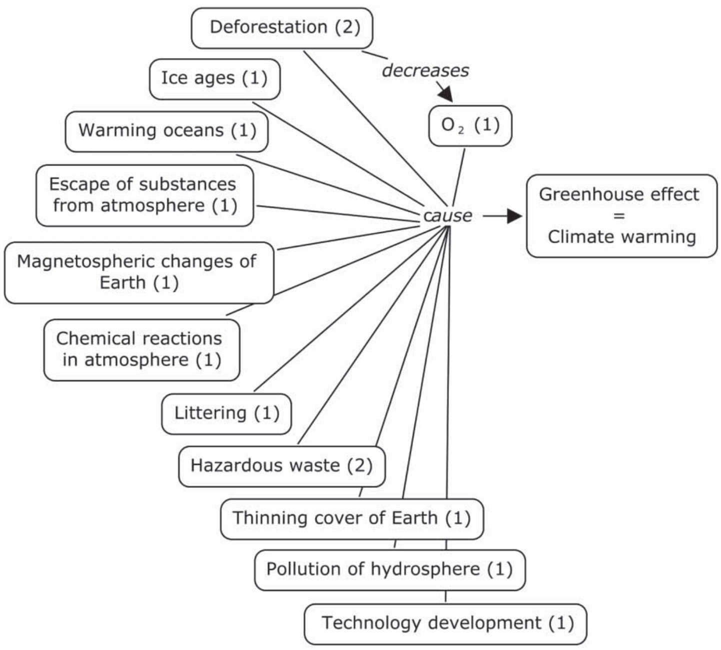

Figure 7. The illogical explanation of the greenhouse effect ($n = 11$). Number given in the parentheses indicates the number of students' mentions

Table 3. Students' responses to the question *If the greenhouse effect gets bigger…*

	True	False	Be unknown	Total
Earth will get hotter	94	4	2	100
More flooding	94	2	4	100
Changes in world's climate	99.6	0	.4	100
More deserts	77	8	15	100
More crop diseases	64	6	30	100
Sea level will rise	89	3	8	100
Polar ice melting	96	2	2	100
Biodiversity will decrease	77	5	18	100
More heart attacks	16	50	34	100
More food poisoning	12	64	24	100
More skin cancer	79	10	11	100
More river fish poisoned	36	33	31	100
More earthquakes	25	44	31	100

Notes: True, Right + I think this is right; False, I think this is wrong + I am sure this is wrong. Non-scientific statements are *italicized*. Results are given as percentages of all responses ($n = 275$).

and acid rain to be 'gaseous' forms of pollution, which may play a role in the generation of these misunderstood associations.

This category was called illogical, because students' responses did not indicate the mechanism by which, for example, ice ages and the Earth's magnetospheric changes affect climate warming. Thus, the respondents' choice of expression did not demonstrate the analytical and scientific power of deduction.

Andersson and Wallin (2000) pointed out that 10% of students in the upper secondary school responded only by describing the results and causes of the greenhouse effect. Nevanpää (2005) found that the secondary-school pupils were aware of the causes and results of the greenhouse effect both before and after instruction.

A Greenhouse as an Analogy of the Greenhouse Effect

Climate warming has been illustrated in the media and at schools by the actual greenhouse. However, according to the present study, the analogy depicts the greenhouse effect scientifically vaguely (Figure 8). Relatively few primary student-teachers (10%) wrote that pollutants, emissions and greenhouse gases constitute a layer in the atmosphere which causes climate warming. Respondents thought that the 'layer' acts like a glass pane in an actual greenhouse which physically prevents heat from radiating out into space. Similarly, they associated the statement that the Sun's rays cannot escape (60%) with the greenhouse effect. Atmospheric greenhouse gases trap heat within the Earth's surface and troposphere system heating up the Earth (P4). However, the students did not spontaneously depict the chemical reactions of the greenhouse gases in their responses. In an actual greenhouse, the mechanism is fundamentally different, because there the air is isolated by the glass so that it is not lost by convection and conduction.

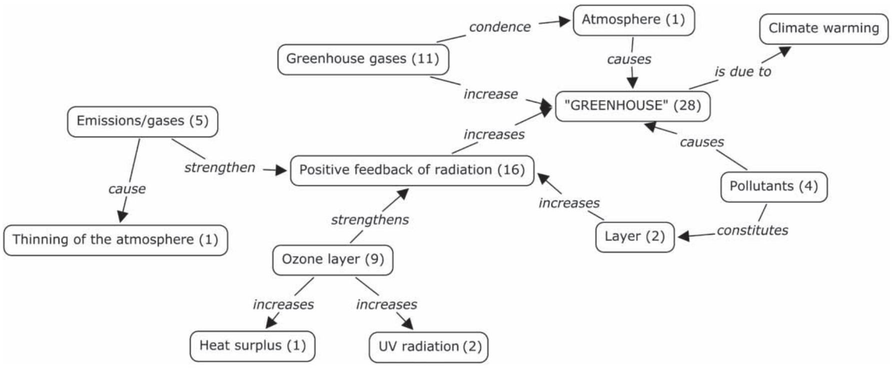

Figure 8. A greenhouse as an analogy for the greenhouse effect ($n = 28$). Number given in the parentheses indicates the number of students' mentions

The Conceptual Distinction between the Roles of the Ozone Layer and the Greenhouse Effect

According to the quantitative analysis of the present study, many primary student-teachers (84%) correctly stated that CFCs are greenhouse gases. Probably, students know that CFCs are the major agents causing ozone layer degradation, which confuses their thinking about the phenomena of ozone layer depletion and climate warming (Boyes & Stanisstreet, 1993; Jeffries et al., 2001). In the present study, comparatively few (34%) students associated ground-level ozone with climate warming. Naturally, it may be difficult for students to be aware that ozone layer depletion is harmful to the environment and that, therefore, ozone is needed in the stratosphere but that ozone is also the greenhouse gas at the lower level of the troposphere. The process of ozone depletion in the stratosphere occurs because ozone is decreased through photo-chemical reactions caused by certain man-made substances, CFCs, halons and nitrogen oxides. This depletion is responsible for the ozone hole that allows more UV radiation to reach the Earth and threaten plant and animal life. A number of earlier studies from different countries have indicated that people causally connect ozone layer depletion with the greenhouse effect (Rye, Rubba, & Wiesenmayer [1997], in Pennsylvania from grades 6 to 8; Jeffries et al. [2001], in the UK for year 1 biology students; Papaditmiou [2004], in Greece for primary student-teachers; and Nevanpää [2005], in Finland from grades 7 to 9). According to Papadimitriou (2004), primary student-teachers have given the explanation that the ozone hole allows more sunlight to penetrate the atmosphere, which heats the Earth. Similarly, primary student-teachers of the present study (49%) indicated the conceptual distinction between the roles of ozone layer depletion and climate warming (Figure 9). A comparatively high proportion of students (74%) endorsed the statement that the greenhouse effect is worsened by holes in the ozone layer. According to Boyes and Stanisstreet (1997) and Nevanpää (2005), but not noted in the present study, students have also thought that climate warming is one reason

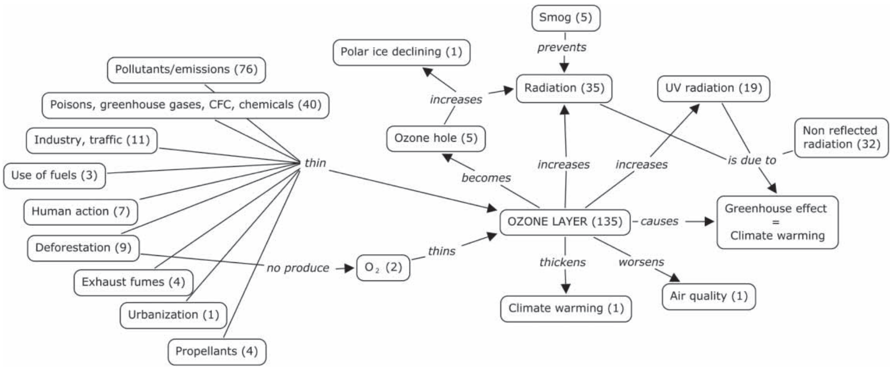

Figure 9. Ozone layer depletion is causally related to the greenhouse effect ($n = 135$). Number given in the parentheses indicates the number of students' mentions

for ozone layer depletion. Scientifically, ozone layer depletion is considered an important factor in global climate change due to its potential to affect the radiative balance of atmosphere and the formation of polar stratospheric clouds. When ozone layer depletion accelerates, the stratosphere cools off, because the smaller the amount of ozone, the less the energy released from UV absorption. A runaway greenhouse effect also makes the stratosphere cooler, and therefore, there are more polar stratospheric clouds in the stratosphere, which accelerate the depletion of ozone molecules. For this reason, it is not unexpected that students may conceptually confuse climate warming and ozone layer depletion.

Some primary student-teachers (20%) associated ozone layer depletion with increasing radiation or UV radiation (Figure 9). The latter is true for the Earth's surface, but students did not understand that the Earth receives energy from the Sun mostly in the form of visible light (P1). Students appreciated that the ozone hole in the atmosphere is the result of pollution, etc. when the Sun's rays (heat) pass through the ozone layer without being filtered by it. Moreover, many students simply thought, without any explanation, that the greenhouse effect is the result of ozone layer depletion. According to the present study, students did not confuse the scientific concepts, but their understanding was based on everyday thinking. The mechanisms for how ozone layer depletion causes climate warming described by students are not generally based on scientific thinking. Rye et al. (1997) found that students often think that the heat from the increased sunlight warms up the planet.

According to the present study and the study done by Koulaidis and Christidou (1999) and Nevanpää (2005), students associated different pollutants and emissions with ozone layer depletion. Moreover, different chemicals (Figure 9; $n = 40$), as seen in earlier studies (Rye et al., 1997), were one of the agents which deplete the ozone layer. The respondents' thoughts about human activity such as deforestation, industry and traffic, along with Fisher's (1998) study, indicate that students associated people with the reason for ozone layer depletion.

Students' Ideas about Real Possible Consequences of the Greenhouse Effect

According to the present study, respondents (94%) thought that the Earth would get hotter if the greenhouse effect were to increase (Table 3). Almost all the students were aware that the greenhouse effect and climate warming could increase melting of polar ice (94%), change weather patterns (99.6%) and cause more flooding (94%). More than half argued that there would be more deserts (77%) and insect pests (64%) on the Earth due to climate warming. Percentages are similar to the results reported by Jeffries et al. (2001).

It seems obvious that the respondents in the present study have a rather good understanding of the real consequences of the enhanced greenhouse effect, because relatively few students associated food poisoning (12%), heart attacks (16%) or earthquakes (25%) with the effect of climate warming. Nevertheless, the most common misconception, held by 79% of students, was that an increase in the greenhouse effect would result in a rise in the occurrence of skin cancer. The results are similar to those obtained from other studies (Jeffries et al., 2001). It is clear, therefore, that students have confused the greenhouse effect with ozone layer damage.

Students' Ideas about Real Possible Cures of the Greenhouse Effect

The quantitative data for answers to the statements about human actions which possibly reduce the greenhouse effect were examined in the present study (Figure 10). Most of the primary student-teachers appreciated the need for reduced use of vehicles (97%), using more wind power (90%) and the implementation of tree-planting programmes (83%) to minimize climate warming. Similarly, eight-tenths (78%) associated energy saving and paper recycling with decreasing climate warming. Nevertheless, only half of the respondents (54%) thought that nuclear power is a climate-friendly way of producing electricity. It is worth noting that one-third were unable to say anything about nuclear power being associated with climate warming.

Students' Self-Perceived Knowledge and Sources of Information about the Greenhouse Effect

About two-thirds of the primary student-teachers thought that they knew a lot or something about the greenhouse effect. More males thought themselves to hold correct beliefs about the greenhouse effect ($\chi^2(1) = 21.196$, $p < 0.001$, $d = 0.686$). Students' scholastic achievement did not affect their self-perceived knowledge. According to the present study, students' self-perceived knowledge and their understanding of the greenhouse effect do not correspond, because only 4% of the respondents conceptualized the greenhouse effect in a scientifically correct way in the open-ended questionnaire. A high proportion of the respondents stated that they had learnt about the greenhouse effect in school (67%), from the media (TV and radio, 61%) or during university studies (47%) (Table 4).

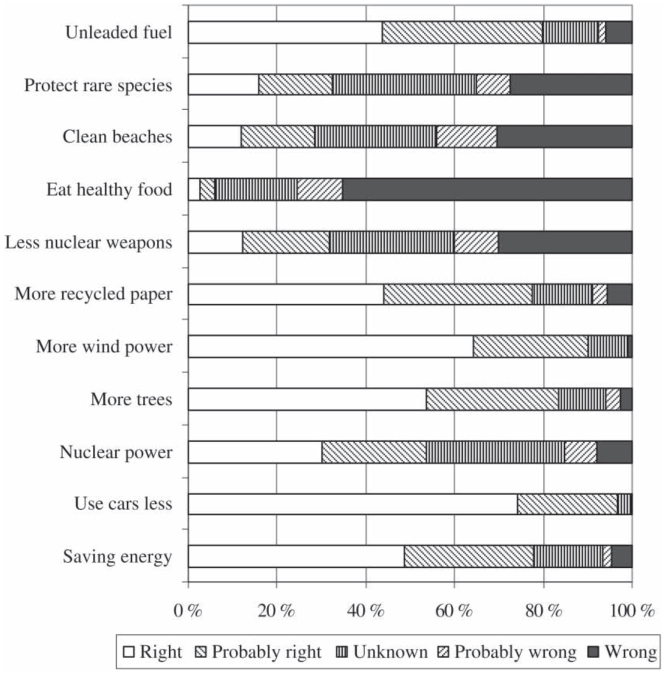

Figure 10. Distribution of students' responses about cures of the greenhouse effect ($n = 275$)

Table 4. Distribution of students' responses to questions on students' knowledge of the greenhouse effect and the assumed sources of that knowledge

	A lot	Something	A little	Nothing at all	No answer	Total
I know	10	58	30	1	1	100
Learnt from school	17	50	29	4	0	100
Learnt from TV	9	45	33	13	0	100
Learnt from radio	7	0	30	61	2	100
Learnt from the press	8	46	36	9	1	100
Learnt from studies	10	37	31	21	1	100

Notes: Results are given as percentages of all responses ($n = 275$).

Differences in Responses by Gender, by Science Studies and by Matriculation Examination Results

The present study indicates that there were differences between male and female responses along 12 variables. Most of the males realized that if the greenhouse effect worsens, desertification will accelerate ($\chi^2(1) = 3.947$, $p < 0.047$, $d = 0.327$)

and sea levels will rise ($\chi^2(1) = 8.297$, $p < 0.004$, $d = 0.439$). They also associated more with the idea of the Sun's rays being trapped as a real mechanism of an enhanced greenhouse effect ($\chi^2(1) = 5.136$, $p < 0.023$, $d = 0.304$). Females had more misconceptions, thinking that trash on the streets ($\chi^2(1) = 6.820$, $p < 0.009$, $d = 0.374$), radioactive waste ($\chi^2(1) = 19.371$, $p < 0.001$, $d = 0.717$), acid rain ($\chi^2(1) = 12.979$, $p < 0.001$, $d = 0.552$) and earthquakes ($\chi^2(1) = 5.216$, $p < 0.022$, $d = 0.346$) contributed to the greenhouse effect. At the same time, females more often expressed the idea that ground-level O_3 accelerates the greenhouse effect ($\chi^2(1) = 11.011$, $p < 0.001$, $d = 0.507$). The questionnaire asked for respondents' opinions on actions for decreasing the greenhouse effect. Females more often wrongly conceptualized that eating healthy food ($\chi^2(1) = 4.447$, $p < 0.035$, $d = 0.247$), avoiding use of nuclear bombs ($\chi^2(1) = 17.279$, $p < 0.001$, $d = 0.570$) and protecting rare species ($\chi^2(1) = 4.991$, $p < 0.025$, $d = 0.333$) would diminish the greenhouse effect. In contrast, males correctly saw nuclear power ($\chi^2(1) = 23.402$, $p < 0.001$, $d = 0.702$) and recycled paper ($\chi^2(1) = 5.241$, $p < 0.022$, $d = 0.246$) as agents which will reduce the greenhouse effect.

According to the results of the KW-ANOVA in the present study, the level of respondents' success in upper secondary-school studies did not very significantly affect their views regarding the greenhouse effect. However, the better the matriculation examination performance, the more likely the students were to consider reduced poisoning of fish and water systems as a result of the greenhouse effect ($\chi^2(4) = 9.825$, $p < 0.043$). Similarly, high-scoring students thought that radioactive waste does not contribute to the greenhouse effect ($\chi^2(4) = 10.008$, $p < 0.040$) and that the phenomenon cannot be mitigated by keeping beaches clean ($\chi^2(4) = 9.660$, $p < 0.047$). Respondents who had successfully completed upper secondary-school studies, therefore, held slightly fewer misconceptions about the causes of the greenhouse effect.

In Finnish schools, the greenhouse effect is mainly taught in geography classes. Students who scored well (mark 8.7) in their geography courses at upper secondary school were more prone to see more flooding as a consequence of the greenhouse effect ($\chi^2(4) = 10.132$, $p < 0.038$). Simultaneously, they less frequently thought that nuclear power will decrease the greenhouse effect ($\chi^2(4) = 9.641$, $p < 0.047$). Similarly, students with excellent marks (9–10) thought that poisoned fish in water systems is not a consequence of the greenhouse effect ($\chi^2(4) = 10.566$, $p < 0.038$), but they thought that the increasing CO_2 level in the atmosphere ($\chi^2(4) = 12.212$, $p < 0.016$) and the fact that the Sun's rays cannot escape from the atmosphere will worsen the greenhouse effect ($\chi^2(4) = 12.375$, $p < 0.015$).

Students' Environmental Attitudes and their Thinking about the Greenhouse Effect

Environmental attitudes were investigated in terms of environmental attitude variables employing statements designed to relate to the attitudes towards nature, science, technology and economic growth. Consequently, the question is different from those used by Ratinen (2005), for example. There were both optimistic and pessimistic statements of attitudes, with the optimistic variables expressing high hopes for a future in which attitudes will be affected by people's own activity, while the pessimistic variables illustrated the fact that people at present are passive in their environmental actions and do not think that the environmental problems are serious.

Students, in general, adopted a positive view towards environmental attitudes. Only about 2% said 'I do not care about the destruction of nature', and most of them (93%) maintained that a built landscape was not as beautiful as a natural landscape and nature would have to be protected even if it does not increase welfare (86%). Ratinen (2005) found similar results, with 87% of his respondents totally or moderately agreeing that nature conservation is important. A parallel result of his showed that 95% of people thought that it was important to protect the environment even if not everybody wished to do so. Eighty-four percent of students totally or moderately agreed that people have to change their lifestyle completely in order to save nature. The results were similar to those reported by Özden (2008), Ratinen (2005) and Tulokas (2002). In the present study, 59% of the students were ready to compromise their own welfare for the better future of the environment. When the claim was made that ordinary people cannot do anything about the state of the environment, 96% of the respondents partially or totally disagreed with this, suggesting that they understood their own ability to influence the state of the environment. Improving the environment was a complex process, and for this reason, 16% of the students believed that they could not achieve it to an appreciable extent. At the same time, students did not, in general, believe in technology and science, as 51% of the respondents were of the view that these could not solve environmental problems. The percentage reported by Ratinen (2005) was similar. Finally, students (96%) thought that attention must be paid to the state of the environment.

Males more often adopted a pessimistic view towards environmental attitudes. They thought that it was not important to protect the environment even if not everybody wished to do so ($\chi^2(1) = 7.769$, $p < 0.005$, $d = 0.367$), and males did not believe in their opportunities to prevent the deterioration of the environment ($\chi^2(1) = 8.127$, $p < 0.004$, $d = 0.415$). However, males more often expressed the view that science and technology can solve environmental problems ($\chi^2(1) = 8.748$, $p < 0.003$, $d = 0.448$).

Three principal components were calculated by PCA (Table 5). Variables demonstrating that students did not care about the state of nature was loaded (>0.5) on the first component, called *Pessimism*, while the second component, called *Protection*, indicated students' attitudes towards environmental protection. Variables which indicated students' attitudes towards nature, science, technology and the anthropogenic environment were given the name *Techno*. These principal components together explained 48% of the total variance.

In order to identify themes running through students' thinking about the consequences and cures of the greenhouse effect, the data were analysed by PCA. All

Table 5. Varimax-rotated principal components calculated from the attitude statements and their variable loadings

Attitude statements	Pessimism	Protection	Techno
I cannot do much to prevent the deteriorating state of the environment	0.731		
Ordinary people cannot affect the state of the environment	0.600		
I do not support protection of the environment if other people do not protect it	0.566		
The state of the environment is so good that is not worth paying attention to	0.549		
People have to change their lifestyle completely in order to save nature		0.771	
Nature would have to be protected even if it does not increase welfare		0.630	
I am ready to compromise my own welfare for the better future of the environment		0.434	
Science and technology can solve environmental problems			0.720
A built landscape is more beautiful than a natural landscape			0.624
Eigenvalue	1.980	1.175	1.143
Explanation of total variance %	22	13	13

principal components were orthogonal and, therefore, independent. All the statements in principal component 1, called *Awareness*, with >0.5 loadings related to correct ideas about the cures of the greenhouse effect (Table 6). Thus, students thought that wind energy, planting trees, recycling paper, conserving energy, reducing car use and nuclear power were ways of lessening the greenhouse effect. Maybe trees have to be seen as absorbing CO_2 from the atmosphere and recycled paper as saving trees, as Jeffries et al. (2001) found.

The second component, named *Misconceptions*, indicated erroneous ideas about the cures of the greenhouse effect. Namely, keeping beaches clean, reducing the nuclear arsenal and protecting rare species would help to reduce the greenhouse effect. These misconceptions are present also in young school students (Boyes & Stanisstreet, 1993), in undergraduate students (Jeffries et al., 2001) and in the context of the Finnish lower secondary school (Nevanpää, 2005).

Three consequences were loaded in principal component 3, called *Consequences*, in which students indicated that melting polar ice, rising sea level and changing climate are possible consequences of the increasing greenhouse effect.

The last component is depicted by food poisoning, fish being poisoned in water systems and people getting heart attacks, named *Illness*. The fact that students' beliefs about the greenhouse effect may result in erroneous ideas about the consequences of the greenhouse effect suggests that there may be some uncertainty in students' understanding of this issue. These principal components together explained 40% of the total variance.

Table 6. Varimax-rotated principal components for students' responses to questionnaire items about possible consequences and cures of the greenhouse effect

Questionnaire item	Awareness	Misconceptions	Consequences	Illness
If the greenhouse effect gets bigger...				
...more food poisoning				0.648
...more heart attacks				0.554
...more fish poisoned				0.548
...polar ice melts			0.696	
...more sea-level rise			0.606	
...more changes in world's climate			0.515	
The greenhouse effect can be smaller...				
...keep beaches clean		0.664		
...fewer nuclear bombs		0.650		
...protecting rare species		0.577		
...more wind power	0.735			
...more trees	0.649			
...using recycled paper	0.647			
...saving energy	0.614			
...not using cars so much	0.504			
...more nuclear power	0.503			
Eigenvalue	4.066	2.715	1.472	1.359
Experience of total variance %	17	11	6	6

Notes: Only loadings greater than 0.5 are given.

Discussion and Implications

How do Primary Student-Teachers Conceptualize the Greenhouse Effect?

The mixed method results demonstrate that primary student-teachers' knowledge about the greenhouse effect and climate change is insecure. For example, the conceptualization of the greenhouse effect as a natural phenomenon that regulates the Earth's climate is not clear. From the systems thinking point of view, their conceptualization of the greenhouse effect is more at the figurative level than at the model or molecular level. Relatively few students understand correctly the nature of solar radiation and its mechanism in the greenhouse effect. The results indicate that students have insufficiently conceptualized the wave and particle models and, in particular, the transient dipole moment of greenhouse gases. In other words, students did not have a good understanding of the mechanism of the greenhouse effect caused by greenhouse gases, water vapour, carbon dioxide, methane, low-level ozone and nitrous oxide. The open-ended questionnaire indicates that students' understanding of atmospheric processes is incomplete, because some of them also associated pollution with the greenhouse effect. The closed-form questionnaire revealed the students' understanding of atmospheric gases from a different point of view. Namely, fewer than half of the students knew that ground-level ozone acts as a greenhouse gas. All in all, there were no mentions of ground-level ozone in the students' replies to the open-ended questionnaire. Eight-tenths of the students imagined that there was a link between the greenhouse effect and skin cancer, and they had an incorrect model of climate warming, which involved excess penetration of solar radiation on the Earth, maybe via holes in the ozone layer. Students incorrectly relate the greenhouse effect to ozone layer depletion and their misconceptions are related to the lack of scientific knowledge. Qualitative analysis indicated that IR radiation was not usually mentioned in connection to the greenhouse effect. Instead, according to the quantitative analysis, UV radiation was confused with thermal radiation. The present study reveals that primary student-teachers' knowledge of the greenhouse effect was inadequate. There is a strong possibility that students have not achieved the three first levels of systems thinking (identifying the components and processes of a system, identifying processes that create relationships between system components, and building up a framework of relationship) in their studies in upper secondary school. Therefore, the basis for a holistic understanding of the greenhouse effect is lacking.

What are Students' Ideas about the Consequences of and Solutions to Climate Warming?

Primary student-teachers had a rather good understanding of the real consequences of the enhanced greenhouse effect. They especially thought that climate warming could change weather pattern. Some misconceptions were common. Almost half of the students thought of acid rain as a consequence of climate warming, and more than half of them thought that unleaded petrol would reduce the greenhouse effect.

How do Students' Environmental Attitudes, Gender and Scholastic Achievement Affect their Conceptualization of the Greenhouse Effect?

Students have, in general, positive and environmentally friendly attitudes towards the environment. It is worth noting that 59% of the students were ready to compromize their own welfare for the better future of the environment, and they believed (51.3%) that science and technology could solve environmental problems. The PCA indicated that the less the present students knew of the consequences and cures of climate warming, the more they held environmentally friendly attitudes. The result is noteworthy, and this has to be taken into account in science education.

Females had more misconceptions and they more often thought that non-scientific consequences such as radioactive waste and acid rain would accelerate the greenhouse effect. Similarly, females more often wrongly conceptualized that eating healthy food, avoiding use of nuclear bombs and protecting rare species would diminish the greenhouse effect.

The present study indicates that students' success in their studies at upper secondary school did not very significantly affect their opinion on the greenhouse effect. However, the high scoring of the matriculation examination certificate marks decreased students' misconceptions about the cause of greenhouse effect such as acid rain and holes in the ozone layer exacerbating the greenhouse effect.

Implications for Instruction

Understanding science is difficult for primary student-teachers, because abstract processes, such as the electromagnetic spectrum, wavelength, absorption and re-emission of electromagnetic energy, are involved. Especially, the molecular level is difficult to achieve. Therefore, in the science class, emphasis should be placed on the chemical reactions of the greenhouse gases and a closer look should be taken at how IR rays are absorbed into the atmospheric gases. Moreover, it has to be kept in mind that CFCs—but not carbon dioxide—have two undesirable effects on the atmosphere. Furthermore, the different layers in the atmosphere and their different physico-chemical reactions should be carefully taught in the science class. All in all, it seems obvious that the illustrative level of instruction is not sufficient for teaching the greenhouse effect in teacher education.

It is possible that traditional ways of teaching, which are based on transmission of knowledge, are inappropriate, because they do not help students to use the knowledge learned in order to understand real issues of everyday life. As Papadimitriou (2004) pointed out, demonstrations or local surveys are also inappropriate due to the abstract nature of science. Therefore, innovative pedagogical strategies are needed, such as concept mapping and the modelling approach, in order to teach complex environmental issues such as climate warming. Concept mapping would be beneficial in initial teacher education, because it helps learners to restructure their knowledge of climate warming. Concept mapping, which includes positive measures to avoid increasing the greenhouse effect, can help not only understand the climate warming, but it can also contribute to form conscious citizens.

Science teaching then explores and organizes learners' ideas in order to align them with scientific views of climate warming. Pupils and students may also assimilate new ideas and experiences of their beliefs regarding measures to decrease global warming and their willingness to act to avoid increasing the greenhouse effect, as Boyes, Skamp, and Stanisstreet (2009) pointed out. However, it should be borne in the mind that it would be beneficial to base learning and teaching on socio-constructivism, where students spontaneously collaborate.

In university education, it would be good to replace the actual greenhouse as an analogy for climate warming with a systems approach (Ben-Zvi Assaraf & Orion, 2005) with physico-chemical reactions, because it does not function using the same mechanism as the atmosphere. Greenhouses work primarily by preventing convection, whereas the atmospheric greenhouse effect reduces radiation loss and not convection. Comprehensive understanding of the greenhouse effect helps students understand how greenhouse gas molecules absorb long-wave radiation.

In the geography class, it would be possible to teach the greenhouse effect as a complex scientific phenomenon which calls for an interdisciplinary approach in order to understand the scientific thinking of students. Moreover, it would be necessary to take into account the different localizations and distributions of greenhouse gases and the ozone layer in the atmosphere during the geography classes. The fact is that greenhouse gases are spread in the troposphere, whereas ozone is localized in a relatively thin layer in the atmosphere. Despite the fact that the atmosphere is stratified, secondary-school students (Nevanpää, 2005) have suggested that carbon dioxide may absorb UV radiation and thus destroy the ozone layer.

Key environmental issues must be included in the teacher education curriculum. These students will be teachers of young pupils in school someday, helping them, in turn, to understand the debate in society related to climate warming and to make decisions based on science. In the light of the present study, however, primary student-teachers do not have adequate knowledge to teach the abstract concepts of the greenhouse effect. Climate change is a challenge to environmental educators and researchers, because it is an issue that is characterized by, for example, controversy, uncertainty, interdisciplinarity and complexity. Therefore, when teaching, students must be aware of both causes and predicted effects but also of the uncertainty of global warming as well as of the economic, political and social dimensions of climate change. The educational reconstruction model (Komorek & Duit, 2004) could be effective in developing systems thinking related to the greenhouse effect. According to the model, the knowledge acquisition process is seen as an active construction process of the individual within a certain social and material setting. Moreover, science knowledge seems to be viewed as a tentative human construction, which is also relevant in Ausubel's *Theory of Meaningful Learning* (Ausubel et al., 1978).

At present, our knowledge of teaching is still inadequate and research in this area is needed. The present study indicates that mixed method approach as an integral part of the study depicts more accurately the primary student-teachers' conceptualization of the greenhouse effect. Bringing together the strengths of qualitative and quantitative research, it is possible to corroborate qualitative results with quantitative finding, for example, that students' scholastic achievement not necessary improves their conceptualization of solar radiation.

Notes for Future Research

A possible subsequent area of research would be the study of possible solutions for the mitigation of climate warming (Figure 1). For example, reforestation and keeping up the Earth's surface vegetated decrease surface spectral emission. When vegetation is standing and it is articulated with regional and global warming, people probably understand their proposal of paying for the avoided deforestation or paying for native forest restoration. In the future, educational research should be focused on teaching and learning sequences for gaining a better understanding of the mechanism of the greenhouse effect. Moreover, research in science and social science should consider concrete measures to avoid the acceleration of the greenhouse effect. Human activities have increased the carbon dioxide concentration of the atmosphere. The best way of protecting the climate is thus to reduce the level of atmospheric carbon dioxide. Comprehension of the greenhouse effect may encourage the public to take actions, such as changing personal lifestyles, which would otherwise be unpopular. Unfortunately, education alone cannot solve climate crises. The economic, political and social dimensions of the greenhouse effect and geoengineering (at university level) should, therefore, be considered in instruction. Without adequate scientific knowledge, people may non-critically view geoengineering—such as iron fertilization of oceans to extract CO_2 from the atmosphere (Bertram, 2010)—as providing a ready solution to the problem of climate warming, remaining unaware of the considerable possible side-effects inherent to such solutions, such as ocean acidification (Caldeira & Wickett, 2003; Wayman, 2008). Clearly, climate change is an important educational concern.

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II

PRIMARY SCHOOL STUDENT TEACHERS' UNDERSTANDING OF CLIMATE CHANGE: COMPARING THE RESULTS GIVEN BY CONCEPT MAPS AND COMMUNICATION ANALYSIS

by

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Primary School Student Teachers' Understanding of Climate Change: Comparing the Results Given by Concept Maps and Communication Analysis

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Abstract Climate change is a complex environmental problem that can be used to examine students' understanding, gained through classroom communication, of climate change and its interactions. The present study examines a series of four science sessions given to a group of primary school student teachers (n=20). This includes analysis of the communication styles used and the students' pre- and post-conceptualisation of climate change based on results obtained via essay writing and drawings. The essays and drawings concerned the students' unprompted pre- and post-conceptions about climate change, collected before and after each of the four inquiry-based science sessions (in physics, chemistry, biology and geography). Concept mapping was used in the analysis of the students' responses. The communication used in the four sessions was analysed with a communicative approach in order to find out the discussion about climate change between teacher and students. The analyses indicated that the students did not have the knowledge or the courage to participate in discussion, but post-conceptualisation map showed that students' thinking had become more coherent after the four sessions. Given the results of the present study, proposals for using concepts maps and/or communication analysis in studying students' conceptions are presented.

Keywords Climate change · Inquiry-based teaching · Pre-service science teacher education

Introduction

In the face of environmental problems such as climate change, a rapid response is required from all parts of society. However, spreading understanding of such complex issues is challenging. The dissemination of scientific knowledge to the general public is an important factor in how they understand and evaluate the issue. Climate change has huge social, environmental and economic consequences. Nowadays, we are beginning to see some of the effects of climate change, such as changes in weather patterns and the melting of the polar ice caps (IPCC 2007).

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Thus, there is a clear need to study and implement both global and local solutions in order to adapt to climate change. Locally, climate change has become an issue for discussion in the science classroom, and this will affect the ability of future decision makers to solve the problems and make the appropriate, far-reaching decisions. Considering how badly informed people feel they are about climate change, more education is needed; the Special Environment Eurobarometer (European Commission 2008) showed that European citizens perceived climate change as one of the problems about which they were least informed. Several European school curricula and policy documents, including those of Finland, refer to the importance of developing pupils' decision-making skills based on science.

Many studies have shown that student teachers know the basic facts about climate change, such as the increasing temperature of the Earth, but that their knowledge is atomistic (Ekborg and Areskoug 2006; Ratinen 2008, 2011). Not only student teachers but also qualified teachers have misconceptions and misunderstandings about global warming (Papadimitriou 2004), and they probably pass their own ideas on to their pupils. Thus, education really matters when countries try to combat climate change.

The present study investigates student teachers' pre- and post-conceptualisation of climate change (i.e. before and after they had participated in a series of four science lessons). In the present study, learning is considered a process that includes social and individual aspects and consists of reviewing or relocating new information within students' existing models (see, e.g. Driver et al. 1994). In the case of climate change, the scientific and social representation depends not only on the quality of the scientific information but also on how such information is presented, processed and applied collectively (Meira 2006). This study analyses the discussion in inquiry-based science lessons on the grounds that learners' subject content knowledge is related to their ability to give appropriate scientific explanations (e.g. Childs and McNicholl 2007). Further, the study proceeds on the assumption that students' communication in the science classroom is more developed if they have internalised content knowledge about science.

Earlier Studies of Students' Conceptions of Climate Change

We cannot understand the processes of climate change without some understanding of the greenhouse effect. It seems evident that the problems of distinguishing between the greenhouse effect and ozone depletion may be due to problems in distinguishing infrared (IR) radiation from ultraviolet (UV) radiation, or even radiation from thermal energy (Boyes and Stanisstreet 1997; Meira 2006; Hansen 2010; Ratinen 2011). Learners from primary to university level do not understand the nature of the Sun's radiation. Lambert et al. (2012) found that students of elementary science methods have difficulty in understanding the greenhouse effect. Hansen's long-term study (2010) examined the development of pupils' knowledge about the greenhouse effect and the effects of the ozone layer from 1989 to 2005. In 2005, more pupils confuse the greenhouse effect with the effects of the ozone layer. At the same time, specific knowledge about the greenhouse effect is improving. Moreover, according to Andersson and Wallin (2000), students (K–9 and K–12) cannot distinguish the greenhouse gases correctly [e.g. they believe that chlorofluorocarbons (CFCs) are responsible for climate change because they destroy ozone and create the ozone hole, which allows UV rays to reach the Earth]. Therefore, some primary student teachers do not understand the role of the greenhouse gases in accelerating the greenhouse effect.

Boon (2010) compared pre-service teachers' and grade 10 secondary students' levels of understanding and knowledge relating to climate change. She found that there were similarities between the two groups, with knowledge and understanding of climate change remaining unacceptably low in pre-service teachers. Her study highlights the importance of curriculum planning to develop tertiary science curricula to bridge pre-service teachers' knowledge and understanding gaps of important school curriculum topics. Lombardi and Sinatra (2012) pointed out that greater knowledge of deep time (the history of Earth) and increased credibility perceptions about human-induced climate change lead to an increased understanding of global warming.

It seems evident that, in science education, the type of conceptual error varies depending on the age and level of the learners, which may be due not only to older and more advanced students having more and higher quality knowledge but also to their being able to discriminate between types of knowledge (Driver et al. 1994). Jakobsson et al. (2009) found in a study conducted though a written test that students' understanding of climate change is poor. They pointed out, however, that a written test does not explicitly reveal students' knowledge. Therefore, in the present study, it is considered that students' understanding or meaning making of complicated issues like climate change will be better if a communicative approach is used in the classroom. Discussion, listening and using video recording enables students to join in the learning processes and communicate more with their teachers, and they thus learn more about climate change. Hestness et al. (2011) emphasised the importance in science teacher education of providing opportunities for student teachers to increase their understanding of the relevant content and of helping student teachers become familiar with appropriate curricular resources, as well as engaging in on-going discussion and being able to evaluate developing views and understandings related to climate change.

While the examples of studies described above examined common conceptions among students, only a few studies have examined how those conceptions have been taken into account in different classroom interventions and their impact on student learning over time. Groves and Pugh (2002) found that students retained their misconceptions of the causes of climate warming, even after instruction. A longitudinal study suggested that many students do not develop understanding of the greenhouse effect during standard science courses in the upper secondary school (Ekborg and Areskoug 2006). However, as Svihla and Linn (2011) pointed out, middle school students can learn about complex systems (such as the greenhouse effect) if the curriculum is carefully designed. McNeill and Vaughn (2012) studied (by pre- and post-test written assessments and post-test interviews) how students' conceptual understandings, beliefs and environmental actions changed. They recommended that climate change curricula should focus on supporting students' development of critical science agency by addressing common student misconceptions.

Aim of the Study and Research Question

The present study aims to consider how students understand climate change based on communication in the teaching sessions and pre- and post-concept mapping. Students' communication in the four science practice sessions were analysed in light of previous studies on learners' conceptualisation of climate change. The post-concept map was used to indicate students' conceptualisation of the climate change after teaching sessions.

This study includes a description of the science sessions taught to primary school student teachers in an introductory course of science education and an evaluation of that course. The aim in the science course was to closely connect the physical and environmental aspects of climate change. The course was developed for university students studying to become primary school teachers as part of their introductory course in science education; it could be further developed in more specific courses at a higher level (e.g. in physical geography) and in in-service education.

Even if learners' knowledge of climate is known and considered in lesson plans, we still do not know how students' understanding takes place in the classroom communication and the dynamics of classroom talk. We know—for example, from McNeill and Vaughn (2012)—that students know more about climate change after a curricular unit; however, we do not know how their knowledge is accrued in classroom communication. Thus, the present study addresses the following question:

- How do sessions' communication analysis and pre- and post-concept maps describe primary school student teachers' understanding of climate change?

Pedagogical Choices and Organisation of the Teaching Module

To understand climate change, students need to be able to conceptualise how the greenhouse effect occurs and how energy is transformed (see, e.g. Lambert et al. 2012). Greenhouse gases in the atmosphere moderate how the Sun's radiation both enters and leaves the Earth's atmosphere. When the Sun's radiation is absorbed by the Earth, it is transformed into thermal energy, which is re-emitted by the Earth into the atmosphere as IR radiation. The greenhouse effect occurs when the greenhouse gases prevent IR radiation from leaving the atmosphere, when the transformed energy cannot get out of the atmosphere.

Teaching Module Description

A the core of the science education course for primary school student teachers is that students make a study of the teaching of one science topic for the duration of one academic year. Most of the course content supports this study project. The students' study project includes a content analysis, finding out pupils' ideas about the topic and finding, selecting or creating the most appropriate presentations and teaching strategies. Students also plan and teach a teaching period of a certain number of lessons. The main purpose of the science education course is to introduce the trainees to inquiry-based science teaching and learning (see Lehesvuori et al. 2011).

The inquiry-based teaching module that we have prepared aims at linking four sessions—physics, chemistry, biology and physical geography—that are closely connected from a conceptual and scientific point of view but are often taught separately in introductory science courses in teacher education in Finland. To give students experience of different ways of teaching and communicating, each session was developed in a pedagogically different way (see Table 1). The sessions consisted of different kinds of tasks, such as lecture, lab work, demonstration and groupwork phases. We considered that the descriptions involved (e.g. guider, co-inquirer or active inquirer) are often unhelpful for a deeper understanding of the complex interactions going on in inquiry-based science classrooms (Oliveira 2010b). In order to avoid that problem, the teachers involved with the course avoided using questions that learners could answer with simple yes or no responses (see Oliveira 2010a). In the sessions, individual thinking by the students was encouraged, and the sociocultural perspective (e.g. Lemke 1997), in which scientific ways of reasoning and acting were socialised, was adopted. The sessions were planned to be cumulative: The physics and chemistry sessions provided the scientific basis of climate change, the biology session was more applied, and the geography session brought the themes together. Students' preconceptions

Table 1 The main ideas of the planned science sessions

Physics session	
Teaching purpose	To familiarise students with the Sun's radiation
Students' misconceptions to be altered	To change students' ideas that the wavelength of radiation is constant. To make students realise that UV radiation does not cause climate change. Ozone depletion does not cause climate change
Main content	Wave and particle models of radiation, the simple principle of black body radiation
Forms of intervention	Demonstrating, reviewing, selecting, sharing and summarizing ideas with the whole class. Inquiring with peers
Inquiry methods	Demonstrations, experiments
Communicative approach	Interactive/authoritative and interactive/dialogic. Non-interactive/authoritative and non-interactive/dialogic
Chemistry session	
Teaching purpose	To understand the source of greenhouse gases and their role in climate change
Students' misconceptions to be altered	To correct the misunderstanding of chemical substances. To correct students' understanding of combustion: students were unable to grasp the role of oxygen in combining chemically with the combustible material. To clarify misunderstandings about the greenhouse analogy
Main content	Matter and its particular properties, combustion, molecular models
Forms of intervention	Demonstrating, reviewing, selecting and sharing ideas with the whole class. Inquiring with peers
Inquiry methods	Demonstrations, experiments, modelling
Communicative approach	Interactive/authoritative and interactive/dialogic. Non-interactive/authoritative and non-interactive/dialogic
Biology session	
Teaching purpose	To understand photosynthesis as circulating biological carbon and oxygen
Students' misconceptions to be altered	To expand students' ideas that rainforests are the lungs of the Earth. To correct misunderstanding of the source of atmospheric carbon
Main content	Photosynthesis, circulation of oxygen and carbon.
Forms of intervention	Demonstrating, selecting and sharing ideas with the whole class. Inquiring with peers
Inquiry methods	Experiment, using the microscope, demonstration
Communicative approach	Interactive/authoritative and interactive/dialogic. Non-interactive/authoritative and non-interactive/dialogic
Geography session	
Teaching purpose	To understand climate change as a system (Ratinen 2011)
Students' misconceptions to be altered	To correct the misunderstanding that the Earth's axel angle causes temperature zones, a belief that prevents students from having the basis to understand that the altered temperature zones are due to climate change. To teach the idea that the higher temperature is explained as a consequence of a non-steady state when more energy enters than exits until flux balances
Main content	Planetary phenomena, synthesis of all sessions
Forms of intervention	Reviewing, sharing ideas and checking understanding with the whole class. Inquiring with peers
Inquiry methods	Demonstrations, calculations
Communicative approach	Interactive/dialogic. Non-interactive/authoritative and non-interactive/dialogic

of climate change were used as background knowledge for the planning of the inquiry-based series of sessions. The total length of the teaching period was 4 weeks, with one triple period of 45 min (i.e. 2 h 15 min) for each session each week. Students were asked not to study climate change outside the sessions. The same teacher designed and guided all four sessions.

Several preconceptions were considered in the developing of our teaching module (Table 1). Firstly, ozone layer depletion is thought to be a cause of climate change, and increased skin cancer rate is considered an effect of global warming. Secondly, the idea of the trapping of the Sun's rays by the atmosphere is used as an explanation of the greenhouse effect (e.g. misunderstanding the greenhouse analogy). Thirdly, the higher temperature inside greenhouses is explained as a consequence of a non-steady state in which more energy enters than exits. In our case, the students focused progressively on each scientific phenomenon, and we assume that when students have gone through this cognitive process they are better prepared to teach climate change themselves. The fact that the teaching module included a series of appropriate experiments (demonstrations and lab work) together with observations (how to learn science) could give students a solid background from which to develop their understanding and preparedness to teach climate change. It is important to activate synergic integration between qualitative experiments (e.g. pupils' misconceptions of light), theoretical systematisations, quantitative experiments (on, e.g. the properties of visible light) and explicative models. The purpose of the course was also to familiarise students with the use of inquiry-based approaches, which they can use in their future teaching.

Methods and Procedures

Participants

The present case study focuses on one group of second-year primary school student teachers (n=20). This case study is descriptive and prospective, and findings are included as they become available from data (Yin 2009). Participants had not studied science before in the university.

Essay Writing and Drawing

The data were collected before and after four inquiry-based science sessions. The essays helped us to gain insight into the respondents' thinking about climate change because the students were able to give spontaneous responses: No answers were suggested or imposed. The open-ended question was as follows: 'What does climate change mean?' Students had about 45 min to write and draw their response. They hand-wrote approximately one A4 page for their essay. The data-based analysis of the essays examined respondents' answers: First of all, they were read through and then they were classified into concept categories. Then, two concept maps were drawn up by the researchers (one before and one after the teaching), based on the concept categories.

Concept Mapping

In the present study, concept mapping was used to represent schematically students' knowledge about the elements of climate change and the interdependence between these elements. Generally, concept mapping opens the way to the schematic representation of knowledge and can help students attain meaningful learning (Novak 1990; see more Novak and Cañas 2008). In this study, two concept maps are presented: the first drawn on the basis of the students' writing before the courses and the second one based on their writing after it, 1 week after the last (i.e. geography) session. Students' answers were analysed in the following way: For example, if there was a sentence, 'climate change increases because of greenhouse gases,' then 'climate change' and 'greenhouse gases' formed concepts, and the verb 'increases' formed a link word between these concepts. When this stage was completed, these 'mini' concept maps from all the responses were gathered together into one concept map. Therefore, the concept maps that were constructed represent the combined students' conceptualisation of climate change. Two researchers compared the final concept maps, and the content of concept maps was qualitatively analysed to make sure that they were similar. These collective concept maps are presented because their connection of classroom communication was analysed in the present study.

Video Recording and Communication Analysis

The science sessions were video recorded, which allowed us to analyse the communication that took place during the sessions. The present study presents an analysis of both the teacher's talk and students' contribution to classroom communication. The video recordings were analysed and

Table 2 Coding scheme for the communication analysis of the sessions

Code	Description	Example
Interactive authoritative (I/A)	In the question answer routine, students' responses are often evaluated and the teacher ignores diverging ideas. The authoritative approach focuses on the scientific point of view	Teacher: Why has the colour of water changed? Student: pH has changed. Teacher: Okey
Interactive dialogic (I/D)	Explores and exploits students' ideas and has no evaluative aspect. Thus, in the dialogic approach the teacher tries to elicit the pupils' points of view and works with these contrasting points of views	Teacher: This figure illustrates radiation. Is it longitudinal electromagnetic radiation or transverse radiation? Student: Longitudinal Teacher: What does that mean? Can somebody demonstrate with a spring? Student: Longitudinal moves like this (shows with the spring) and transverse like this. Teacher: Okey. Let's look closer at electromagnetic radiation… … look at this spring. How does it move? What do you think? Is the electromagnetic radiation longitudinal or transverse radiation? Student: I think that's transverse. Teacher: Yeah
Non-interactive authoritative (NI/A)	Teacher is presenting the scientific content by lecturing and takes no account of contrasting points of view	Teacher: Methane is a simple hydrocarbon: four hydrogen atoms and one carbon atom
Non-interactive dialogic (NI/D)	Teacher is working with contrasting points of views, for example with students' everyday views, and moves on to a scientific way of explaining things. So, even though the teacher is lecturing, diverging ideas are discussed. Thus, the teacher talk is dialogic	Teacher: As we did the exercise and learnt about it, now we can better understand that the visible light radiates to the Earth

systemically coded with the Atlas.Ti software into the four categories used by Mortimer and Scott (2003). In the present study, the approaches (Table 2) were, firstly, the *interactive/authoritative (I/A)* approach, where, in the question–answer routine, students' responses are often evaluated and the teacher avoids diverging ideas. The authoritative approach focuses on the scientific point of view. Secondly, and in contrast, the *interactive/dialogic (I/D)* approach explores and exploits students' ideas (e.g. their untutored, common views), and is not evaluative. Thus, in the dialogic approach, the teacher tries to elicit students' points of view and works with these views (which might contrast with their own). Thirdly, in the *non-interactive/authoritative (NI/A)* approach, the teacher presents the scientific content by lecturing and takes no account of contrasting points of view. Finally, in the *non-interactive/dialogic (NI/D)* approach, the teacher works with contrasting points of views—for example with students' common views—and moves on to a scientific way of explaining matters. Thus, the teacher talk is dialogic in nature.

In this study, we concentrate on interactive communication, considering it an indication of students' understanding of climate change. Interactive dialogic communication reveals students' own understandings (both scientific and non-scientific), and if students can take part in interactive authoritative communication, it is an indication of their understanding of scientific concepts. We also analysed the closing down phases of the communication. Scott and Ametller (2007) stress that meaningful science teaching should include both dialogic and authoritative aspects. If discussions are 'opened up' by a dialogic approach and pupils are given the chance to work with different ideas, at some point, discussions should also be 'closed down' with the authoritative approach. The 'closing down' phase can be very important—for instance, when clarifying the differences between pupils' everyday views and the views of science.

Two researchers coded the session independently and then compared episodes ($\kappa=0.66$, $p<0.001$). A written report and figures (see Figs. 2, 3, 4 and 5) were produced by summarising the analysis of the communication in each session separately. In this study, an episode was considered a teaching sequence that included a coherent entirety when considering the communication exchanges and classroom activities in their context. For example, if the teacher was giving instruction and shifted to another topic, the episode is considered a change. Similarly, the beginning of students conducting an inquiry session could be defined as the start of a new episode. Changes in the communicative approach were considered when making decisions about the episodes: The end of an episode (and beginning of another) was considered to occur when there were changes in activity, topic or communication.

Coded categories were compared to the main ideas of the science session plans (Table 1) to allow analysis of how the teacher's demonstrations, working in groups with peers, whole-class questioning and students carrying out practical activities managed to achieve the teaching purpose of the sessions. The descriptive analysis of the teacher's and students' activity is presented as explanatory episodes (see Childs and McNicholl 2007). Selected explanatory episodes indicate the ways in which the teacher used the discourse to develop suitable scientific explanations about climate change with the students. In the present study, the interpretation of communication was mostly based on the video recordings. Therefore, the extracts of classroom communication are mainly provided without symbols for discourse transcription, since they were considered redundant (Littleton and Howe 2009).

Results

The results section includes an investigation of students' pre- and post-conceptualisation of climate change and illustrations from the inquiry-based science sessions.

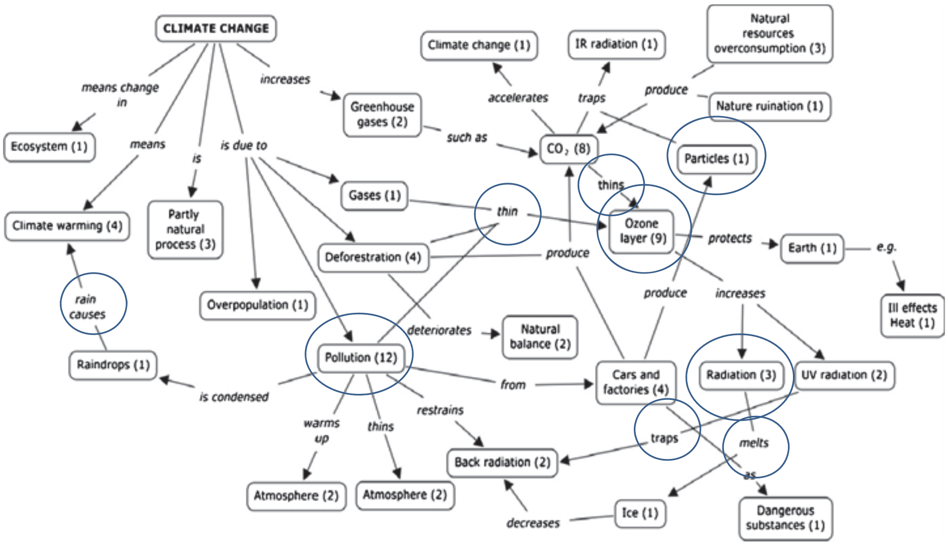

Fig. 1 Concept map constructed according to students' preconceptions of climate change. The *numbers in parenthesis* indicate the number of students having the ideas

Students' Pre-conceptualisation of Climate Change

The collective pre-concepts were used for the planning of science course sessions. The students' non-scientific statements are circled with a solid line in Fig. 1. The overview of Fig. 1 suggests that students often have three different groups of models: one focused on greenhouse gases, another on the ozone layer and the third one on pollution. Students correctly thought that carbon dioxide, as a greenhouse gas, causes climate change (40 % of students, Fig. 1); however, they were wrong to think that it causally connects to ozone layer depletion (45 % of students). Before receiving instruction, 60 % of the students particularly associated climate change with pollution, and their thinking is evidenced by their responses (Fig. 1). Many students thought that pollution and carbon dioxide thin the ozone layer and therefore allow more radiation from the Sun to reach the Earth. One student thought before the course that rain causes climate change and, thus, associated climate change with weather events. Similarly, another student thought that emissions from cars and factories trap IR radiation. Students had scientifically incorrect preconceptions about what causes climate change. Overall, the students' preliminary knowledge of climate change complicated the use of a wide range of dialogic inquiry-based science sessions.

Student Understanding of Climate Change Based on Communication Analysis

The communication varied quite a lot in the sessions, as presented in Figs. 2, 3, 4 and 5 and Table 3. Firstly, we will look in detail at the communication types, especially occurrence of interactive authoritative and interactive dialogic communication, the closing downs and expert guided talk at each session separately. Subsequently, conclusions will be drawn. It should be noted that every teaching session included students working in groups. The physics and chemistry sessions each included 22 such episodes (total length, 1 h 40 min and 2 h 2 mins, respectively). The biology session included 15 episodes lasting 2 h 6 min, and the geography session included 19 episodes lasting 2 h 4 min.

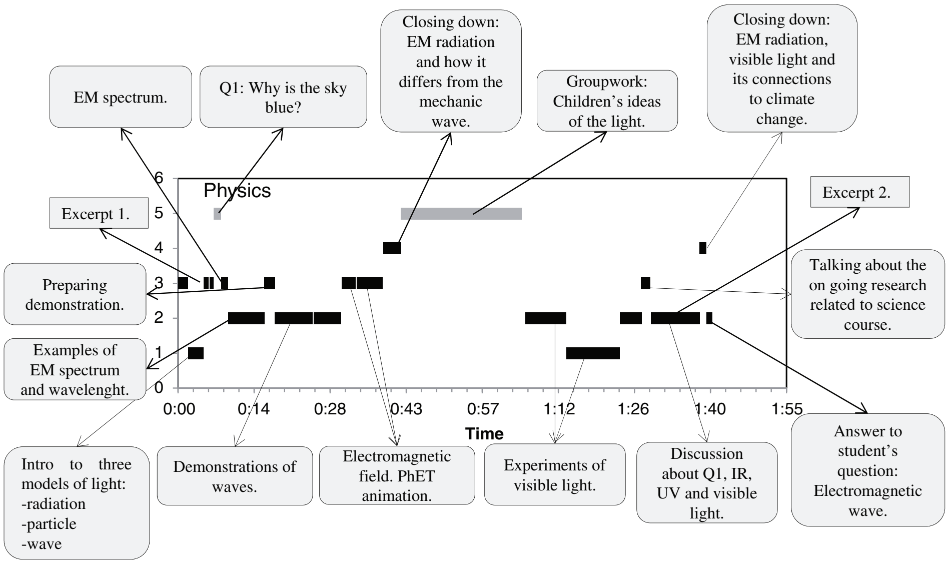

Fig. 2 Communication in the physics session. *1*=I/A, *2*=I/D, *3*=NI/A, *4*=NI/D and *5*=Inquiry. The location of each excerpt in the session is shown by a *rectangle*

Physics Session

As is known, the Sun's radiation reaches the Earth mainly as visible light. Therefore, the physics session mainly focused on the visible light part of the electromagnetic spectrum. As the students' pre-conceptions (Fig. 1) about climate change indicated, their basic knowledge about climate change was inadequate for the purposes of taking part in any wide-ranging communicative interaction. Excerpt 1 shows that the students' communication on the subject of Sun's radiation was poor. They thought that the main types of incoming radiation were IR and UV radiation.

Excerpt 1 (I/D), (0:03:49–0:04:45)

1. *Teacher*: Now we'll look more closely at visible light. Why we are doing it in this way?
2. *Student*: [*Nobody answers*.]
3. *Teacher*: What kind of radiation mostly comes from the Sun to the Earth?
4. *Teacher*: Say something.
5. *Student1*: IR radiation.
6. *Teacher*: One of you thinks IR radiation.
7. *Student2*: UV radiation.
8. *Teacher*: UV radiation. So, from there come the different wavelengths of radiation.
9. *Teacher*: Do you have any more sophisticated guesses for consideration?
10. *Student*: [*Nobody answers*.]
11. *Teacher*: Ok, let's look at these two cases.

In the dialogic discourse type presented in Excerpt 1, the teacher collects examples but does not work with these further in discussion, instead taking electromagnetic radiation into consideration in demonstration in waves (0:14:38–0:16:00) (Fig. 2). Later in the physics session (1:12:38–1:26:31), the three concepts—visible light, UV and IR radiation—were conceptualised as different types of electromagnetic radion with expert guided discourse based on experiments.

Overall, as Fig. 2 shows, various kinds of communication were used in the physics session. Interactive dialogic talk (42 %) was the predominant type of communication, occurring throughout the session. Interactive authoritative talk (13 %), non-interactive authoritative talk (16 %) and non-interactive dialogic talk (5 %) played relatively minor roles in the session. Figure 2 also illustrates the types of communication and their timing, showing the communication dynamics and when each event occurred. Students' prior knowledge (the Sun's radiation was conceptualised poorly in Fig. 1) about the electromagnetic spectrum was deficient, and this influenced the discussion of the wave and the photon models; relatively simple demonstrations had to be shown. The electromagnetic waves were the most difficult issue for students to conceptualise; therefore, non-interactive authoritative communication was used in the early phase of the teaching of the principles of the electromagnetic spectrum (Fig. 2, 0:08:08–0:09:27). At the end of the session, the question of why the sky is blue was examined by interactive dialogic communication, as Excerpt 2 shows.

Excerpt 2 I/D, (01:33:30–01:35:55)

1. *Teacher*: Why is the sky blue?
2. *Student*: [*Wait time* (Chin 2004).]
3. *Teacher*: Why are there different colours in the sky?
4. *Student3*: It [colour] depends how the light refracts.
5. *Teacher*: Yes. What colour is (the sky) on the Moon?
6. *Student4*: It is black.
7. *Teacher*: Why is the sky black on the Moon?
8. *Student5*: There is nothing which refracts light. There isn't any atmosphere.
9. *Teacher*: Yes, there isn't any atmosphere on the Moon. But what is the air? What are the elements of the air, mainly? What [element] is there most of?
10. *Student3*: Oxygen.
11. *Teacher*: Oxygen is the second. What is there more of?
12. *Student3*: Hydrogen.
13. *Teacher*: [*Teacher did not hear the student's answer.*]
14. *Teacher*: N—i.e., nitrogen.
15. *Teacher*: So, there are nitrogen and oxygen molecules in the atmosphere, and they refract [scatter] light like, we can imagine, the dust particle [shows data projector and former demonstration] did, and because the wavelength of blue is shorter, we see the sky as blue.

The question "Why is the sky blue?" (line 1) was asked to determine students' prior knowledge of electromagnetic waves, which was one of the key issues in the session and did not occur in students' pre-concepts (Fig. 1). Because one of the students did know about light refraction, it would have been useful for the development of communication if the teacher had used the student's knowledge to develop a more sophisticated discussion. The physics session ended (1:38:44–1:39:55) in an interactive and dialogic type of discussion, which is relatively uncommon in science lessons (Scott and Ametller 2007). On the other hand, a non-interactive end to discussion of the Sun's radiation took place at the beginning of the chemistry session, so there was thematic continuity between the sessions.

Chemistry Session

Interactive dialogic talk (46 %) was the pattern most commonly used in the chemistry session (Fig. 3). Overall, the interactive communication approach was used to gather students' ideas and to convert their wrong pre-knowledge of climate change to more correct knowledge. This is seen in the dynamics of the chemistry session; for example, the teacher used an interactive communicative approach to present water molecules to describe molecular mass and movement (0:09:27–0:15:04), since molecular ideas are necessary knowledge for understanding the greenhouse gases mechanism. However, as the interactive authoritative Excerpt 3 indicates, students did not know enough about science (Excerpt 3, line 4), and they were unsure about discussing these issues, just as they had earlier hesitated to take part in discussion in the physics session.

Excerpt 3 (I/A), (0:31:01–0:32:11)

1. *Teacher*: Why doesn't water burn (asked twice)?
2. *Student6*: It's wet.
3. *Teacher*: Isn't petrol wet?
4. *Student6*: Yes, but it is somehow different (other students laughed).
5. *Teacher*: Oh, every combustion reaction produces water. Water is the product of combustion, so it cannot burn any more.

One of the major reasons for students' passive discussion behaviour was that they were afraid of answering incorrectly. Excerpt 3, line 4 indicates that the student stopped answering because the other students began to laugh. Students' deficient preconceptions (Fig. 1) about chemistry complicated authentic communication between teacher and students.

Interactive authoritative communication (4 %), non-interactive authoritative communication (22 %), and non-interactive dialogic communication (5 %) played relatively minor roles in the chemistry session. Figure 3 shows that the chemistry session started with the non-interactive authoritative closing down of the Sun's radiation, which reviewed the physics session; later (0:36:20–0:39:08), expert guided knowledge was associated with the greenhouse gases by interactive dialogic communication and a review of the electromagnetic spectrum.

It was necessary to close by expert the groupwork discussion and construct correct models of the molecules of the greenhouse gases and carbon dioxide produced by combustion, especially as students did not have sufficient prior knowledge of them (Fig. 1). Students were shown the

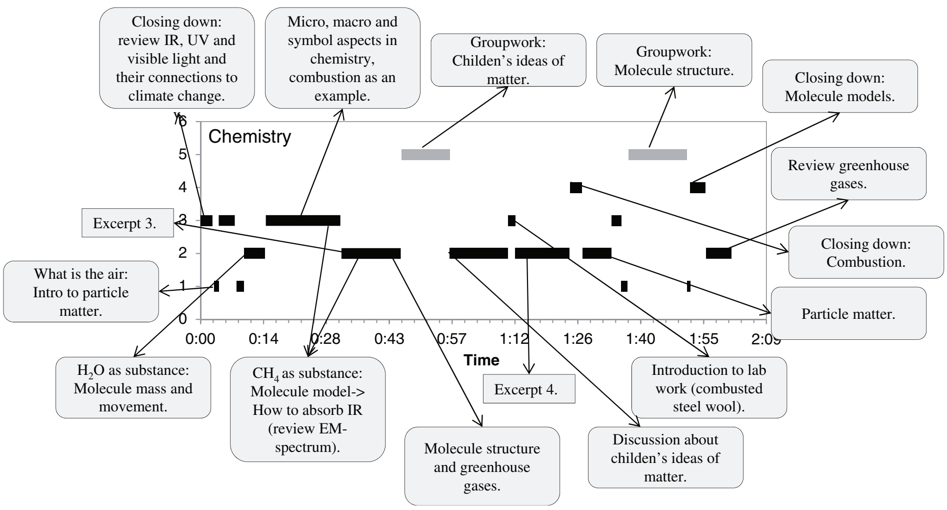

Fig. 3 Communication in the chemistry session. *1*=I/A, *2*=I/D, *3*=NI/A, *4*=NI/D and *5*=Inquiry. The location of the excerpt is shown by a *rectangle*

micro-, macro- and symbolic aspects of chemistry by demonstrating to them the combustion of steel wool. The experiment showed that, in the combustion, the substance reacts with oxygen, and the micro-, macro-, and symbolic aspects of chemistry were used to help learners to understand the chemical reaction related to climate change. Although teachers mostly used the non-interactive/authoritative approach (0:14:55–0:29:20), the teacher was also able to move along the non-interactive dialogic dimension (1:24:40–1:27:20) in his interactions with the students (e.g. when dealing with combustion). Overall, we can see that interactive dialogic communication did not work well because most of the students were loath to become involved in the discussion in the classroom. Students' passivity led the teacher to eventually fall back on more closed questions (Excerpt 4, lines 10, 12 and 14).

Excerpt 4 (I/A), (01:15:20–01:24:20)

1. *Teacher*: If we think about very simplified combustion. [Draws on the blackboard] There is steel and oxygen (shows steel wool to the students). The grey is steel, but what is that blue? Is it still steel?
2. *Student*: [*Nobody answers*.]
3. *Teacher*: If we think about the issue [burning steel wool] from the point of view of particle matter, and this burnt steel wool consists of something. So, it included 330 mg of steel molecules [steel wool weighed before the experiment], but in combustion, the oxygen reacted and then the steel wool weighed about 30 mg more. Has the colour [Teacher shows steel wool] changed? What does that tell us?
4. *Student*: [*Nobody answers*.]
5. *Teacher*: What does the increased weight tell us about from the viewpoint of particle matter?
6. *Student*: [*Nobody answers*.]
7. *Teacher*: What is combustion always?
8. *Student7*: Oxidation.
9. *Teacher*: Do not confuse combustion with oxidation–reduction reactions. If we think about the oxidation of copper, we can think in this case that combustion is very rapid oxidation. So, oxygen reacts and it has molecule mass. If we think about the molecule mass [of oxygen]… …and weight [of the steel wool] has increased and changed colour…
10. *Teacher*: …Can somebody say what this is [steel wool]?
11. *Student*: [*Nobody answers*.]
12. *Teacher*: Iron plus oxygen means?
13. *Student*: [*Nobody answers*.]
14. *Teacher*: Iron oxide. This demonstration has tried to show that, in combustion, oxygen reacts with matter and iron as other metals constitute new compounds. And the reaction with oxygen means increased weight.
15. *Student8*: So, combustion, is it always a reaction with oxygen?
16. *Teacher*: Yes.

Students did not know enough about combustion and its relation to climate change. Their conceptualisation of combustion was based on everyday beliefs on the subject. The physics and chemistry sessions helped students to construct what they needed to understand the physical–chemical principles of the greenhouse effect (electromagnetic radiation—especially visible light, particle matter, an IR radiation absorption by the greenhouse gases); this did not really occur in students' preconcepts. This knowledge would then be applied during the following biology and geography sessions.

Biology Session

Interactive authoritative (30 %) and interactive dialogic communication (26 %) were the predominant types of communication in the biology session (Fig. 4). As the dynamics of Fig. 4 show, before the first groupwork (0:43:36–0:50:46), interactive talk played an important role in the preparation for the experiment of photosynthesis. For example, the concept of pH was dialogically discussed because the experiment was based on the use of changing indicator colours (0:14:28–0:24:21). Non-interactive authoritative (8 %) and non-interactive dialogic (2 %) talk played relatively minor roles in the biology session.

Nevertheless, students' ideas about photosynthesis as a chemical reaction were inadequate for an appropriate understanding of climate change. They did not, for example, understand how photosynthesis influences CO_2 and O_2 circulation and relates to climate change (e.g. the formation of fossil fuels) (Excerpt 5). It seems clear that, even after the physics and chemistry sessions, the students' continued to be uncertain about the principles of the greenhouse. This uncertainly led the teacher to use many additional questions, as can be seen, for example, in Excerpt 5 (e.g. lines 11 and 15).

Excerpt 5 (I/D), (01:53:49–01:59:00)

1. *Teacher*: … How is it possible that the oxygen concentration has increased in the Earth during a million years even if an equal amount of oxygen is demanded in plant respiration ["degradation" in the worksheet] or when plants have been eaten. So, there is a balance. How is it possible? We should have more carbon dioxide in the atmosphere, but there is more oxygen.
2. *Student3*: Is it somehow more efficient photosynthesis or plants absorb more carbon dioxide, and when the conditions for photosynthesis have got better, more oxygen has been released?

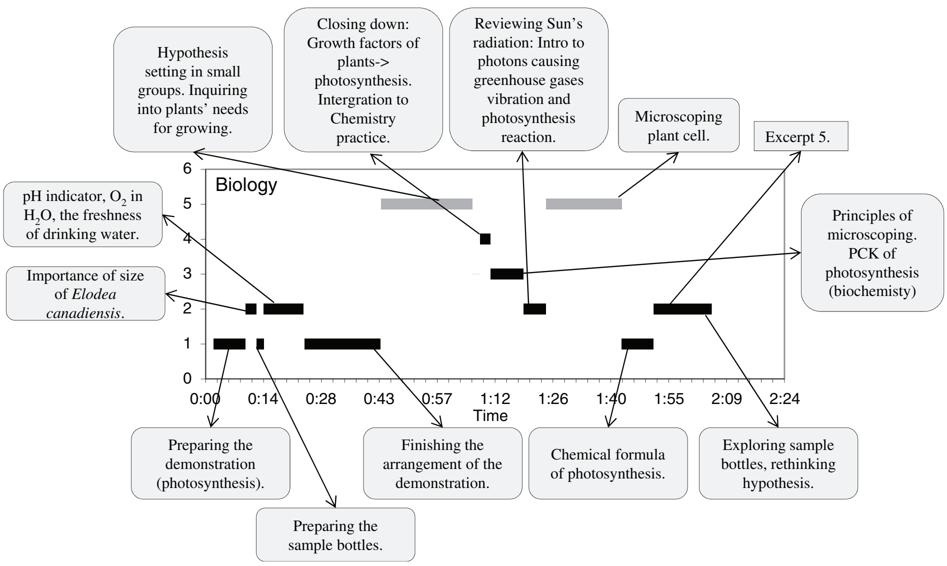

Fig. 4 Communication in the biology session. *1*=I/A, *2*=I/D, *3*=NI/A, *4*=NI/D and *5*=Inquiry. The location of the excerpt is shown by a *rectangle*

3. *Teacher*: A good answer, but more efficient photosynthesis means that plants will grow faster, and when they are eaten, the same amount of carbon would be released… … Do you have any other guesses? [Nobody answers.]…I'll help you and we'll connect the issue with climate change… …In the pre-test, your answers included pollution, cars and factories, and so on. Why did you say that? [Nobody answers.]… Why do they accelerate climate change?
4. *Student9*: I guess that greenhouse gases disintegrate.
5. *Teacher*: But where are those greenhouse gases released?
6. *Student10*: From space (mumbles).
7. *Teacher*: Where do those greenhouse gases come from?… …Take an example: a car. The car releases greenhouse gases. Why?
8. *Student3*: It burns gasoline, due to combustion.
9. *Teacher*: Combustion produces greenhouse gases. What burns?
10. *Student7*: Carbon dioxide.
11. *Teacher*: Carbon dioxide formed, but what burns?
12. *Student(?)*: Fossil fuels (mumbles).
13. *Teacher*: What do fossils burn? [Teacher did not hear student's answer completely].
14. *Student7*: Oil.
15. *Teacher*: Oil, but what is oil? How we can associate it to fossils?
16. *Student11*: It is compressed, some organisms inside the earth's crust.
17. *Teacher*: Yeah. Compressed organisms. We are getting closer now… …So, there are compressed organisms, which are converted into oil as you said. So, what is oil?
18. *Student(?)*: Fossil fuel (mumbles).
19. *Teacher*: Exactly. When we burn those fossil fuels, they release carbon dioxide, greenhouse gases, due to combustion reactions, as we saw before. Carbon dioxide accelerates climate change, and this is associated with the third task [groupwork for students] so that over time, a huge amount of organic matter has remained non-decomposed and it is stored in the crust, and oxygen has not totally failed to decompose. And, therefore, there is so much oxygen in the atmosphere. But if all the oxygen was used in decomposition, the situation would be balanced…

Overall, the interactive dialogic communication and expert guided teaching were needed for students to sufficiently develop (see, e.g. Jakobsson et al. 2009) their scientific knowledge about climate change and the release of CO_2 from burnt fossil fuels as an accelerator of the greenhouse effect. However, as Excerpt 5 shows, the teacher spoke as if telling a story (lines 19 and 20), and this probably made it more difficult for students to participate in a natural discussion.

Geography Session

The basic idea of the geography session was to bring together the facts of climate change dealt with in the previous sessions by raising students' awareness about the planetary phenomena of Earth and their connections to climate change. Thus, the planetary phenomena acted as an example to handle students' preconceptions of climate change. Interactive dialogic talk (43 %) and non-interactive dialogic communication (28 %) mostly featured in the geography session (Fig. 5), non-interactive authoritative communication (8 %) played a minor role and interactive authoritative communication (0 %) was absent. The dynamics of the session (shown in Fig. 5) indicate that the geography session started with interactive dialogic talk in a review of the photosynthesis experiment and concluded with non-interactive dialogic communication on the subject of teaching photosynthesis in elementary school. The dynamics of the geography session differed from those of the other sessions, especially at the end of the session, in that the teacher talked non-interactive dialogically to bring together the themes of the sessions (planetary phenomena and the solar system model). Towards the end of the geography session, the facts of climate change dealt with in the previous sessions were brought together, so that the session ended in a review consisting of non-interactive authoritative talk (1:44:40–1:46:20 and 2:01:48–2:03:08).

Therefore, the expert guided teaching contributed to students' learning and altered their understanding of climate change to be more scientific. After the groupwork (0:22:10–0:33:12), the whole class interactive dialogic talk helped the students to link their everyday thinking to their scientific knowledge.

As Fig. 5 shows, before the review (1:44:40–1:46:20), non-interactive dialogic communication had been the dominant mode. Excerpt 6 illustrates its use when the discussion of climate change closed down, which is not so common in a science lesson (e.g. Scott and Ametller 2007). Although this was the end of the teaching sessions, students still had difficulty in taking part in the discussion (lines 2, 4, 6, and 8), and many questions about the greenhouse effect remained unclear to them.

Excerpt 6 (NI/D), (01:50:35–01:59:16)

In this excerpt, the teacher initially tried to lead the subject around to the greenhouse effect by asking about the balance between incoming and outgoing radiation; however, the lack of response from the students led the teacher to use easier questions, and he talked about the greenhouse gases as a cause of equilibrium (line 13). It would have been better to ask how the greenhouse gases act on the atmosphere, for example.

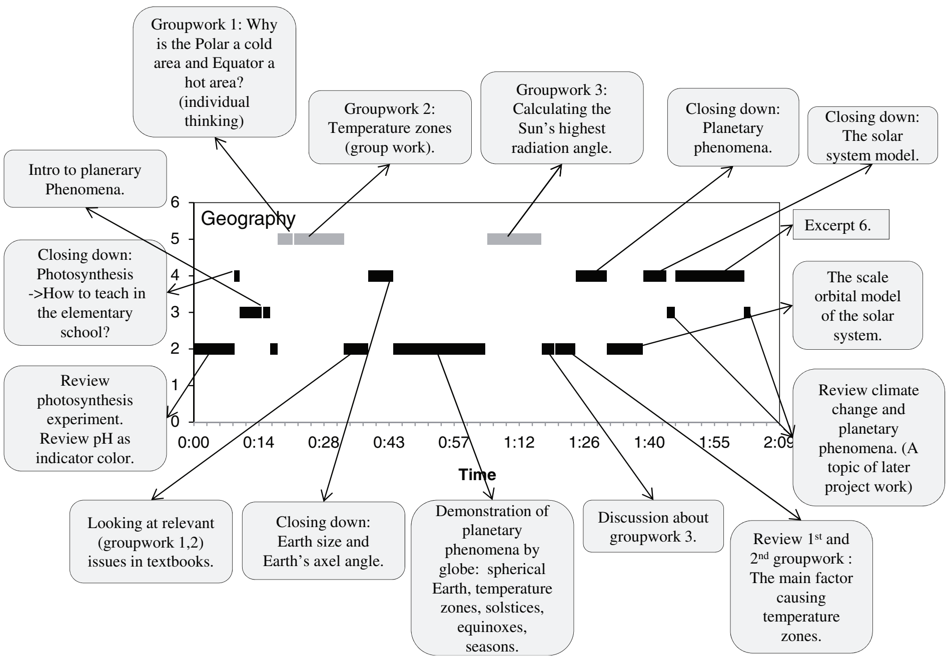

Fig. 5 Communication in the geography session. *1*=1=I/A, *2*=I/D, *3*=NI/A, *4*=NI/D and *5*=Inquiry. The location of the excerpt is shown by a *rectangle*

Principle of the Greenhouse Effect

1. *Teacher*: … Here is [Teacher shows the blackboard] outgoing IR radiation 240 W/m^2 and outgoing solar radiation 103 W/m^2 and it equals 340 W/m^2 [incoming solar radiation was presented before], right?
2. *Student*: [*Nobody answers.*]
3. *Teacher*: So, there is the balance. And we think that equilibrium does not occur [the teacher is thinking about climate change] due to the model of black body radiation. But in the Earth's system the balance is true because there is a factor which we have been considering in our course. What is the reason for the equilibrium?
4. *Student*: [*Nobody answers*.]
5. *Teacher*: Meaning that incoming and outgoing radiation is balanced. *Or it has been, but not really nowadays*. What does the atmosphere include?
6. *Student*: [*Nobody answers*.]
7. *Teacher*: What have we done? What did we do in the chemistry session?
8. *Student*: [*Nobody answers*.]
9. *Teacher*: I think that you know.
10. *Student(?)*: I don't know (mumbles).
11. *Teacher*: Who doesn't know? (more than half of the students raise their hand)
12. *Student*: Do you mean who *doesn't* know?
13. *Teacher*: Yes. Raise your hand, honestly. What causes this equilibrium?
14. *Teacher*: What are water vapour, carbon dioxide, methane, CFCs.
15. *Student(?)*: Greenhouse gases (mumbles).
16. *Teacher*: They are the greenhouse gases, and they can absorb IR radiation because of their molecular structure.
17. *Student3*: Dipole moment transition.

From the greenhouse effect, the teacher moved on to climate change and talked about radiative force. The radiation balance can be altered by the various greenhouse gases related to climate change. It would have been necessary to associate implicitly (teacher's talk) the alteration in the radiative force with balanced incoming and outgoing radiation (line 5) for a new balance to be reached.

Principles of Climate Change

18. *Teacher*: Yes, very good, dipole moment transition. And, therefore, incoming and outgoing radiation is more or less balanced. But nowadays there are more and more greenhouse gases in the atmosphere, and, therefore, in 2005, if I remember correctly, it was calculated [teacher writes on the blackboard] that there would be fewer outgoing. The warming potential would be 0.85 W/m^2±0.15 W/m^2. And this is the reality [teacher circles numbers on the blackboard]: that the radiative force of the greenhouse gases would seem to get bigger and bigger because there are more and more greenhouse gases.
19. *Student(3)*: And so less radiation is going out into space?
20. *Teacher*: Yes.

Then, the teacher non-interactively and authoritatively presented the information that incoming radiation from the Sun, mainly visible light, was converted into heat and emitted from the Earth's surface as IR radiation, illustrated by the model of black body radiation. In fact, the teacher made a mistake and first talked about emitted shortwave radiation, but later corrected it to IR radiation.

Excerpt 6 (continued)

> 21. *Student(3)*: Can you say more about how black body radiation associates with climate change.
>
> 22. *Teacher*: Yes. But it would take two hours.…I don't have any figures. We'll think about that issue later (The model of black body radiation was presented in the next session). But let's agree, because it is a very complicated issue, that we should not study it now. But you need to understand that the model of black body radiation explains the solar radiation changing to IR radiation. And according to the model of black body radiation, the Earth's temperature would be about minus 16 °C without the greenhouse gases.

Finally, the teacher non-interactively and authoritatively concluded the subject of climate change on the blackboard, which clarified students' thinking. He said that the greenhouse gases capture 88 % of emitted longwave radiation and that, if that 88 % rises, the problem will get bigger (compare Fig. 6: less IR to space and more incoming than outgoing radiation).

Overall, student participation in climate change education showed the difficulties of teaching these student teachers complex issues. The greenhouse effect and climate change touch upon so many difficult areas of science that students had difficulties participating in an interactive discussion. However, as Table 3 shows, the communication patterns varied in the sessions. This is not surprising because the original plan for the sessions had included different kinds of classroom activities at different stages of the course. The particular topic and the different methods of instruction influenced the pattern of communication.

The biology session included less interactive dialogic communication (26 %) and more interactive authoritative communication (30 %) than the other sessions. The main reason for this is the time-consuming photosynthesis experiments (34 % for inquiry) and

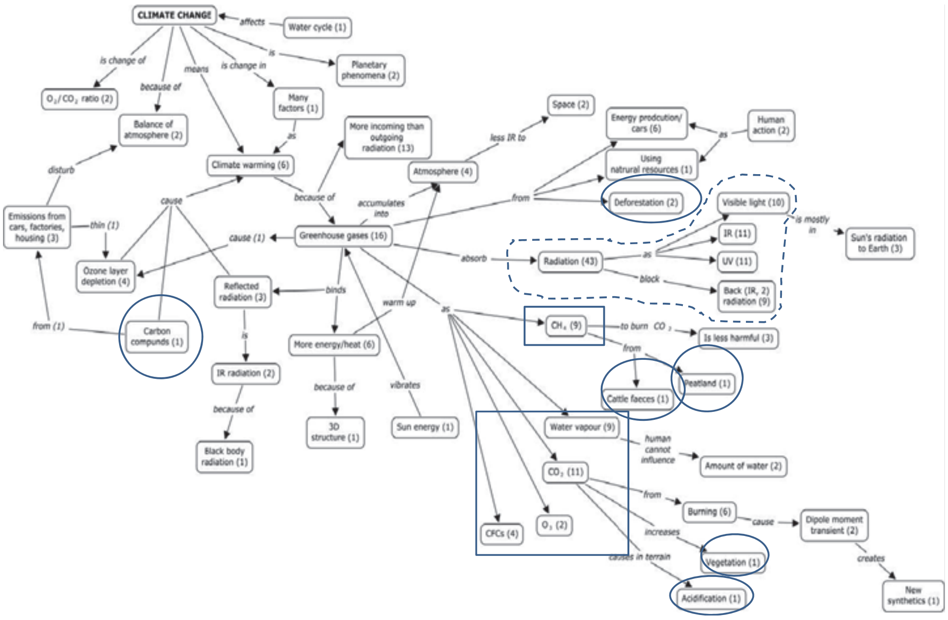

Fig. 6 The concept map constructed according to students' post-conceptions of climate change. The *numbers in parentheses* indicate the number of students

their authoritative nature. A similar interpretation can be made in physics with the experiment on visible light. Another remarkable difference can be found in the percentage of non-interactive dialogic communication, especially in the geography session (28 %); that is because the geography session included many closing down phases, and it brought together topics from the previous sessions. Opening up phases were similar in sessions other than biology. There was more lecturing, and thus non-interactive authoritative talk, in physics (16 %) and chemistry (22 %) than in the biology (8 %) and geography (8 %) sessions because in physics and chemistry the teacher introduced and defined many abstract concepts. It is not surprising that the sessions were different from each other because the purpose of the teaching and the forms of intervention were planned differently (Table 1). However, the teacher's need to use many additional questions and other sorts of encouragement reflected the students' inability to participate in dialogic inquiry-based teaching of climate change because of their ignorance on the subject. However, we will take a closer look at how the students' conceptualisation of climate change altered during the sessions.

Students' Post-conceptualisation of Climate Change

The pre-concept map includes 30 % of the same linking phrases as the post-concept map. It can, therefore, be said that students' conceptualisation of climate change became more varied. The concept map drawn after the course includes 16 concepts more than the initial concept map does. Unfortunately, misunderstanding about the role of ozone in climate change persisted after the course, as can be seen from Fig. 6.

About 20 % of students still thought that ozone depletion causes climate warming. This result is odd in the light of the content of the geography session, since in that session the greenhouse effect and its connection to climate change were explained and the issues from the earlier teaching sessions were drawn together. The results show how difficult it is to change students' ways of thinking. The students' pre-conceptualisation of climate change seemed to be relatively simple. However, students' thinking on the subject did develop after the four sessions: afterwards (Fig. 6), students named water vapour (45 % of students), methane (45 %), ozone (10 %), carbon dioxide (55 %) and CFCs (20 %) as the greenhouse gases. In the post-concept map (Fig. 6), most of the students (80 %) somehow associated the greenhouse gases with radiation. However, most students' understanding of how the Sun's radiation and the Earth emitting IR radiation cause climate change remained poor. They had insufficiently conceptualised the wave and particle model and, especially, the transient dipole moment of the greenhouse gases (students did not mention the transient dipole moment in their essays and did not participate in the discussion of it). In other words,

Table 3 Differences in the communication in the different teaching sessions (numbers are percentage of teaching time used)

Type of communication	Physics (%)	Chemistry (%)	Biology (%)	Geography (%)
Interactive authoritative (I/A)	13	4	30	0
Interactive dialogic (I/D)	42	46	26	43
Non-interactive authoritative (NI/A)	16	22	8	8
Non-interactive dialogic (NI/D)	5	5	2	28
Inquiry	24	20	34	22
Total	100	100	100	100

students did not achieve a coherent understanding of the mechanisms of climate change caused by greenhouse gases.

Analysis of the post-concept map (Fig. 6) also indicates how students correctly thought that radiation from the Sun associated with the accumulation, absorption and binding of the greenhouse gases reduced outgoing radiation; however, they named the forms of the Sun's radiation [visible light (50 %), IR (55 %), and UV (55 %)] without giving any thought to the context. Most of the students (65 %) wrote in the post-questionnaire that the climate is warming up because there is more Sun's radiation coming onto the Earth than is radiating out. Thus, the idea that the higher temperature is explained as a consequence of a non-steady state was reasonably well understood. According to the concept maps and students' participation in the discussion at the end of the geography session, students' understanding of black body radiation remained poor. Students did not understand that the black body is an idealised physical body that absorbs all electromagnetic radiation while its thermal equilibrium emits absorbed electromagnetic radiation.

Overall, students did not very deeply understand the greenhouse gases as climate change accelerators, even after instruction. Surprisingly, after instruction 10 % of students confused climate change with planetary phenomena (e.g. temperature zones), which was one of the topics of the geography session. Therefore, it can be said that non-interactive authoritative communication at the end of the geography session was not very successful.

Figure 6 shows the influence of the four teaching sessions on students' post-conceptions of climate change. The important role of the Sun's radiation causing the greenhouse effect by greenhouse gases and as accelerating climate change, which was taught in the physics session, can be clearly seen in Fig. 6 (circled with a line of dashes). The greenhouse gases are presented in detail in the post-concept map, and the gases were associated with the mechanism of climate change, especially in the chemistry session (in the square in Fig. 6). In Fig. 6, there are many biological concepts (circled with a solid line); however, the disturbance of oxygen and carbon circulation due to using fossil fuels no longer occurred in students' responses. It is evident that students' thinking began to move towards the idea of systems thinking about climate change, even if they are still uncertain about many things. Nevertheless, students' thinking was more coherent after these four dialogic inquiry-based sessions. Overall, it could be expected that students' thinking would be more coherent. However, as the number of concepts indicates, the level of students' conceptualisation of climate change varied a lot.

Discussion

To give students experience of different ways of teaching and communicating, each session was developed in a different way, including many kinds of group work, lab work, demonstration and discussion. Earlier research (e.g. Ratinen 2011) has pointed out the difficulties that students training to become primary school teachers have had in understanding complex scientific issues such as climate change, and this could also be seen in the present study. The present findings suggest that these primary school student-teachers' knowledge about climate change was inadequate, even after four inquiry-based science sessions. Students' conceptual understanding of climate change increased, though it remained incomplete. Therefore, the present study agrees with Groves and Pugh (2002), who also found that students in university held on to their misconceptions of the cause of climate warming after instruction. However, according to Lambert et al. (2012), student teachers in university were able to learn a number of specific concepts related to climate change after a short span of instructional intervention.

The present study examined (methodologically innovatively) how primary school student teachers' pre- and post-concept maps of climate change compare in inquiry-based science teaching. The study reveals that students probably would have been more able to participate in the discussion at the end of the geography session than they were before. Students' post-conceptions (especially those achieved from physics and chemistry sessions) did not occur in students' discussion activity when the physico-chemical basis of climate change were communicatively studied and reviewed at the end of the geography session. Unfortunately, even if communication analysis reveals students' way of thinking, we do not yet know exactly why the students, who have all passed their school matriculation examination with high grades of science (Ratinen 2011), are so timid about participating in discussions. Nevertheless, this study indicates the interconnection between discussion and knowledge: without relevant knowledge, students do not have the courage to discuss, and if students do not discuss, teachers do not know exactly what learners know and how they think. Otherwise, students' fear of wrongly answering the question may paralyse the discussion.

In addition, because students' preconceptions of climate change were quite inadequate, the sessions concentrated on altering students' understanding of climate change: (e.g. studying the concept of electromagnetic radiation, expanding their ideas about the greenhouse gases as chemical substances caused by combustion. Helping students understand photosynthesis as the biological circulation of carbon and oxygen and climate change as a non-steady state in which more energy enters than exits from Earth until it is balanced again). Instruction in the physics and chemist\ry, and partly in the geography sessions was on quite an abstract level, and this perhaps made it more difficult for the students to participate in the discussion.

Our thesis that the more learners have internalised the content knowledge of climate change the more their communication is developed seems to be substantiated in this study. With inadequate prior knowledge of climate change, it is difficult to discuss it. However, when, in the present study, the teacher used the simplified example of climate change, students understood better and joined the discussion more actively. When the knowledge is meaningful, it is also easier to internalise it. Therefore, in terms of meaning-making, students' understanding of complicated issues like climate change could be better. Expert guided teaching actualised students' internalisation of scientific issues in all the groupwork activities when students were more confident in giving their opinions.

Conclusion and Implications for Instruction

Climate change is a challenge to environmental educators and researchers because it is an issue that is characterised by controversy, uncertainly, interdisciplinarity and complexity. Therefore, when teaching, learners must be made aware not only of its causes and predicted effects but also the uncertainty of climate change and its economic, political and social dimensions. In addition, teachers need to understand the natural and human-induced factors affecting climate, their potential consequences and ways to mitigate climate change (Lambert et al. 2012). Learners find it difficult to understand climate change because abstract processes and concepts are involved, such as the electromagnetic spectrum, wavelength and the absorption and re-emission of electromagnetic energy. As students' preconceptions reveals, their prior knowledge of climate change tended to be unstructured. In addition, as the communicative approach indicates, classroom discussion should include opportunities for students to engage in discussion. Based on these findings, we suggest the following implications for instruction.

Firstly, inquiry-based teaching should be used in the teaching of climate change. Without inquiry, students cannot gain a relevant concept for their knowledge construction. The process of inquiry helps to construct the information piece by piece, and the teacher's role is to help the student in his/her learning process. However, any issue-based teaching and learning sequences (for example, on a subject like climate change) should also be closely based on learners' preconceptions; the knowledge acquisition process should be seen as an active construction process of the individual within a certain social and material setting. It seems evident that teaching of climate change for primary student teachers requires a relatively simple inquiry if the teaching purpose is to include students in active discussion and well-constructed knowledge structuring. Also Hansen (2010) recommended linking the conceptual problems to hands-on experiences.

Secondly, the active construction process also seems to be a coherent approach in an inquiry-based learning and teaching module, especially when attention is paid to the forms of communication. Learners should be active and motivated to join discussions. When students are involved in communication, it allows the teacher to gauge their thinking and understanding as well as helping to further develop inquiry-based teaching sessions. The interactive dialogic communication for gathering students' ideas and authoritative expert-guided teaching were needed for students to sufficiently develop their scientific thinking. In addition, in pre-service primary teacher education it is better to ask questions based on processes (e.g. how the greenhouse gases act on the atmosphere) because students' knowledge of the greenhouse effect reveals the difficulty in understanding the complexity of the processes involved. Boon (2010) discussed a constructivist approach, which requires teaching to be built upon the learner's existing knowledge of the greenhouse effect and their exiting frames of reference.

Thirdly, Lambert et al. (2012) showed the need for valid and reliable instruments to measure knowledge of climate change so that effective curricular and instructional implementation can be measured. The present findings support the view that combined communication analysis and concept mapping probably help the teacher to develop more instructive teaching and learning sequences.

Limitations

The results of the present study as a guideline or a model for the development of teaching are limited in potential application. The result is a combined understanding of only 20 students. Nevertheless, a similar study with a larger number of subjects (and teachers) would be beneficial to confirm the findings. Further research is required to get more information about the learning processes related to complex issues.

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III

PRIMARY STUDENT TEACHERS' PRACTICAL KNOWLEDGE OF INQUIRY-BASED SCIENCE TEACHING AND CLASSROOM COMMUNICATION OF CLIMATE CHANGE

by

Ilkka Ratinen, Jouni Viiri, Sami Lehesvuori and Tuukka Kokkonen (2015)

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Primary Student-Teachers' Practical Knowledge of Inquiry-Based Science Teaching and Classroom Communication of Climate Change

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A teacher's practical knowledge contains the teacher's beliefs about the goals, values and principles of education that guide his or her actions in the classroom. There is still a lack of knowledge about how teachers' practical knowledge influences their teaching. The present study examines student teachers' practical knowledge in the context of teaching climate change in elementary schools. Participating student-teachers planned their lessons using the principles and ideas of inquiry-based science teaching and the communicative approach. The same two approaches were applied in analysing the lessons, providing a broader basis on which to study student-teachers' beliefs about teaching science. The analysis revealed different levels of success in terms of implementation of inquiry-based learning; the communicative approach was not comprehensively realised in any class. Stimulated recall interviews highlighted that most student-teachers possessed sufficient knowledge to reflect on their lessons and the necessary awareness to use the communicative approach. By comparing the results of lesson plan analysis, communication analysis and stimulated recall interviews, we can better understand student-teachers' practical knowledge in the classroom.

Keywords: practical knowledge, inquiry, communicative approach, elementary school

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INTRODUCTION

In teacher knowledge research, one important area of study is what teachers know and how their knowing is expressed in their teaching (Connelly, Clandinin, & He, 1997; Simmons et al., 1999; van Driel, Beijaard, & Verloop, 2001; Meijer, Verloop, & Beijaard, 2002; Meijer, Zanting, & Beijaard, 2002; Lotter, Harwood, & Bonner, 2007; Kleickmann et al., 2013). Teachers' practical knowledge has been defined as "the integrated set of knowledge, conceptions, beliefs, and values that teachers develop in the context of the teaching situation" (van Driel, Beijaard, & Verloop, 2001, p. 141). In the case of inquiry-based teaching, teachers' practical knowledge includes, for example, their knowledge about implementation of inquiry-based teaching and their views about its importance (values) and possible benefits for the student learning (beliefs). Teachers' practical knowledge helps their decision-making in developing the ideas that drive their teaching. These decisions are based on their conceptions and beliefs of how to teach specific science content, such as climate change.

Climate change is among the most pressing global challenges currently facing humankind, and as Sharma (2011) has said, science education helps us to live and prosper equitably and sustainably in the era of climate change. Because of its importance there are numerous studies reporting common conceptions of climate change among students or student-teachers (Boyes & Stanisstreet, 1997; Meira, 2006; Johnson, et al., (2008); Jakobsson, Mäkitalo, & Säljö, 2009; Taber, & Taylor, 2009; Boon, 2010; Hansen, 2010; Bell, Matkins, & Gansneder, 2011; Liarakou, Athanasiadis, & Gavrilakis, 2011; Ratinen, 2013; Ratinen, Viiri, & Lehesvuori, 2013; Reinfried & Tempelmann, 2014; Niebert & Gropengießer, 2014). It seems likely that the main problem to understand climate change lies within the distinguishing infrared radiation from ultraviolet radiation, or radiation from thermal energy. Because some primary student-teachers do not understand the nature of the Sun's radiation (Ratinen, 2013), they also fail to understand the role of greenhouse gases in accelerating the greenhouse effect.

Besides the studies concerning student teachers' content knowledge of climate change there are studies about teachers' beliefs of climate change (see more Ratinen, Viiri, & Lehesvuori, 2013). But we still lack understanding of how teachers' personal beliefs about the goals, values, and principles of science education influence their teaching climate change in primary schools. The present study addresses this deficit through four inquiry-based lessons about climate change that were developed by student-teachers for four elementary school classes. The student-teachers' practical knowledge was revealed by how they conceptualised inquiry-based science teaching in their lesson planning and implementation.

Teachers' practical knowledge

Teachers' beliefs about the goals, values and principles of science education are elements of their practical knowledge. Teacher growth is a process of construction of various knowledge types: content knowledge, pedagogical content knowledge and practical knowledge. According to Shulman (1987), content knowledge represents teachers' understanding of the subject matter taught, and pedagogical content knowledge is the knowledge needed to make the subject matter accessible to students. It is known that insufficient content knowledge leads to inappropriate teaching practices (e.g. Gruenewald, 2004). Moreover, in their studies of student-teachers' content knowledge and pedagogical content knowledge, Käpylä, Asunta and Heikkinen (2009) and Kleickmann et al. (2013) have found a close relationship between the two. Unlike those studies, the present research does not address the knowledge needed by a teacher as an advisory script for how to implement a classroom session or lesson plan, and in consequence, no detailed analyses of student-teachers content knowledge and pedagogical content knowledge of climate change are offered here. Instead, this study focuses on the practical knowledge that guides teachers' actions in the classroom, where their beliefs about the goals, values and principles of education play a very important role (Simmons et al., 1999; van Driel, Beijaard, & Verloop, 2001; Meijer, Verloop, & Beijaard, 2002; Meijer, Zanting, & Beijaard, 2002; Lotter, Harwood, & Bonner, 2007). Connelly, Clandinin and He (1997) pointed out that a teacher's practical knowledge resides in the teacher's past experience (their own school history), in the teacher's present mind and body (e.g. based on their level of educational achievement) and in their future plans and actions. In this sense, even novice student teachers without longer teaching experience have some practical knowledge, based on their own history.

For the purposes of this study, two aspects of teachers' practical knowledge are noteworthy: a teacher's beliefs about practice and a teacher's views about effective teaching (Lotter, Harwood, & Bonner, 2007). The present study focuses on teacher's beliefs. According to Hollingsworth (1989) and Pajares (1992), teacher beliefs often include information about students, learning, and instructional strategies. For instance, teachers may believe that they need to transmit knowledge to passive students so that those students will be better prepared for tests. Otherwise, teachers may have particular beliefs about inquiry-based teaching strategies such as a lab work, as the results of this study will subsequently reveal.

Practical knowledge includes elements of formal knowledge within the teaching context. In this study, such elements will be derived from the participating student-teachers' lesson plans for using inquiry-based science education and communication in the classroom. For beginning science teachers, their practical knowledge often consists of elements that are not integrated (van Driel, Beijaard, & Verloop, 2001). This non-integration appears often in novice teachers' teaching, as in differences between their personal beliefs about science teaching and their own actual classroom practice (e.g. Simmons et al., 1999). According to Meijer, Verloop and Beijaard (2002), the relationship between a teacher's practical knowledge and their practice of teaching is unclear. Connelly, Clandinin and He (1997) described a range of methods, such as field notes, interviews, journal writing and autobiographical writing that can be used for studying practical knowledge. However, these methods do not reveal how actual classroom teaching reflects teachers' practical knowledge.

Student-teachers' practical knowledge implementation in real classroom contexts is analysed here by means of the communicative approach (Mortimer & Scott, 2003; Lehesvuori et al., 2011; Ratinen, Viiri, & Lehesvuori, 2013). It is important to know more about student-teachers' practical knowledge because there still is a lack of understanding about how teachers integrate knowledge from different sources, such as inquiry-based teaching and the communicative approach, into the conceptual frameworks that guide their actions in practice.

Inquiry-based learning

The basic principle driving inquiry-based learning is that this approach can more effectively prepare pupils for future challenges and supports a better understanding of science and conducting science in general (Lederman, Antink, & Bartos, 2014).

Pupils participating in inquiry-based teaching achieved better learning outcomes than those in traditional courses (Akkus, Gunelb, & Handc, 2007; Minner, Levy, & Century, 2010). A controversial argument related to inquiry-based learning from Abrahams and Millar (2008) and Hodson (2014) has suggested that doing experiments alone does not lead to better learning outcomes, and that in order to support pupils' learning, teachers must be more aware of the different phases and aspects of inquiry-based learning. Furtak, Seidel, Iverson, and Briggs (2012) pointed out that the pupils who participated in inquiry teaching having teacher-led activities had larger effect sizes than those with student-led conditions. Also there is no single way to do inquiry, but it may entail different levels of openness (Banchi & Bell, 2008):

- *Confirmation inquiry* is useful when a teacher's goal is to reinforce a previously introduced idea; students are provided with a question and procedure for confirming or reinforcing a previously learned idea or practising specific skills of data collection and recording.
- In *structured inquiry*, the question and procedure are posed by the teacher, but students generate an explanation, supported by the evidence they have collected.
- In *guided inquiry*, the teacher provides students with only the research question, and students design the method to test both the question and any resulting explanations.
- At the highest level of openness, *open inquiry*, students have an opportunity to act like scientists: deriving questions, designing and carrying out investigations, and communicating their results.

In summary, inquiry-based science teaching and learning holds that it is important for pupils to consider their own ideas and arguments alongside experimental exercises, and that teachers must be sensitive in collecting pupils' ideas at the appropriate moment and in the other moments guiding students by providing relevant information.

The communicative approach

Although inquiry-based learning can provide a very suitable context for various forms of communications, the danger remains that the approach will not be applied as is intended. Too often, the teacher may be excessively concerned with supplying the right content during inquiry and so fail to incorporate pupils' views into the classroom discourse. To avoid such shortcomings, teachers must be aware of the different aspects of the communicative approach (Mortimer & Scott, 2003), especially the dialogic dimension, which takes pupils' views into account and works with them, free of any evaluative tone.

Mortimer and Scott's (2003) communicative framework accommodates both dialogic and authoritative approaches in the science classroom. Classroom discourse consists of four categories, generated from the combination of two dimensions: interactive/non-interactive and authoritative/dialogic. Within these categories, the communicative approach addresses both the everyday understanding or prior knowledge of learners and the authoritative view of science. The interactive/non-interactive dimension indicates the different ways in which teachers can use talk, whether through whole-class discussions, question/answer sessions or lecturing. Here, the "closing down" phase is potentially very important—for instance, if discussions are "opened up" by a dialogic approach, in which learners are given the opportunity to work with different ideas, discussions should also at some point be "closing down" by advancing an authoritative view.

Communication approach ideas and ideas of inquiry-based teaching are combined in a process model (Table 1) which was introduced to the student-teachers' to use for planning and implementing their learning sequences. They, for example, participated to inquiry-based teaching of combustion and analysed classroom communication in the class where they taught later. This model combines the ideas of both inquiry-based teaching and communication analysis, accommodating all levels of openness of inquiry. The *initiation phase* includes probing pupils' preconceptions, and even though preconceptions might at this point be viewed as misconceptions, pupils should be given the opportunity to express them. Using inquiry-based teaching, the teacher can reveal these (mis)conceptions by employing a dialogic approach and opening up problems to inquiry. At a later stage, the views can be further reflected upon, using the results of the executed inquiry.

The *practising phase* includes planning, executing and reflecting on the results. Hypotheses are made and tested, and results are discussed among peers. The role of the teacher should be more as tutor than director, so laying the ground for meaningful planning and inquiries. Although pupils are expected to do the thinking, the teacher can still raise questions that further guide pupils' work and thinking. It should be emphasised that, in this phase, the teacher should especially encourage pupil-pupil interaction. The *reviewing phase* is essential to achieving educational goals. Although in this phase more authoritative communication is emphasised, preconceptions and misconceptions should be reviewed against scientific results and theories to make explicit the connections between views (e.g. everyday views and the science view) and possible gaps in previous thinking. Since different ideas are still being considered, the dialogic approach remains present, but the authoritative approach should still be implemented when drawing final conclusions, about the content and about the procedure itself. All in all, for meaningful learning of science (Scott & Ametller, 2007), when problems are opened up (dialogic approach) they should also subsequently be closed down (authoritative approach).

Table 1. A process model for planning an inquiry-based learning sequence, showing the learners' action and the classroom communication appropriate to each phase

	Inquiry-based learning 1)	Communicative approach 2)
Initiation phase	Learners are engaged by scientifically oriented questions. Learners give priority to evidence.	Opening-up phase: Dialogic and interactive Dialogic and non-interactive
Practising phase	Learners formulate explanations from evidence.	(Emphasis on pupil-pupil interaction)
Reviewing phase	Learners evaluate their explanations in light of alternative explanations. Learners communicate and justify their proposed explanations.	Closing-down phase: Dialogic and non-interactive Authoritative and interactive/non-interactive

Notes. 1) NRC (2000); 2) Mortimer & Scott (2003); Scott & Ametller (2007); Lehesvuori et al. (2011).

This process model was used here to analyse how inquiry-based teaching and the communicative approach was realised in four elementary school classes.

Research question

As described, student-teachers' practical knowledge has remained unclear when autobiographical writing and interview methods are used. This study examines student-teachers' communications in inquiry-based classrooms as a method of revealing their practical knowledge. Stimulated interviews were used to gather student-teachers' self-evaluations of realised classes. The research question is:

- What kind of practical knowledge is revealed by student-teachers' planning and implementation of inquiry and the communicative approach in primary science classrooms?

Detailed analyses of student-teachers' content knowledge and pedagogical content knowledge of climate change play no part in this study, which instead focuses on student-teachers' beliefs about inquiry-based science climate change teaching.

METHODOLOGY

Participants

Participated student-teachers studied in the University of Jyväskylä, in Finland. The university has altogether 15 000 students of which about 2300 in the faculty of education. Data for this study were collected from 20 student-teachers who took part in a course in elementary science pedagogy. Before the present study the student-teachers have accomplished two guided teaching training sessions.

The participants worked in subgroups of five. All twelve three-hour meetings were guided by one university lecturer over a period of four months. Four of those meetings focused on the topic of climate change (see detailed course analysis in Ratinen, Viiri, & Lehesvuori, 2013). Participants were also allowed to ask for help from the lecturer between meetings, either by email or by direct contact. The process model (Table 1) was used as a theory-based planning tool for inquiry-based teaching and learning. Participants analyzed the content taught, examined the teaching material and ascertained pupils' ideas about the topic before teaching. They were provided with different examples of teacher-talk, with directions for classifying classroom interactions within the communicative framework. Following this, each subgroup visited a local elementary school and observed a Grade 6 class. They created teaching strategies and collaboratively wrote a lesson plan for a teaching-learning sequence of four lessons on the topic of climate change. Subsequently, they implemented the lesson plan for Grade 6 students (aged 12 years) in the class they had observed earlier.

Data collection

As Figure 1 indicates, lesson plan content analysis, communication analysis and stimulated recall interviews were used to reveal student-teachers' practical knowledge.

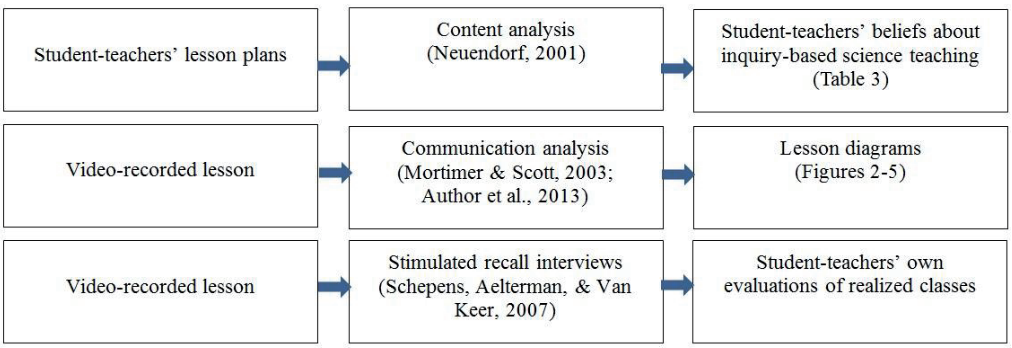

Figure 1. Conceptualization of data analysis

Lesson plan analysis

Lesson plans (n = 4) were checked against the participating student-teachers' ideas of the process model of inquiry-based teaching (Table 1) and their beliefs (Table 2), noting the differences between lesson plans and instruction. Lesson plans generally focus on the pedagogical knowledge and decisions of the teacher (Jacobs, Martin, & Otieno, 2008), and in this study, interpretative content analysis (Neuendorf, 2001) was used to see how the student-teachers' goals, values and principles of teaching (in their lesson plans) embodied their own practical knowledge of elementary science teaching. The purpose was to illuminate their practical knowledge of planning, implementing and evaluating the lesson on climate change, which brings out student-teachers' own thinking and understanding of inquiry-based science teaching.

In order to analyse the lesson plans, categories were developed from combinations of types of practical knowledge. The plans reflected their beliefs about inquiry-based teaching and classroom communication. As a summary, beliefs may form a coherent system for inquiry-based and dialogic teaching or they may be incoherent—for instance, teachers may believe (incoherently) that it is important to teach the facts. As shown in Table 2, the categories included three types of practical knowledge, modified after Meijer, Verloop and Beijaard (2002). *Type I* represents student-teachers who focused mainly on their own teaching strategies and concentrated on the subject matter. *Type II* represents student-teachers whose teaching focused primarily on pupils as individual learners. *Type III* student-teachers' practical knowledge centred on understanding and appropriately using inquiry-based teaching.

Table 2. Description of practical knowledge

Practical knowledge type	Description	Student-teachers' *beliefs* in their lesson plans
Type I	Focus on teaching strategies and content	• The goal was to use dialogic teaching. • Values and principles of inquiry-based teaching were included partly in the lesson plan. • Three-part structure of the model (Table 1) was included incompletely in the lesson plan.
Type II	Focus on individual learners	• The goal was to use collaborative learning. • Values and principles of inquiry-based teaching were included in the lesson plan. • The inquiry itself remained incomplete within the three-part structure of the model.
Type III	Focus on inquiry-based teaching	• The goal was to use diverse communication, and inquiry-based teaching methods were quite well known. • Values and principles of inquiry-based teaching were included in the lesson plan. Three-part structure of the model was well included in the lesson plan.

Notes. Modified from Meijer, Verloop and Beijaad (2002) and Schepens, Aelterman, and Van Keer (2007).

Communication analysis

The video-recorded lessons were systematically coded into the four communicative approach categories developed by Mortimer and Scott (2003) (Appendix 1). The first approach is the *interactive/authoritative* (*I/A)* approach, in which students' responses in the question-answer routine are evaluated, and the teacher avoids diverging ideas. The authoritative approach focuses on the scientific point of view (i.e. the content). Second, and in contrast, the *interactive/dialogic* (*I/D*) approach explores and exploits students' ideas and is not evaluative. Here, the teacher tries to elicit students' points of view and to work with these views (which may contrast with their own). Third, in the *non-interactive/authoritative* (*NI/A)* approach, the teacher presents the scientific content by lecturing, taking no account of contrary points of view. Finally, in the *non-interactive/dialogic* (*NI/D)* approach, the teacher works with contrasting points of view—for example, with common student views—and moves on to a scientific way of explaining phenomena, making the teacher's talk dialogic in nature.

Based on the video analysis, a communication graph was generated. As shown in Figure 2, each of the lessons was mapped, providing a visual representation of the lessons through their patterns of interaction. The communication analysis aims to present, in a readily accessible format, the implementation of the process model (Table 1), including the different teachers' and pupils' interactions and periods of inquiry during the lessons. In the graphs, the practical knowledge types are also marked with symbols I, II and III.

In the present study, the classroom communication analysis began by selecting episodes consisting of teacher-student exchanges, constituting a meso-level analysis of classroom discourse (Tiberghien & Malkoun, 2008; Lehesvuori et al., 2013). The meso-scale approach was selected to create an overview of communications during a 90-minute teaching sequence. Episodes were first selected on the basis of activity type, topic and changes in communication. For example, if the teacher was giving instruction and then shifted to another topic, the episode would be considered to have changed. Changes in communicative approach were considered when making decisions about the episodes; the end of an episode (and the beginning of another) was considered to occur when there were changes in activity, topic or communication. After that, the dominant communicative approach was selected for each episode, enabling scrutiny of whether structures resembling inquiry-based teaching (opening up/inquiry/closing down) could be identified. The communicative approaches adopted by the teacher towards the end of the lesson indicated the closing-down phase, with increased emphasis on the scientific view.

Three researchers independently coded the communications used in the classes and then compared the codings and discussed possible differences to arrive at a common view. Mapping the interaction patterns of the lessons provides an outside observer's overall picture of classroom talk, which can be used for analysis of student-teachers' practical knowledge in real-life teaching situations. While communication analysis revealed researchers' interpretations of the implemented classes, the stimulated interviews clarified in greater depth student-teachers' own thinking about inquiry-based teaching and classroom communication. This triangulation method also improved the study's validity. According to Meijer, Verloop and Beijaard (2002), multi-method triangulation is a worthwhile procedure for enhancement of the internal validity of qualitative studies, especially on a complex topic such as teachers' practical knowledge. The level of openness in inquiry was analysed by reference to Banchi and Bell's (2008) categories presented earlier.

For classroom video recording, pupils' parents signed consent forms, which is an essential part of ethical practice in science education research. Consent forms allow respondents to decide which parts of their data can be used for the purposes of the study, and whether they require anonymity and removal of the pupil's facial image.

Stimulated recall interviews

Stimulated recall group interviews (e.g. Schepens, Aelterman, & Van Keer, 2007), (n = 4) were used to gather student-teachers' own evaluations of their written lesson plans and of their implementation of the inquiry-based lesson. Video clips of various communicative approach episodes during the implemented lessons was played back to stimulate retrieval of any thoughts the participants had during their own lesson plans and teaching.

RESULTS

In this section is presented how lesson plan content analysis, communication analysis and stimulated recall interviews were used to reveal student-teachers' practical knowledge.

Lesson analysis of class A: Polar bear

The topic of this lesson was the melting of polar ice and its influence on the lives of polar bears in the Arctic region. The student-teachers planned nine episodes, of which four were dialogical. Lesson plans revealed their intention the student-teachers' planned to consider pupils' everyday views at the beginning of the class, as well as pupils' pre-knowledge of science in various contexts during the lesson. The lesson was planned to end with conversation about the hypothesis of the experiment: dirty ice melts faster than clean ice (the black carbon as an absorbing component). They planned five authoritative episodes, including storytelling about the polar bear and the setting up of the lab work. The topics for the three planned group sessions were principles of climate change, consequences of climate change and prevention of climate change.

The communicative approaches and active inquiry phases of the lesson as realised are graphically presented in Figure 2, which again uses the symbols I, II and III to mark the practical knowledge types used in the lesson plan, along with short bubble descriptions of the three types. The figure shows explicitly the degree of coherence between beliefs (plan) and enacted practice; differences or compatibility between lesson plan and realised teaching are described in the text boxes.

In Figure 2, the initial opening-up phase (about 0–5 min) is realised by means of the different communication approaches used by the teacher. This leads into periods of inquiry-based activities, punctuated by further guidelines given by the teacher—in this instance, through the reading of a story—so that the pupils were engaged by scientifically-oriented questions.

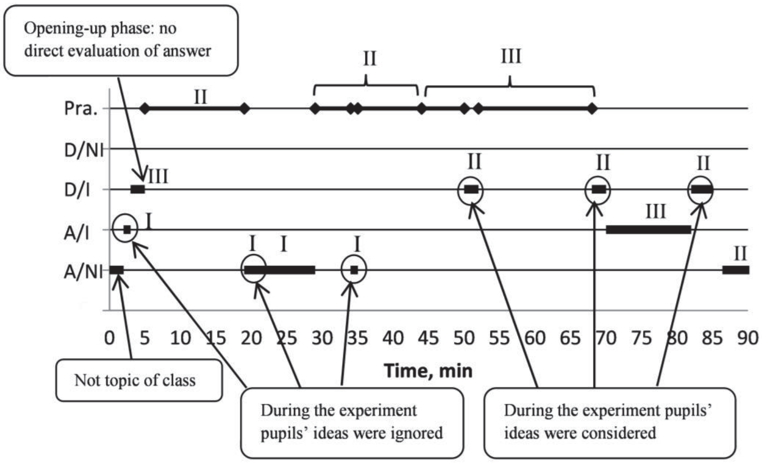

Figure 2. Lesson diagram of Class A. (A/NI = Authoritative and non-interactive, A/I = Authoritative and interactive, D/I = Dialogic and interactive, D/NI = Dialogic and non-interactive, Pra. = Practising phase; I = Focus on own teaching and concentration on subject matter. II = Focus on pupils as individual learners. III = Basic understanding of inquiry-based science in lesson plan and its implementation).

Here, the student-teacher asked pupils about the melting of clean and dirty ice. He collected pupils' ideas without directly evaluating the answers; in this way, pupils' prior ideas could be taken into account before their group work began. After brief instructions, pupils commenced work in three groups. Each group carried out three tasks, with the purpose of formulating explanations based on the evidence provided by the student-teacher. The first inquiry-based task (minutes 5–19) followed the confirmation inquiry, where the student-teacher's goal was to reinforce a previous introduced idea. Pupils' ideas about the greenhouse effect were gathered through small-group work, guided by the student-teacher. Between the first and second task, a story about a polar bear was told by the student-teacher (minutes 23–29). The second task (minutes 29–44) was a structured inquiry related to the story about a polar bear and the melting of a northern polar glacier, in which the pupils generated an explanation, supported by the evidence they had collected from the experiment and the story. The third task (minutes 44–68) included planning an advertisement to encourage the reduction of climate change. This included sources for guided inquiry, and pupils designed and conducted a procedure before presenting their findings and results as a poster.

The melting of two different types of ice was measured at approximately 15-minute intervals. While the teacher carried out the actual measurements, the whole class was encouraged to make observations. Once the final measurements were conducted, observations were made on the amount of melted ice. During this phase, an interactive/dialogic communicative approach was used, although authoritative passages gently directed the discussion toward conclusions. Pupils enacted a play (minutes 70–82), in which each pupil was assigned a character (e.g. polar bear, atmosphere, sun ray etc.). Each time this character was mentioned in the play, the pupil(s) had to demonstrate the actions of this character. Pupils' preconceptions were then addressed within the final conclusions (minutes 82–90).Throughout the teaching sequence, communicative approaches can be clearly identified that signal the purposeful use of various discursive strategies. During the dialogic episodes, pupils' contributions were noted in a supportive or neutral tone, fostering an open climate that invited further contributions from pupils. With the student-teacher acting as co-inquirer, group work aimed to embrace collective and reciprocal approaches to pupil inquiry.

Student-teachers did not dialogically open up the lesson, so ignoring pupils' pre-knowledge. During the inquiry session, planned interactive dialogic sessions were realised as authoritative and interactive. Dialogic and interactive teaching was clearly realised during the applied task towards the end of the class and during the task in which pupils examined dirty and clean ice. Overall, student-teachers' practical knowledge was relatively good in this class because they used the three-part pattern of the model (Table 1). However, the review of the lesson did not take account of pupils' pre-knowledge, and so knowledge was not constructed by dialogic interactive communication. Clearly, there was a conflict between the interactive/dialogic approach and finding the right answers with a teacher's support.

Lesson analysis of class B: The greenhouse effect

The topic for Class B was the greenhouse effect and CO_2 as a greenhouse gas, planned as five dialogic and two authoritative episodes. Lesson plans noted that dialogic conversation in the class would consist of engagement with the topic, discussion of how people can affect climate change and discussion about the results of the experiment on the greenhouse effect. The planned authoritative episodes included a "lecture" about the greenhouse effect as a natural process and the experimental setup. The group tasks consisted of a poster-making session and a gallery presenting the posters, ending the class dialogically.

This class began with the student-teacher's introduction of the class topic (0–1 min). Subsequently, the class consisted of sessions led by the student-teachers (1–6 min), (6–8 min), (8–22 min), (22–29 min); the experiment on the greenhouse effect, in which water vapour and CO_2 were heated up (29–32 min and 57–59 min); guidance for group work on the greenhouse effect (32–38 min) and group work implementation (38–57 min); and, finally, review of the group work (59–71 min). At the end of the class, student-teachers reviewed the class as a whole and gave feedback on students' participation in the class (72–75 min).

To some extent, the teaching sequence here mirrors the model of inquiry-based learning (Figure 3). However, the dialogic opening-up phase is closed before the experiment, as seen in the dominating authoritative episodes (7–38 min). The practising phase itself was carefully planned and followed a confirmation inquiry in which pupils conducted investigations and practised a specific inquiry skill, such as collecting and recording data. The practising phase represented coherent practical knowledge, and pupils had the freedom to peer-evaluate the results before a student-teacher reviewed the essentials. During this phase, an even more authoritative and goal-directed approach would have been appropriate for the closing phase of the inquiry.

As Figure 3 shows, authoritative communication dominated Class B. Lesson plans showed that the student-teachers' purpose was to apply the interactive dialogue approach in considering pupils' everyday views of climate change at the beginning of the class. However, the opening-up phase was not implemented and so pupils did not express their own ideas, nor did student-teachers review pupils' ideas with reference to the scientific point of view (principle of the greenhouse effect: emitted IR-radiation is absorbed by the greenhouse gases and heat is re-radiated in all directions). This teaching reflects incoherent practical knowledge of inquiry-based and communicative science classes.

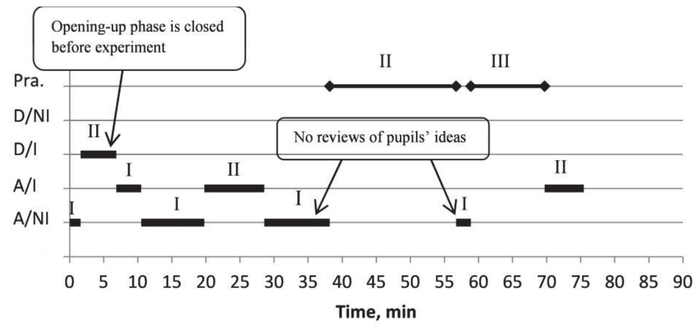

Figure 3. Lesson diagram of Class B. (A/NI = Authoritative and non-interactive, A/I = Authoritative and interactive, D/I = Dialogic and interactive, D/NI = Dialogic and non-interactive, Pra. = Practising phase; I = Focus on own teaching and concentration on subject matter. II = Focus on pupils as individual learners. III = Basic understanding of inquiry-based science in lesson plan and its implementation).

Lesson analysis of class C: The life cycle of porridge

In this class, student-teachers had difficulties with the communicative approach in lesson planning. They planned seven episodes, but only two were dialogic or interactive; two were authoritative, and the rest of the episodes were not determinate as any of the communication types. The dialogic and interactive episodes consisted of conversation about the consequences of climate change and the life cycle of porridge and its environmental impacts. In this lesson energy consumption of porridge cooking was measured and further discussed it's influence to the life cycle of porridge. Authoritative episodes included teacher's talk about the principles of the greenhouse effect and climate change. The principle of life cycle analysis was planned as group work in which pupils would discuss the phases of the life cycle of porridge. The plan was to end by summarising the main topics of the class with the pupils' involvement.

To begin Class C (Figure 4), the teacher contrived some practical issues and collected pupils' preconceptions about climate change (0–5 min). The class consisted of student-teacher-led sessions with the children (5–7 min, 7–15 min, 15–23 min, 23–26 min, 32–36 min and 66–75 min); completion of a worksheet (26–32 min); and the initiation and implementation of an experiment, cooking porridge in a saucepan with and without a cover (36–38 min, 41–56 min, 56–66 min).

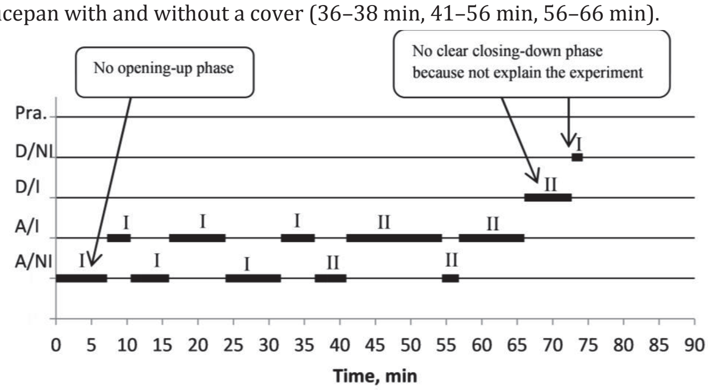

Figure 4. Lesson diagram of Class C. (A/NI = Authoritative and non-interactive, A/I = Authoritative and interactive, D/I = Dialogic and interactive, D/NI = Dialogic and non-interactive, Pra. = Practising phase; I = Focus on own teaching and concentration on subject matter. II = Focus on pupils as individual learners. III = Basic understanding of inquiry-based science in lesson plan and its implementation).

This teaching sequence involving the life cycle of porridge did not appropriately follow the inquiry-based learning approach (Figure 4). Unfortunately, the lesson failed to employ the full range of communicative options and, as can be seen from the communication graphic, practising phases were completely absent from this lesson. Whereas Class A effectively illustrated the three-part pattern of the model, Class C had no opening-up, maintaining authoritative communication throughout the lesson and omitting any authentic phases of inquiry or dialogue. Closing-down was student-teacher guided classroom communication which was unrelated to the experiment of cooking porridge. In short, this class represents student-teachers' incoherent practical knowledge of inquiry-based science teaching and failed to follow any of the types of inquiry identified by Banchi and Bell (2008). In particular, porridge cooking as an example experiment failed because, among other things, student-teachers neglected to measure electricity consumption after cooking.

Despite their plans to use dialogic communication for gathering pupils' ideas, the student-teachers' lesson included neither opening-up nor closing-down. The class as implemented maintained the authoritative view of science throughout the lesson, omitting any authentic phases of inquiry or dialogue. Because the concept of the life cycle of porridge was challenging for the student-teachers, they talked authoritatively. While pupils' lack of participation in the discussion also reflected their insufficient pre-knowledge, student-teachers' dialogic talk (as they planned it) could have prompted more active conversation.

Lesson analysis of class D: Climate change and temperature zones

Class D involved temperature zones and the relationship between planetary phenomena and climate change. Student-teachers planned eight teaching episodes; of these, two were planned to be non-interactive and authoritative, and the remaining episodes were intended to be interactive and dialogic. Lesson plans noted that the intention was to use pupils' everyday views in dialogic conversation at the beginning of the class. A teacher-centered episode of the principles of temperature zone was also planned as dialogic. Pupil-centered group work on the influence of climate change for temperature zones was also planned as dialogic and interactive. Student-teachers planned to end the class with a dialogic conversation about "What you have learned about climate change".

At the beginning of the class (Figure 5), student-teachers introduced the topic and themselves (0–3 min). The class continued with sessions controlled by the teacher (3–17 min, 17–29 min, 29–33 min, 70–72 min and 72–81 min); teacher's instructions for group work on climate change influences and changing temperature zones (33–43 min); group work implementation (43–60 min); and students' presentation of the group work to the other pupils (60–70 min).

In this class, the teaching sequence partially followed the process model of inquiry-based learning, indicating that student teachers' practical knowledge was good enough. Pupils' preconceptions were mapped and foregrounded before executing inquiries (Figure 5); however, in the class, pupils did not advance their own thinking because the student-teachers did not open up the class by asking scientifically relevant questions. Although the student-teachers' purpose was to dialogically review the class, pupils' alternate perspectives were ignored when the student-teacher compared and linked pupils' concepts to the scientific point of view. The student-teachers' planned dialogic interactive sessions were realised most clearly during the inquiry session on planetary phenomena which was a mental model for illustrating the greenhouse effect. The class did include confirmation inquiry because pupils confirmed a previously learned idea in their group work. In addition, the essential concepts were reviewed at the end. Despite the dialogic aspect of the reviewing episodes, however, the student-teachers were concerned with scientific correctness at this point. As the diagram reveals, authoritative episodes followed the dialogic ones before the actual inquiry, and so the dialogic model was not fully implemented, reflecting relatively incoherent practical knowledge. Although the student-teachers' purpose was to dialogically review the class, pupils' perspectives were ignored.

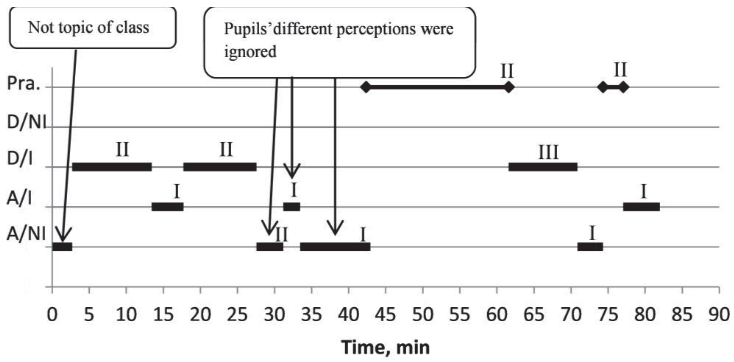

Figure 5. Lesson diagram of Class D. (A/NI = Authoritative and non-interactive, A/I = Authoritative and interactive, D/I = Dialogic and interactive, D/NI = Dialogic and non-interactive, Pra. = Practising phase; I = Focus on own teaching and concentration on subject matter. II = Focus on pupils as individual learners. III = Basic understanding of inquiry-based science in lesson plan and its implementation).

The detailed analysis of student-teachers' lesson plans reveals a mixture of different practical knowledge types (Table 2). Table 3 shows the results of the analysis, in which, for instance, number 4 in the Class A Type I cell indicates that student-teachers fourthly had an idea in their lesson plan that was categorised as Type I practical knowledge. These four realisations of type I practical knowledge are also marked in Figures.

Table 3. Student-teachers' beliefs (i.e. their practical knowledge of inquiry-based science teaching) revealed from their lesson plans and lesson realization

Class	Student-teacher's practical knowledge due to communication analysis		
	I	II	III
Class A; Polar bear	4	6	3
Class B; The greenhouse effect	5	4	1
Class C; The life cycle of porridge	7	5	0
Class D; Climate change and temperature zones	5	5	1
Sum of types	21	20	5

Notes. Each cell gives the number of instances the student teachers' lesson plan evidencing use of a certain type of practical knowledge (see Table 2). (I = Focus on own teaching and concentration on subject matter. II = Focus on pupils as individual learners. III = Basic understanding of inquiry-based science in lesson plan and its implementation).

As a summary of the results of communication analysis the main differences between lesson plans and lesson implementations were:

- Class A: Student-teachers did not dialogically open up the lesson, thereby ignoring pupils' pre-knowledge (See Figure 2).
- Class B: The opening-up phase was closed before experiment. Student-teachers did not review pupils' ideas according to the scientific point of view. (See Figure 3)

- Class C: No opening-up; no dialogic closing-down; student-teachers did not explain the experiments. (See Figure 4)
- Class D: Pupils did not advance their own thinking, and their perspectives were ignored when the student-teacher compared and linked pupils' concepts to the scientific point of view. (See Figure 5)

And when compared with the practical knowledge types of Table 2 the main differences revealed by communication analysis were:

- Type I: Dialogic teaching was realized as authoritative, values and principles of inquiry-based teaching were ignored in the lesson. Three-part structure of the model was incomplete.
- Type II: Pupils did not mutually share their ideas, values and principles of inquiry-based teaching remained deficient in the experiment, the inquiry itself remained incomplete within the three-part structure of the model.
- Type III: Dialogic and inquiry-based teaching was realised quite well, values and principles of inquiry-based teaching realised in the class and lesson were critically reflected, three-part structure of the model was realised quite well in the class.

Stimulated recall interviews

Stimulated recall interviews revealed student-teachers' incoherent practical knowledge and the fact that they failed to comprehensively implement the communicative approach in their science classroom, and so the ideas of the lesson plans were not realised in their teaching. Student-teachers initially proposed to use interactive dialogic talk, but in the stimulated recall interviews, many student-teachers admitted to having used closed questions, which lead learners to give direct, concise answers. It follows that real dialogue did not occur, especially at the beginning of lessons. Stimulated recall interviews revealed that student-teachers in Class C had not internalised the principles of the communicative approach and inquiry-based science teaching.

During the stimulated recall interviews, student-teachers critically evaluated their teaching, reflecting their practical knowledge. Even where their beliefs about teaching included dialogic aspects, they ignored these in their teaching as they evaluated the implementation of the communicative approach in their science classrooms.

> Student-teacher b (Class A): Not just a teacher lecturing ... but I bet that we sought some answers. We might not underpin the pupils' answers, nor begin to lead the instruction on that basis. We had specific questions, and the discussion was not entirely of dialogue, because we did not rely on the children's thinking. We expected the children to give certain answers, and we confirmed it when we got the right answer. I did not know that, how it could have to do with it.

Student-teachers understood the difficulties in asking relevant, open-ended and encouraging questions. When asked how pupils discussed among themselves in their small groups, student-teachers' responses included the following.

> Student-teacher a (Class A): I basically steered the discussion and helped pupils to think, and the pupils did not, actually, ask spontaneously (scientific questions).
>
> Student-teacher d (Class C): In the beginning of the class, I worked hard to motivate pupils to participate in the discussion.
>
> Student-teacher a (Class C): I could have given time to the pupils to answer, and not immediately give a new question… we followed IRE discussion type (Student c).

> Student-teacher c (Class D): Pupils' activities varied according to different subjects and different tasks.
> Student- teacher c (Class B): If we would have known pupils and their discussion culture better… it would have been easier to communicate with them.
> Student- teacher b (Class A): I do not know about … or how to make the learning situation more familiar.

It seems clear that the student-teachers in all classes had Type II practical knowledge (Table 4) in that they focused primarily on pupils rather than on their ability to act as a Type III expert in a science classroom. Specifically, student-teachers viewed pupils as individual learners during group work. When the topic of the lesson was scientifically challenging, the authoritative talk type was more predominant in student-teachers' lessons, indicating that the content level of the class significantly influences communication in the science classroom. According to student-teachers, their lesson plans were carefully designed, and the teaching implementation did not manifest major subject-matter mistakes. However, stimulated recall interviews revealed student-teachers' worries (especially in class C) about the insufficiency of their understanding for use of inquiry in climate change teaching.

The stimulated recall interviews highlighted student-teachers' challenges in starting discussions with pupils and creating real interactions among groups, with other groups and with the teacher. However, student-teachers indicated in the interviews that pupils' ability to participate in the discussions varied significantly, according to the type of task. Overall, the stimulated recall interviews revealed the integrated set of knowledge, conceptions, beliefs, and values that student-teachers developed in the context of teaching about climate change.

DISCUSSION

FINDINGS

Our aim was to find what kind of practical knowledge is revealed by student-teachers' planning and implementation of inquiry and the communicative approach in primary science classrooms. Teachers practical knowledge has been studied in many studies (e.g. Connelly, Clandinin, & He, 1997; Simmons et al., 1999; van Driel, Beijaard, & Verloop, 2001; Meijer, Verloop, & Beijaard, 2002; Meijer, Zanting, & Beijaard, 2002; Lotter, Harwood, & Bonner, 2007) but the present study brings a new perspective to the methodological discussion for studying teachers' practical knowledge. As Meijer, Verloop and Beijaard (2002) pointed out teachers' practical knowledge is viewed as a multi-dimensional concept, requiring multiple instruments for its exploration. We aimed to reveal the multi-dimensionality by comparing the results of lesson plan analysis, communication analysis and stimulated recall interviews. The lesson plan analysis gave a picture that their beliefs seem to be relatively coherent in relation to the elements of inquiry-based teaching as presented in Table 1. They planned to use relevant inquiry-based "learn by doing" experiments (Johnston et al. (2008) such as melting ice and also model-based experimental demonstration for illustrating the greenhouse effect (Reinfried, & Tempelmann, 2014). The results is not very congruent with Käpylä, Asunta, and Heikkinen (2009) who discovered that primary student-teachers' had problems in choosing the most important content in their lesson plans.

According to van Driel, Beijaard, and Verloop (2001), teachers develop their practical knowledge in the context of the teaching situation. The communication analysis reveals explicitly the kind of practical knowledge student-teachers really used in the classroom. These findings are in contradiction to the picture given by the lesson plan analysis. Student-teachers' teaching was not in line with their lesson plans (see Table 3). The experiments they used remained vague, because interaction with pupils did not foster pupils' thinking. Student-teachers (other than class C) planned to teach the principles of climate change dialogically, but they ignored pupils' pre-knowledge. Additionally, the "closing-down" component (see Ratinen, Viiri, & Lehesvuori, 2013) of the classes reveals the incoherence of student-teachers' practical knowledge, as they did not clearly close down the lesson or review the main points of the climate change class. For example, the results of measurement of electricity consumption was ignored in relation to the amount of greenhouse gases. Moreover, the stimulated recall interview reinforced the impression that student-teachers' purpose was to use both inquiry-based teaching methods and experiments as well as considering pupils' own ideas and arguments. This result aligns with Childs and McNicholl (2007) where the student-teachers mentioned primary science teaching requiring teaching without formulas, with a stronger focus on phenomena and the science teaching explanations. Othervise, the result is similar with the finding of Meijer, Zanting and Beijaard (2002) that student-teachers' recall in interviews looked beyond the "how" and into the "why" of teaching.

As the lesson diagrams illustrate, the analysis reveals different levels of success in terms of implementation of inquiry-based learning, and that student-teachers' practical knowledge remained relatively incoherent. Their practical knowledge also varied significantly, with extremes represented by the teachers of Classes A and C. The student-teachers of Class A demonstrated their above-average ability to plan, implement and critically evaluate an inquiry-based science lesson. In contrast, student-teachers in Class C did not refer to the provided model at all. Student-teachers' readiness to apply dialogic communication in their teaching also varied significantly. Those classified as Type III (i.e. having a basic understanding of inquiry-based science in lesson planning and its implementation in actual classroom communications) performed relatively poorly in all four classes. This means that student-teachers knew the appropriate teaching strategies even for dialogic teaching, but they did not know how these should be enacted in the classroom.

Implications

The interactional graphics (Figures 2, 3, 4 and 5) could be applied in teacher education while student-teachers observe classroom practice (Viiri, & Saari, 2006). Following the observations, in which individual notes are made in an assigned form, student groups could negotiate a communication graphic of the observed lesson, encouraging them to truly engage with the different interactional options and what they mean for their practical knowledge. This would hopefully support student-teachers in lesson planning and in the realisation of inquiry-based teaching.

One interesting option for further research would be to use the lesson diagrams with student-teachers as well as in-service teacher education to develop practical knowledge in science classrooms. As indicated by their lack of coherent practical knowledge here, student-teachers may well need more concrete practice in implementing a dialogic approach.

Aside from the questions of time and discipline (Scott, Mortimer, & Aguiar, 2006), the dominant school culture may not be open to dialogic innovations. These challenges arguably also apply to the professional development (PD) of in-service teachers. The present study also suggest that, to be successful, a PD course must not only include inquiry-related knowledge but must also assess and address teachers' core teaching conceptions of the goals, values and principles of education (Lotter, Harwood, & Bonner, 2007). To challenge this prevailing culture, dialogic issues and teachers' practical knowledge must be emphasised in both initial and in-service teacher education. However, student-teachers are not often able to make effective or appropriate use of pedagogical strategies as discussed in PD courses because their practical knowledge is compared at novice level (Meijer, Zanting, & Beijaard, 2002). Indeed, student-teachers' perceptions and methods of teaching are based strongly on their own school experiences as pupils (Abell, 2007), and if PD fails to explicitly address different approaches to teaching, there is a danger that those beliefs will persist throughout teacher education and teaching service (Fajet, Bello, Leftwich, Mesler, & Shaver, 2005). On this basis, increasing teacher awareness at both pre-service and in-service levels will be essential in initiating any reform of practice (Kagan, 1992).

CONCLUSION

Our findings show that student teachers' practical knowledge is not coherent and different methods to reveal it may give different and even contrary pictures. Future studies should use besides the methods applied in previous studies (e.g. field notes, interviews, journal writing) also methods more related to actual classroom teaching. Those could include the graphical analysis based on lessons videos.

Limitations

The results of the present study have potential as a guideline for the development of teaching. Since the results are from some lessons they should not be generalized and they should only be taken as examples. Further research is required to get more information about the learning processes related to practical knowledge.

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APPENDIX

Description of communication analysis

Communicative approach	Description	Example	Comment
Interactive authoritative approach I/A	The teacher's aim is to arrive at the idea of some specific and scientific point of view	*Teacher: Just think about melting glaciers. When glaciers melt, then something else also happens in the ocean. When you look at this picture, what do you think has happened in the ocean? When you look at that strip of land and its surroundings?* *Student: It has been contaminated.* *Teacher: Yes, it's quite dark. But what else has happened? Think about the fact that there is water in this picture and there is also a kind of border here?* *Student: The water level has risen.* *Teacher: Yes, yeah, that is what happened. That's right: the city is now located under the sea.*	This excerpt is an example of a typical student-teacher's authoritative communication (lines 1 and 3). In the third line, the teacher ignores the pupil's thinking and restrains the direction of the communication by guiding the pupil towards the answer that is in her mind.
Interactive dialogic approach I/D	The teacher listens to and considers students' points of view, and tries to elicit students' views	*Teacher: What do you think: does dirty or clean ice melt faster?* *Student 1: Dirty.* *Teacher: Why do you think that dirty ice will melt faster?* *Student 1: I don't know. It's somehow warmer. I think. It gets warmer faster.* *Teacher: Okay. (Gives the floor to the next student)* *Student 2: It's clean.* *Teacher: Hmm. So why do you think that clean ice will melt faster?* *Student 2: It's clean, so probably its molecules will melt easier.*	This excerpt shows how the student-teacher explores students' understanding by asking them to clarify and focus their ideas (lines 3 and 7). The student-teacher does not evaluate the correctness of the students' answers but makes it possible for the students to share their ideas.
Non-interactive authoritative approach NI/A	The teacher explores a specific and scientific point of view.	*Teacher: Jape felt sad and asked the bird, "Why is this all happening?" Jape had been having a strange day. The bird answered, "My cousin, far away in Australia, told me yesterday that there have been floods in their nesting area, and their own nest was flushed away. And the new risk for my cousin will be hurricanes." The bird sighed. She knew the reason for the changing situation, but she did not want to tell the cause to small Jape.*	This example shows how the teacher read a story about a polar bear called Jape. There is only the scientific point of view in this story.

Non-interactive dialogic approach NI/D	The teacher explores various points of view, setting out, exploring and working on the different perspectives	*Teacher: You have many opinions and responses for the meaning of climate change. And all of your responses indicated that climate, somehow, changes. And you are right. So, climate change means, literally, a change in climate and a change in the Earth, somehow. So, it has been observed that the average temperature has, over the years, risen across the Earth.*	This excerpt was taken from the lifecycle class. The student-teacher reviews pupils' pre-knowledge and associates those ideas with climate change.

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