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International Peer Collaboration to Learn about Global Climate Changes

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Climate change is not local; it is global. This means that many environmental issues related to climate change are not geographically limited and hence concern humans in more than one location. There is a growing body of research indicating that today's increased climate change is caused by human activities and our modern lifestyle. Consequently, climate change awareness and attention from the entire world's population needs to be a global priority and we need to work collaboratively to attain a sustainable future. A powerful tool in this process is to develop an understanding of climate change through education. Recognizing this, climate change has been included in many science curricula as a part of science education in schools. However, teaching such a complex and global topic as climate change is not easy. The research in this paper has been driven by this challenge. In this paper, we will present our online science module called Global Climate Exchange, designed with inquiry activities for international peer collaboration to teach climate change. In this study, we engaged 157 students from four countries (Canada, China, Sweden, and Norway) to collaborate in Global Climate Exchange. To explore the opportunities that international peer collaboration in Global Climate Exchange gives, we have analyzed how students develop their explanations about climate change issues over time. Our analysis showed that the students increased the proportion of relevant scientific concepts in relation to the total number of words in their explanations and that they improved the quality of links between concepts over a six-week period. The analysis also revealed that the students explained more perspectives relating to climate change issues over time. The outcomes indicate that international peer collaboration, if successfully supported, can be an effective approach to climate change education.

Keywords: climate change education, international peer collaboration, inquiry-based science teaching

INTRODUCTION

Climate change is one of the greatest challenges of our time, as it has effects in profoundly adverse ways on ecological, social, and economic levels. Climate change issues are closely related to our modern lifestyle in our global society and,

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consequently, need attention from the entire world population (IPCC, 2013). Even though climate change issues may vary between regions and nations, they are all interconnected (Steffen, Rockström, Kubiszewski, & Costanza, 2013). Acknowledging that climate change is a serious challenge has made the topic become a compulsory part of science education and it is now included in many schools' science curricula. However, teaching such a complex and global topic as climate change is not easy, and several studies point out that teachers, students, and people in general struggle to understand climate change (Daniel, Stanisstreet, & Boyes, 2004; Dove, 1996; Gowda, Fox, & Magelky, 1997; Myers, Maibach, Roser-Renouf, Akerlof, & Leiserowitz, 2013; Papadimitriou, 2004). It has been shown how climate change is often taught in a traditional lecture format with an emphasis placed on the physical aspects and that this way of teaching could be the reason for a lack of understanding surrounding the topic (Papadimitriou, 2004; Rebich & Gautier, 2005).

An alternative to teaching climate change in lecture format is inquiry-based science teaching where students are more actively engaged in activities through a hands-on and minds-on approach. Inquiry-based science education has been found to be effective in creating autonomous (self-directed) and reflective learners (Scardamalia & Bereiter, 1993a, 2006; Slotta & Jorde, 2010), and in developing student understanding (Gerard, Tate, Chiu, Corliss, & Linn, 2009; Hoadley, 2004; Mork & Jorde, 2004). Peer collaboration, which is a central part of inquiry processes, has likewise been found to be effective in terms of student reflection and learning, because the learners are exposed to new ideas, new perspectives, and new knowledge through collaboration with their peers (Dillenbourg, 1999; Duit & Treagust, 1998; Hakkarainen, 2003b). When connecting students with their peers to capitalize on cultural and geographic differences during international peer collaboration, students gain access to an even greater diversity regarding ideas and global perspectives on science issues than when limited to interactions with their national or local peers (Slotta & Jorde, 2010; Slotta, Jorde, & Holmes, 2005). Only a small number of studies have explored the potential of international peer collaboration in climate change education and the knowledge is insufficient.

This study has been driven by the fact that climate change education is important, but that it is difficult to understand and to teach. Recognizing the potential of inquiry-based science teaching and peer collaboration, we have developed and implemented an online science module called Global Climate Exchange. The notion behind Global Climate Exchange is that in giving the students the opportunity to collaborate and communicate with peers from other countries, they will be exposed to peers who have other perspectives on climate issues, and on other climate change issues that are personally relevant to them. The expectation is that this might make the topic more relevant and less distant for the students, and hence enhance their motivation for learning (National Research Council, 2005; Howe, Tolmie, Greer, & Mackenzie, 1995).

To explore the opportunities that international peer collaboration in Global Climate Exchange gives, we have analyzed how students develop their explanations about climate change issues over time. The research questions are "How do students develop their explanations about climate change issues over time when participating in Global Climate Exchange?" and "Is the development of the students' explanations of climate change issues correlated to how the students interact with their peers?"

Climate change education

Studies on climate change education reveal that complex and multifaceted topics such as climate change are often taught using a standard lecture format with limited student engagement (Papadimitriou, 2004). The general conclusion that is drawn is that the way in which climate change is taught may well be the reason for the students' incomprehensive understanding (Dove, 1996; Moser & Dilling, 2004; Rebich & Gautier, 2005). This is not surprising, given that it is commonly accepted among science education researchers that an active construction of knowledge is necessary for understanding (Bransford, Brown, & Cocking, 2000; Donovan & Bransford, 2005).

The active construction of knowledge can be achieved through student participation in inquiry tasks such as diagnosing problems, identifying questions, searching for information, collecting evidence, planning investigations, researching conjectures, interpreting evidence, formulating explanations, communicating findings, debating with peers, and forming coherent arguments (Lee, Linn, Varma, & Liu, 2010). The educational principles of inquiry-based science teaching are derived from a social constructivist perspective of learning (i.e., that students should be active participants in the learning process, learning to think critically, and be reflective). This theoretical perspective interprets scientific knowledge as being socially constructed, and learning as a social process of knowledge construction involving both individual and collaborative activities (Driver, Asoko, Leach, Mortimer, & Scott, 1994). An inquiry-oriented perspective on learning contrasts rather sharply with that of traditional instruction, with its focus on lecturing, memorization of scientific facts, and practical work guided by teacher instruction (Bell, Urhahne, Schanze, & Ploetzner, 2010; Minner, Levy, & Century, 2010).

Reviews of inquiry-based science teaching conclude that this approach in general has a positive impact on developing diverse competences in students such as scientific literacy, understanding science processes, vocabulary knowledge, conceptual understanding, critical thinking and attitudes toward science, and greater student motivation (Anderson, 2002; Minner et al., 2010). These major review studies conclude that inquiry-based science teaching is especially effective when students are actively engaged in their own learning processes through inquiry investigations, critical thinking, and drawing conclusions from data.

Studies have also explored the effect of peer collaboration in inquiry-based science teaching. In peer collaboration during inquiry activities, students either work individually followed by them contributing their results as a group product, or collaboratively, where together they solve problems, investigate issues, have discussions, and so on (Stahl, Koschmann, & Suthers, 2006). There can be great variations in terms of how students collaborate and communicate with their peers during such activities, but the main purpose is to stimulate students to learn from their peers (Dillenbourg, 1999; Duit & Treagust, 2003; Hakkarainen, 2003a). In several studies, peer collaboration is supported by computer-enhanced environments, and many of these have demonstrated the positive potential for peer collaboration in science education (Gerard, Spitulnik, & Linn, 2010; Gerard et al., 2009; Hoadley, 2000, 2004; Peters & Slotta, 2010; Scardamalia & Bereiter, 1993a, 1993b, 2003, 2006; Slotta & Linn, 2009; Slotta & Najafi, 2010). The potential of computer-supported peer collaboration becomes evident when connecting peers to capitalize on the different regions that they come from, and, as in international peer collaboration, when connecting peers from various countries.

Understanding and explaining climate change

Research shows that understanding climate change is difficult for teachers, students, and people in general (Daniel et al., 2004; Dove, 1996; Ekborg, 2003; Ekborg & Areskoug, 2006; Papadimitriou, 2004; Rye, Rubba, & Wiesenmayer, 1997). The reason is probably that climate change is complex. Processes and mechanisms in the climate system are inter-correlated in such ways that even though scientific knowledge has increased immensely over the last few decades, much of this knowledge still contains elements that are uncertain and tentative (IPCC, 2007, 2013; NASA, 2012). Consequently, a comprehensive understanding of climate change is more than about finding the "correct" answers.

Understanding the science of climate change entails some understanding of the interactions between biotic and abiotic factors in the Earth's ecosystem (Begon, Harper, & Townsend, 1996; Campbell, Reece, & Mitchell, 1999). Interactions in ecosystems have been found to be challenging for students to understand (Green, 1997; Hmelo-Silver & Pfeffer, 2004), especially when grasping the larger global picture of ecosystems, and when understanding how connections within a smaller system may be a part of larger systems (Leach, Driver, Scott, & Wood-Robinson, 1995, 1996a, 1996b).

The challenges of understanding systems are likely linked to a lack of or a weak understanding of causalities; that is, the relationship between cause(s) and effect(s). In fact, studies researching students' understanding of ecological causalities reveal that both primary and lower-secondary students (Goldring & Osborne, 1994; Grotzer, Kamarainen, Tutwiler, Metcalf, & Dede, 2013; Helldén, 2012; Shepardson, Roychoudhury, Hirsch, Niyogi, & Top, 2013), as well as the majority of upper-secondary students and adults (Carlsson, 2002; Green, 1997; Palmer, 1998), tend to identify only simple linear causalities. A limited understanding of ecological causalities (i.e., failing to understand complex and subtle causalities) prevents a coherent understanding of ecological systems (Perkins & Grotzer, 2005).

Exploring students' understanding and explanations of climate change

Perkins and Grotzer (2000) developed the taxonomy of Causal Models in an attempt to capture the increasing complexity of students' causal explanations. Later, they applied the taxonomy to analyze student comprehension of causal patterns in ecosystems (Grotzer, 2003; Grotzer & Basca, 2003; Grotzer et al., 2013). In these studies, the taxonomy was used to develop a coding scheme with four different categories of connections in ecosystems: one-step linear, multi-step linear, cyclic, and mutually causal. These categories refer to patterns of interaction between cause and effect, and appear to be vastly relevant for the analysis of how students understand and explain climate change issues.

Another taxonomy, relevant for analyzing the students' explanations of climate change issues, is the SOLO taxonomy (Biggs & Collis, 1982). Several studies indicate that SOLO is suitable for examining students' abilities to make coherent connections and formulate relationships between ideas, and may thus be useful for following the development of students' explanations (Biggs, 1979; Biggs & Tang, 2007; Boulton-Lewis, 1995; Brabrand & Dahl, 2009; Chan, Tsui, Chan, & Hong, 2002; Hodges & Harvey, 2003; Lake, 1999; Leung, 2000; Levins, 1992).

In this study, students explanations are first converted into concept maps, and then analyzed using the taxonomy of Causal Models and the SOLO taxonomy.

METHOD

The science module: Global Climate Exchange

Considering the challenges of understanding climate change and the possibilities of inquiry-based science teaching and international peer collaboration, we have developed a science module called Global Climate Exchange[1]. In Global Climate Exchange, students collaborate with their peers from other countries in online

[1] http://climate.oise.utoronto.ca/2010/

inquiry-based activities. The design of Global Climate Exchange builds on the prior work on "knowledge community and inquiry (KCI) in the classroom" (Slotta & Najafi, 2010). The module was designed as a scaffolding wiki, in other words, as an online knowledge community where students were scaffolded through activities, by tasks given by the designers and the teachers, to explore and discuss climate change issues. When implemented, the Global Climate Exchange wiki was without any content and it was gradually filled up with the students' contributions as they were guided through the activities (Figure 1).

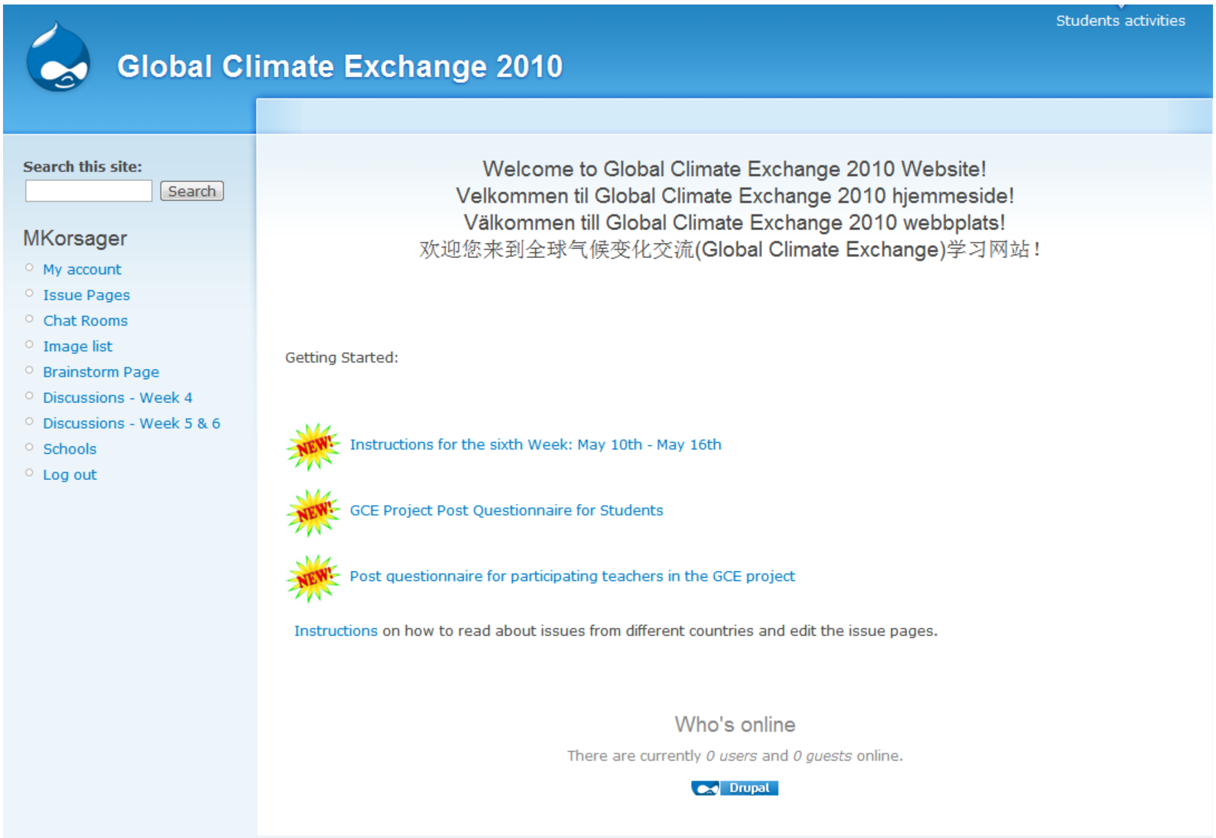

Figure 1. The front page of Global Climate Exchange, welcoming the student in four different languages: English, Chinese, Norwegian, and Swedish. Elsewhere, the collaboration language was English. The Global Climate Exchange functioned as a wiki without any content and it was gradually filled up with the students' contributions as they were guided through the activities: Brainstorm activity, Issue activity, Discussion activity, and Chat activity.

In Global Climate Exchange, students were guided to collaborate with their peers through four different activities: *Brainstorm activity, Issue activity, Discussion activity,* and *Chat activity,* during a 6-week period. During the first week, the students worked on the brainstorm activity, where they identified national climate change issues, added these to a Google Map developed specifically for this activity, and described the issues on a brainstorm page (Figure 2). The focus of this activity was to engage students in thinking about climate change topics by promoting their curiosity and eliciting their prior knowledge. Through this activity, the students started to communicate national and local climate change issues to their peers. When working on the brainstorm activity, students inquired through diagnosing problems, identifying questions, searching for information and communicating findings.

After finishing this activity, the students' work was examined by teachers and researchers to identify global issues that were relevant for further elaboration in the subsequent activities. The twelve issues were acid rain; the changing acidity (pH) of waterways; changing ocean currents; changing species in ecosystems; changing weather patterns; deforestation; drought and desert formation; erosion and flooding of coastal areas; greenhouse gas emissions from automobiles; melting glaciers and snow; pollution from industry; smog and haze and rising sea levels. These issues were not in themselves climate change issues, but issues that could be explored in relation to global climate change.

Figure 2. The Google Map students worked with in the brainstorm activity. They placed national climate change issues on the map and located their school on the map.

After the brainstorm activity, each student was assigned to one of the twelve climate change issues, building groups containing students from different countries. These climate change issues were suggested by the students in the opening brainstorming activity, and hence, the issues were selected by teachers as relevant for all four countries to be further elaborated on in subsequent activities.

The students' task was, in collaboration, to investigate and describe their climate change issue further; more specifically, they were asked to describe the issue, give relevant examples from their own countries, and explain the science related to the issue. The objective of the issue activity was to engage students in exploring and explaining climate change issues. Through exploration, students can use their prior knowledge to generate new ideas, explore questions, and through explanation, the students can clarify their understanding of concepts and ideas. In the issue activity, students inquired through diagnosing problems, identifying questions, searching for information, collecting evidence, planning investigations, formulating explanations and communicating findings.

Still working in their groups from the issue activity, the students were introduced to a *discussion activity*. The discussions were initiated by questions posed by the designers and teachers about climate change topics. The aim of these questions was to catalyze the students' discussion within climate change topics. The students answered these questions, raised their own questions, and commented on other students' contributions. The first main question was "What is 'Global' in Global Climate Change?" This was guided by the following questions: "How are the problems in our countries inter-related?" and "How does the climate change in one part of the world affect other parts of the world?" The next main question was "How can changes in your lifestyle improve climate change?" guided by "After reading about the climate change issues in the other countries, how does your lifestyle influence climate change?" The following questions were "What could be done?", "What has been done?", and "What might happen if we do nothing?" When discussing these questions, students' probed what *could* and *had been* done by the government, in remediation programs and through policies and in their personal lifestyles. They were also considering what impact different remediation could have on both national on global environments. The aim of the discussion activity was to engage the students in further elaborations of climate change issues and remediation, and apply their prior and new knowledge to a new context.

During the discussion activity, students inquired through researching conjectures, debating with peers, and forming coherent arguments.

Embedded in Global Climate Exchange there was also the option for students to, at any time, create a *chat room*. There was no guidance provided for the use of chat rooms in Global Climate Exchange, except for some ethical rules, which were monitored by researchers and teachers in each country. The chat rooms allowed students to collaborate on tasks, receive technical or instructional help, or simply to have informal communication with their peers.

Sample and data collection

The peer collaboration in Global Climate Exchange included 157 students from four high school classes in Canada (n = 30), China (n = 46), Sweden (n = 52), and Norway (n = 29) working with climate change issues for 6 weeks. In this study, we were especially interested in how the peer collaboration in Global Climate Exchange affected one of the cohorts, the Norwegian students. To answer the first research question, students' explanations about climate change issues in the *issue activity* were analyzed qualitatively. To answer the second research question, each student's interactions with his or her peers in all activities in Global Climate Exchange were analyzed quantitatively, and were correlated with data from the qualitative analysis.

Analyses

In our analysis, we had an overall focus on the development of students' explanations of climate change issues. The students' explanations were a product in progress during the 6 weeks of participation, and there were great variations in how often, and in what way they developed these explanations. By tracing each student by their username, it was possible to extract each student's work, and to follow the development of their explanations, even during collaborative work.

The analyses were conducted in following three steps. In the first step, scientific concepts, links, and perspectives in students' written explanations were identified and coded (Table 1).

Table 1. In the first analytic step, scientific concepts, links, and perspectives in students' written explanations were identified and coded according to the criteria for categorization.

VARIABLE	DESCRIPTION FOR CATEGORIZING
Concepts	Concepts are things that are usually referred to by nouns or noun phrases. Only new concepts are coded (not repetitive concepts). The concept level is estimated based on the proportion of relevant scientific concepts in relation to the total number of words used in the explanation.
Link quality	Links are usually verbs and sentences between concepts that explain or give information about the concept. Link quality refers to how well concepts are linked (related and correlated) together and they are coded as misunderstood, weak, irrelevant, a relevant description, or relevant example. The link quality level is estimated from the proportion of weak/irrelevant/misunderstood and relevant links.
Perspectives	Perspectives refer to the purpose of the explanation. These are coded into causes (why does it happen?), mechanisms (how does it happen?), or predicted consequences (what might happen?), evidence (what has happened?), adaptations (has the "phenomena/system" adapted to changes?), remediation (what could be done/has been done to change?).

Secondly, after students' explanations were categorized into concepts and links, they were converted into concept maps. Concept maps were used for two reasons: they visualized the structural organization of students' explanations and provided an illustration of the developmental progress when students elaborated on their explanation.

Third, based on coding and concept maps, the students' ability to explain causal patterns was evaluated. This coding included an organization of the explanations in terms of how coherent the explanations were and the relevance of different parts fitting the explanation as a whole. In this step, explanations of cause and effect relationships were evaluated. The categorizations of explanations are based on the taxonomy of Causal Models and the SOLO taxonomy. The criteria for each category are described in Table 2.

Table 2. Students' explanations are categorized. The categorizations of explanations are based on the taxonomy of Causal Models and the SOLO taxonomy.

Category	Description
Low	The explanation is mainly a description of an issue. It includes the names of the components of an ecological system, but the information is scattered, unconnected, and without organization. Cause and effect relationships are misunderstood or not identified. Few concepts are used and the quality of links (prepositions) between concepts is poor, wrong, or misunderstood. The issue is only described from one or two perspectives.
Low–medium	The explanation contains information about relationships among the ecosystem's components. This includes the direct connection between components of an ecological system. The correlations in these connections are characterized as simple linear causality, described as one-step linear connections that are unidirectional in nature. A few cause and effect relationships are identified, but they are only understood in a linear manner. Few concepts are used and the quality of links between concepts is poor. The issue is only described from two or three perspectives.
Medium	The explanation contains information about how the ecological system's components and processes are organized within a framework of relationships. The correlations in these connections are characterized as multiple linear causality, multi-step linear connections involving multiple components, and indirect connections. Cause and effect relationships are identified and understood in a multi-linear way. A variety of concepts is used and the quality of links between concepts are valuable examples or complementary. The issue is described from at least three perspectives.

Medium–high	The explanation contains information about the dynamic relationships within the ecological system. This involves the identification of dynamic relationships such as mutually causal (two-way) correlations between components, and how the dependence between these relationships is a part of the whole system. The magnitude of the correlation (e.g. amount, concentration, or number) is included in these relationships. Cause and effect relationships are identified and understood in a mutual way. A variety of relevant concepts is used and the quality of links (prepositions) between concepts are valuable examples or descriptive for concepts. The issue is described from at least four perspectives.
High	For explanations in this category, concealed dimensions about an issue described as patterns and interrelationships that are not seen on the surface are noted. This involves recognizing the pattern of cyclic causal correlations in the ecosystems, where each ecosystem consists of several subcycles and minor systems, but that together they are a part of the Earth's global ecosystem. The explanation also includes factors such as a temporal dimension, retrospection, and prediction. Cause and effect relationships are identified and understood in a cyclic way. A variety of relevant concepts is used and the quality of links between concepts are valuable examples or descriptive for concepts. The issue is described from at least five perspectives.

To answer the second research question, the developments of students' explanations of climate change issues were correlated with how the students interacted with peer students' online activities. By tracing each student by username, it was possible to register how many times they entered and worked in Global Climate Exchange (# activity entries), the number of times they interacted with national and international peers (# interaction with peers), and the number of times they interacted with international peers (# interaction with peers). Seen in relation to the development of students' explanations, the impact of the students' interaction with their peers could be discussed.

RESULTS

Limitations

Ten of the original 29 Norwegian students were excluded from the analysis due to a significant lack of data (i.e., because of limited participation in the online environment due to absence from school), which made it difficult to follow the development over time. The data analyzed are hence from 19 Norwegian students (aged 17). Participation in the Global Climate Exchange module required students to communicate in English. However, students were allowed to use all types of supporting tools to write and translate their contributions. When answering a post questionnaire, only one of the 19 Norwegian students responded that they had considered their English language ability to be a "barrier" to their contribution within the Global Climate Exchange module. Language has therefore not been considered as a problem influencing the results of this study. This is a case study; hence, conclusions drawn from the results should be interpreted with this in mind.

How do students develop their explanations about climate change issues over time when participating in Global Climate Exchange?

In our analysis of the 19 Norwegian students' written explanations of climate change issues, we registered 151 distinct explanation events, which is an average of approximately eight times for each student. The students' explanations were analyzed in the following four steps. In the first step, the variables from the first dimension (*scientific concepts, links and perspectives*) in students' written explanations were identified and coded. Secondly, student explanations were categorized in concepts and links and converted into concepts maps, a valuable tool for visualizing the students' explanation (Kinchin, Hay, & Adams, 2000; Rye & Rubba, 2002). Concept maps were used for two reasons; they visualize the structural organization of student explanations, and provide an illustration of the developmental progress when students elaborate their explanation. Both of these characteristics make concept maps an important and supportive tool in the analysis of conceptual understanding. Third, based on coding and concepts maps, variables in the second dimension (*organization and causalities*) were coded. Finally, the causal patterns, and overall organization in each of the student's explanations was evaluated and assigned a level, based on the overall impression from coding at the first and second dimension.

Analyses of the three variables (concepts, link quality, perspectives) are shown in Table 1.

Use of concepts

Concepts—usually nouns or noun phrases—in the students' explanations were identified. Coding revealed that the five concepts that were most frequently used were sea, water, acid, ice, and rain. Many of these concepts occurred mainly in noun phrases, for example, "When the [sea level] rises, the outer boundary of the wetlands will erode" and "The most serious damage caused by [acid rain] in Norway today is probably acidification of water in lakes and rivers." However, stand-alone concepts were sometimes mentioned: "Flooding was due to late snow melt and [rain]." After identifying all of the concepts, the concept–word ratios were calculated. Since only relevant and new concepts (not repetitive concepts) were coded, these values tell us something about the use of scientific concepts in the explanation.

The results show that the proportion of relevant scientific concepts in relation to the total number of words used in the explanation increased on average from 0.16 in the first week to 0.20 in the last week (Figure 3). The proportion of concepts that the

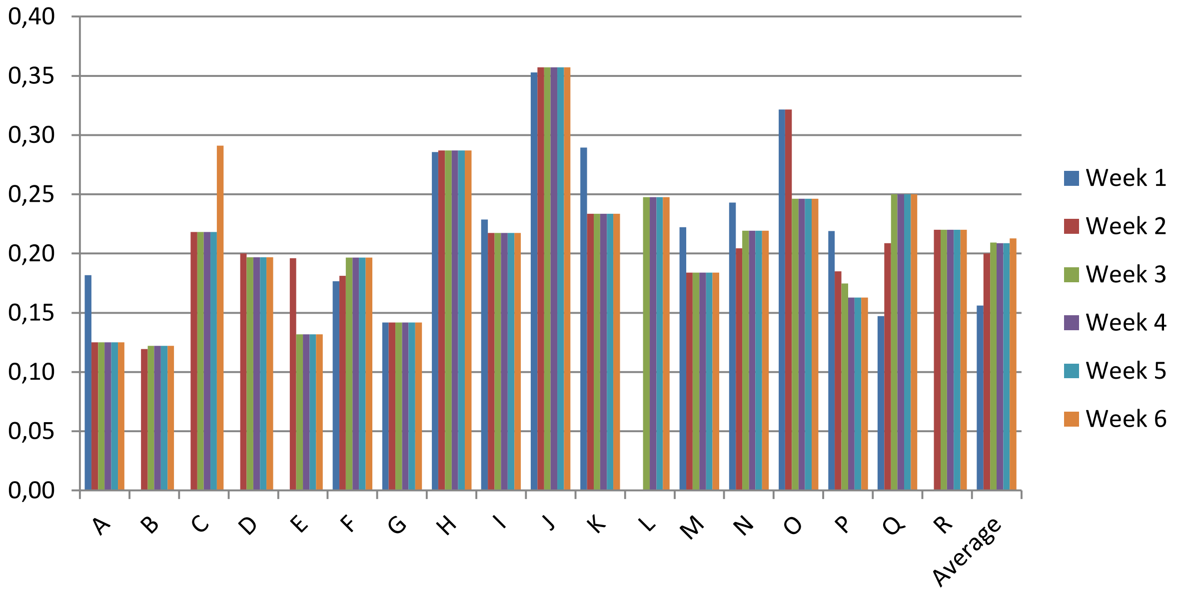

Figure 3. The average proportion of relevant scientific concepts in relation to the total number of words the students (A-R) used in their explanations.

students used in their explanations varied from 0.12 to 0.36 between students, whereas there was less variation within each student's explanation over time. The greatest difference was between the students' use of concepts in the first week (SD = 0.13), which declined to 0.8 in week 2, and then to 0.6 from week 3 to week 6.

Link quality between concepts

Words and sentences, usually verbs and adverbs, before or between concepts that explain or give information about the concept were coded as links. These links were categorized as misunderstood, weak, irrelevant, a relevant description, or relevant example. One student explained: "[Many] things [that have happened to the] ocean [are linked to] global warming." This sentence was coded as weak because it did not actually explain much about the concept "ocean"; that is, *what* has happened, or *why* this is linked to global warming. After categorizing the links, they were divided into high quality (relevant descriptions and examples) and low quality (weak, irrelevant, and misunderstood) links.

The distribution of the link quality is illustrated in . The first week had links in students' explanations that were dominated by low quality: weak/irrelevant/misunderstood. The proportion of low quality links decreased in the third week and remained stable until week 6. In the last week, only four students had a dominating proportion of weak/irrelevant/misunderstood links in their explanations. Other students were better at using relevant links, as shown by this student: "Acidification of rivers and lakes [has caused complete loss of many] fish stocks. Norway [has for example lost eighteen] salmon stocks." The student first gives a relevant description and then a relevant example. Twelve students used a majority of relevant links, descriptions, and examples, whereas two students had roughly the same number of high quality and low quality links.

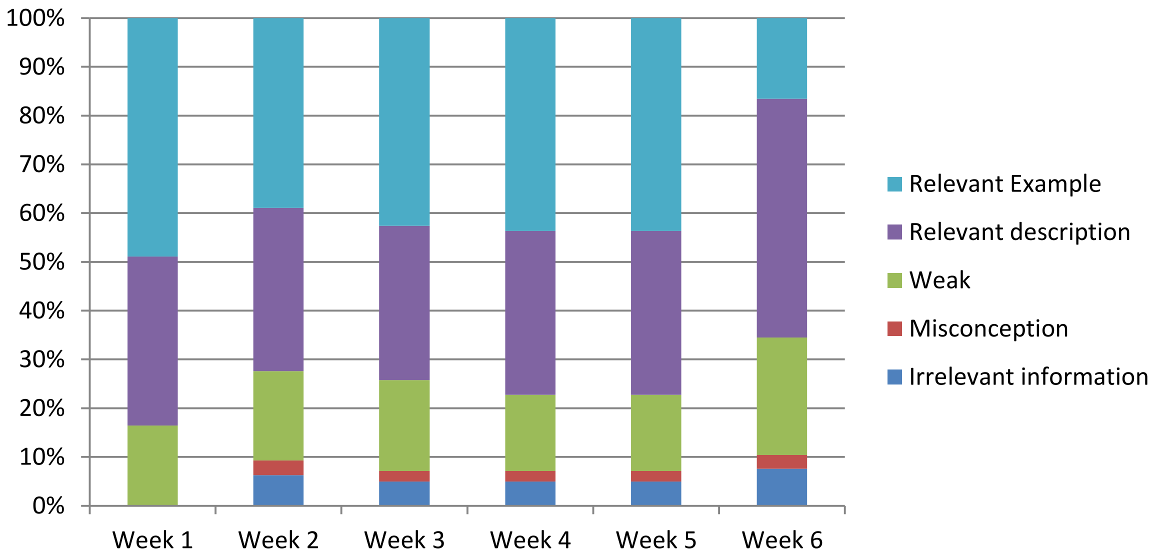

Figure 4. The distribution of link quality. Link quality refers to how well concepts are linked (related and correlated) together and they are coded as misunderstood, weak, irrelevant, a relevant description, or relevant example.

Perspectives on issues

Six perspectives were identified in the students' initial explanations: cause, evidence, mechanism, predicted consequence, remediation, and adaptation. An example of coding relates to this student explaining acidification of the oceans: "It's expected that organisms producing calcareous shells, like shellfish, will have problems due to acidification." The student first gives an example of what will happen from acidification of the oceans for one of the species in this biotope and this is coded as a predicted consequence. She further explains why this will happen: "Shellfish are mostly made up of the mineral calcium carbonate ($CaCO_3$). And when it reacts with acid, it will slowly dissolve"—this is coded as a mechanism.

In the first week, students focused mostly on explaining predicted consequences (37%). In week 6, the students focused similarly on predicted consequences (29%), evidence (27%), and mechanisms (23%) (Figure 5). However, they paid little attention to adaptation, such as explaining how organisms or ecosystems could adapt to changes in the environment. This lack of a conceptual element was consistent throughout the project.

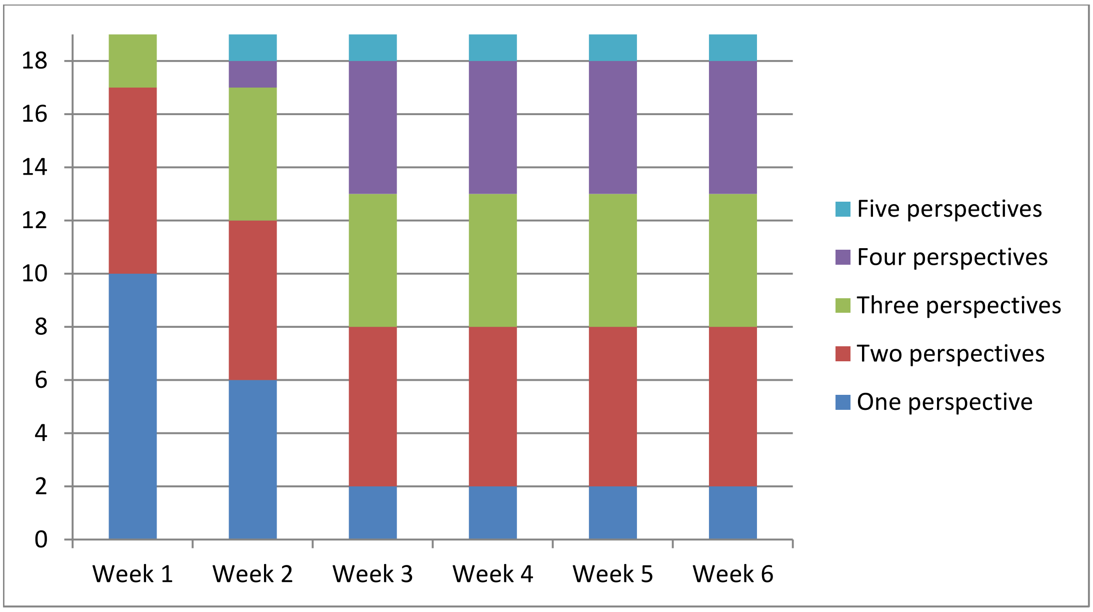

Figure 5. The number of explained perspectives from week 1 to week 6.

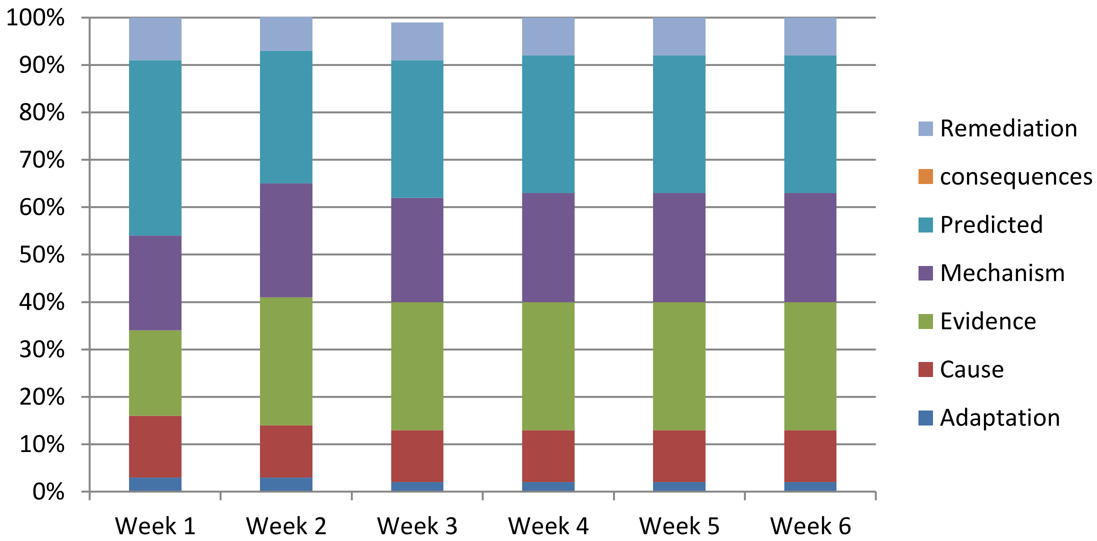

Figure 6. Amount (%) of students' explanation with a focus on the different perspectives of climate change issues: evidence, predicted consequence, mechanism, cause, adaptation, remediation.

The number of explained perspectives varied from one to five (Figure 6). In the first week, ten students only explained one perspective and no one explained more than three perspectives. The average number of perspectives explained was calculated as one in week 1.

The number of perspectives explained increased until week 3, and then became stable until week 6. On average, the students explained three perspectives in week 6, but it varied from one to four.

The number of perspectives explained can point toward whether students have a rich or limited understanding of an issue or phenomenon; however, there might be other reasons as to why students only explain a few perspectives.

Causal patterns and overall organization of students' explanations

After analyzing the three variables (concepts, link quality, and perspectives), the causal patterns, and overall organization in each of the student's explanations was evaluated. The explanations were hence categorized according to the criteria described in Table 2 in the analyses section. The results in Figure 7 present the distribution of students' explanations in each of the five categories: Low, Low–medium, Medium, Medium–high, and High.

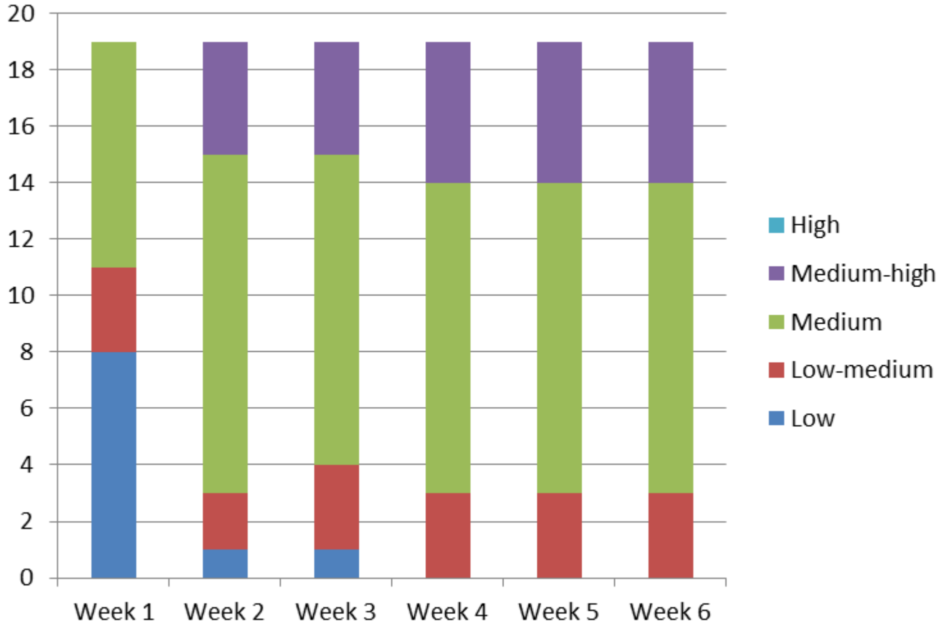

Figure 7. Distribution of students' explanations after coding the concepts, link quality, and perspectives, and evaluating causal patterns, and overall organization. The criteria for each category—Low, Low–medium, Medium, Medium–high, and High—are described in Table 2 in the analyses section.

In the sixth week, a large majority of the students' explanations were categorized as Medium (n = 11) or Medium–high (n = 5). Compared to the first week, this is an increase of 41%. It is also worth noting that none of the students' explanations was at Medium–high in the first week, whereas almost a third were in this category by week 6. These students developed their explanations in terms of describing multiple causes and effects, and by describing how these causal relationships were a part of the whole system. Complex causalities are made up of multiple linear patterns including both indirect effects, and cascading effect patterns in which causes can be seen as effects and effects as causes. A student can explain how climate change has an impact on the ecosystem, by describing complex causalities in this way:

An increase of climate gases in the atmosphere can lead to a variety of temperature changes. Both higher and lower temperatures had an impact on the ecosystem, resulting in plants and animals increasing or decreasing in number. Either too little food and nutrients or too much food and nutrients can be a problem, because too little food can cause animals to starve, and too much food can cause overgrowth of plants and increased population size in animals, and the ecosystem will be unbalanced. (Norwegian student)

In their explanations, they used a variety of relevant concepts and linked them correctly together, and they were able to illuminate multiple perspectives on climate change issues. Some of these students had small sequences in their explanations that were considered as High. Nonetheless, these were not consistent enough to be categorized overall as High, e.g. when parts of the explanation lacked concepts or included concepts that were not connected to the rest then the overall impression of the explanation became fragmented

More than half of the students (n = 11) ended up having a medium quality to their explanations of climate change issues, meaning that they identified multiple linear causalities involving multiple indirect connections, used a variety of concepts, and linked them properly together as valuable examples or complementary information, and they described at least three perspectives for climate change issues. None of the students ended up having explanations categorized as Low in the end. The three students whose explanations were Low–medium in the sixth week mainly focused on direct connections between causes and effects. An example is given by the following student's explanation: "A decrease of the polar bear population is caused by less water covered with annual sea ice" (Norwegian student). While this statement may not be wrong, it is incomplete, because there is seldom only one cause to any such effect, nor one effect from any given cause. A decrease in the polar bear population could, for example, also be caused by the fact that many polar bears suffer from infertility due to accumulated levels of persistent organic pollutants, which have a major impact on polar bears given their position at the top of the food pyramid. When students limit their explanations to simple linear causalities, they neglect such "multiplexed" accounts of causes and effects. Consequently, students might fail to understand the more complex and subtle causal relationships.

Students at this level also used relatively few concepts, which were poorly linked together, and only described one or two perspectives for climate change issues. As seen in Figure 7, the positive development of students' explanations remains stable after the fourth week. This tendency could be explained by the introduction of discussion themes, resulting in students paying more attention to these than to developing their explanations of issues.

In summary, students gradually organized their explanations more coherently in terms of describing aspects of climate change issues and integrating them into a whole. Another result is that differences between student levels declined over time, indicating the students as a group had a more homogenous understanding of climate change at the end of Global Climate Exchange than at the beginning.

Is the development of students' explanations of climate change issues correlated to how the students interact with their peers?

Twelve of 19 students developed their explanations in terms of advancement; for example, they better explained causalities using scientific concepts, by linking concepts together, and explaining their perspectives regarding climate change issues. These students interacted with their peers three times more often on average compared to those who did not advance. These interactions included both collaborative writing in the *issue activity,* but also comments and replies in the *discussions* and *chat rooms*.

In the issue activity, interactions between peers lead to improvement of explanations of issues in terms of students clarifying each other's sentences, added information or new relevant concepts. Communicative interaction between peers in *discussions* and *chat rooms* often challenged the students to clarify their explanations and form coherent evidence based arguments (Korsager, Slotta, & Jorde, 2014).

Students who advanced also had twice as many online activity entries for Global Climate Exchange on average compared to those who did not advance. The five students who ended up with a Medium–high explanation entered the forum three times more often compared to those three students whose explanations were categorized as Low–medium.

DISCUSSION

In this study, we explored the opportunities that international peer collaboration in Global Climate Exchange could give, by analyzing how the Norwegian students developed their explanations of climate change issues over time. Our analysis showed that the students, over 6 weeks, increased the proportion of relevant scientific concepts in relation to the total number of words in their explanations, and that they improved the quality of the links between concepts. The ratio of concepts alone is not in itself an indication of the good quality of an explanation; however, students using few concepts in relation to words might have poor scientific literacy, and vice versa for a high ratio. The quality of links between concepts might likewise refer to scientific literacy, but also to the ability to understand the relationship and interactions in ecosystems, and hence to comprehending the causal links between concepts in climate change issues (Begon et al., 1996; Campbell et al., 1999).

The analysis also revealed that the students explained more perspectives regarding climate change issues over time. The number of perspectives explained by a student can point toward whether she or he has a rich or limited understanding of an issue. Collaboration and communication between peers has been found to be effective because students can exchange ideas and knowledge (Fawcett & Garton, 2005; Hoadley, 2000, 2004; Peters & Slotta, 2010; Rojas-Drummond & Mercer, 2003; Scardamalia & Bereiter, 1993a, 1993b, 2003, 2006; Slotta & Najafi, 2010). In this exchange, students can build connections between new and existing knowledge, and thereby expand their understanding toward a more coherent one (Krajcik, Slotta, McNeill, & Reiser, 2008; Slotta, 2009; Slotta & Linn, 2009). The fact that the students tended to explain more perspectives over time could be an indication that collaboration with their peers enriched their perspectives regarding climate change issues.

When analyzing students' explanations as a whole, taking together the analysis of concepts, link quality, and perspectives, we observed a significant improvement. In summary, the students became, in general, better at organizing and connecting relevant concepts to explain their climate change issue, and could explain cause and effect patterns in suitable ways. Their ability to explain causal patterns were on average good. Only three of the students' explanations for climate change were categorized as Low–medium and none of the explanations was Low. In Global Climate Exchange, students are not explicitly taught causalities, but are instead guided by inquiry tasks to find the information by themselves or through peer interactions with international peers. An explanation for this positive result could be that in Global Climate Exchange students work with the context of a topic (climate change), which they all have some sort of prior knowledge about and personal experiences of. The connection of new knowledge with prior knowledge is a key factor for learning (Bransford et al., 2000; Donovan & Bransford, 2005; Duit & Treagust, 2003).

The analysis of the interactions with peers points toward students who develop their explanation the most, interact most with their peers, and also have the most entries in Global Climate Exchange. This can be explained through international peer collaboration providing students with exposure to diverse cultural and geographic perspectives through their peers, giving them new insights and other perspectives on climate change issues. Similarly, student participation in inquiry tasks with their peers could have a positive impact on their engagement, and hence on their motivation to develop their explanations. Through communication with their peers, the students could relate the topic to their personal lifestyle and even gain an insight into the lifestyles of their peers. This gave the students an opportunity to make personal sense of new knowledge, which is important for motivation and learning (Howe et al., 1995; Tao, 1999).

However, the analysis in this paper can only be used to draw a quantitative inference, and we realize the need for further investigations concerning the quality of these peer interactions. The reason why students develop their explanations of climate change issues could be as simple as the amount of time that they spend working on the topic. However, this does not explain the increased quality of their explanations. The correlation between development and peer interaction and activity entries could also be the other way around; for example, that students with a higher potential are more likely to interact with their peers and are more engaged in the task they are given. Anderson (2002) states that one of the great challenges during inquiry activities is that students must be active, engaged learners who take responsibility for their own learning. Nevertheless, students who managed to take such responsibility (i.e., interacting frequently with their peers, with a high number of entries) have benefited from the international peer collaboration in Global Climate Exchange. Furthermore, these results stress the importance of science teachers' role as facilitators and supervisors, supporting and encouraging their students to actively engage in and contribute to peer collaboration.

CONCLUSION

In a time where climate change is one of the greatest threats to our planet, we face many challenges in preparing students for a future of climate change and work for sustainable development. In Norway, it has been decided on the political level that science education shall comprise education for sustainable development to ensure that scientific knowledge is more convenient, relevant, and realistic (Kunnskapsdepartementet, 2012). To accomplish such a goal, there is a need for education that enhances students' understanding of climate change by making it more personally relevant. The results of this study indicate that international peer collaboration, if successfully supported, can be an effective approach to climate change education. To strengthen and further globalizing the results we encourage others to replicate the study in other potential countries. For detailed information on the study, contact the authors.

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REFERENCES

Anderson, R. D. (2002). Reforming science teaching: what research says about inquiry. *Journal of Science Teacher Education, 13*(1), 1-12.

Begon, M., Harper, J., & Townsend, C. (1996). *Ecology: individuals, populations, and communities*: Wiley-Blackwell.

Bell, T., Urhahne, D., Schanze, S., & Ploetzner, R. (2010). Collaborative inquiry learning: models, tools, and challenges. *International Journal of Science Education, 32*(3), 349-377.

Biggs, J. B. (1979). Individual differences in study processes and the quality of learning outcomes. *Higher Education, 8*(4), 381-394.

Biggs, J. B., & Collis, K. F. (1982). *Evaluating the Quality of Learning: The Solo Taxonomy: Structure of the Observed Learning Outcome*: Academic Press.

Biggs, J. B., & Tang, C. S. (2007). *Teaching for quality learning at university*: Open university press Buckingham.

Boulton-Lewis, G. (1995). The SOLO taxonomy as a means of shaping and assessing learning in higher education. *Higher Education Research & Development, 14*(2), 143-154.

Brabrand, C., & Dahl, B. (2009). Using the SOLO taxonomy to analyze competence progression of university science curricula. *Higher Education, 58*(4), 531-549.

Bransford, J., Brown, A., & Cocking, R. (2000). *How people learn*: National Academy Press Washington, DC.

Campbell, N., Reece, J., & Mitchell, L. (1999). *Biology. 5th*: New York: Addison Wesley Longman, Inc.

Carlsson, B. (2002). Ecological understanding 2: transformation-a key to ecological understanding. *International Journal of Science Education, 24*(7), 701-715.

Chan, C., Tsui, M., Chan, M., & Hong, J. (2002). Applying the structure of the observed learning outcomes (SOLO) taxonomy on student's learning outcomes: An empirical study. *Assessment & Evaluation in Higher Education, 27*(6), 511-527.

Council, N. R. (2005). *How Students Learn: History, Mathematics, and Science in the Classroom*. Washington, DC: The National Academies Press. Division of Behavioral and Social Sciences and Education.

Daniel, B., Stanisstreet, M., & Boyes, E. (2004). How can we best reduce global warming? School students ideas and misconceptions. *International journal of environmental studies, 61*(2), 211-222.

Dillenbourg, P. (1999). What do you mean by collaborative learning? In P. Dillenbourg (Ed.), *Collaborative-learning: Cognitive and Computational Approaches* (pp. 1-19). Oxford: Elsevier.

Donovan, S., & Bransford, J. (2005). *How students learn: History in the classroom*. Washington D.C.: The National Academies Press.

Dove, J. (1996). Student teacher understanding of the greenhouse effect, ozone layer depletion and acid rain. *Environmental Education Research, 2*(1), 89-100.

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing Scientific Knowledge in the Classroom. *Educational Researcher, 23*(7), 5-12.

Duit, R., & Treagust, D. F. (1998). Learning in Science - From Behaviourism Towards Social Constructivism and Beyond. In B. Fraser & K. Tobin (Eds.), *International handbook of science education* (pp. 3-26).

Duit, R., & Treagust, D. F. (2003). Conceptual change: a powerful framework for improving science teaching and learning. *International Journal of Science Education, 25*(6), 671-688.

Ekborg, M. (2003). How student teachers use scientific conceptions to discuss a complex environmental issue. *Journal of Biological Education, 37*(3), 126-132.

Ekborg, M., & Areskoug, M. (2006). How student teachers' understanding of the greenhouse effect develops during a teacher education programme. *Nordic Studies in Science Education, 5*(5), 17-29.

Fawcett, L. M., & Garton, A. F. (2005). The effect of peer collaboration on children's problem solving ability. *British Journal of Educational Psychology, 75*(2), 157-169.

Gerard, L. F., Spitulnik, M., & Linn, M. C. (2010). Teacher use of evidence to customize inquiry science instruction. *Journal of Research in Science Teaching, 47*(9), 1037-1063.

Gerard, L. F., Tate, E., Chiu, J., Corliss, S., & Linn, M. C. (2009). *Collaboration and knowledge integration.* Paper presented at the International conference on Computer supported collaborative learning.

Goldring, H., & Osborne, J. (1994). Students' difficulties with energy and related concepts. *Physics Education, 29*, 26.

Gowda, M. V. R., Fox, J. C., & Magelky, R. D. (1997). Students' understanding of climate change: Insights for scientists and educators. *Bulletin of the American Meteorological Society Boston MA, 78*(10), 2232-2240.

Green, D. (1997). Explaining and envisaging an ecological phenomenon. *British Journal of Psychology, 88*(2), 199-217.

Grotzer, T. A. (2003). Learning to understand the forms of causality implicit in scientifically accepted explanations. *Studies in Science Education, 39*(1), 1-74.

Grotzer, T. A., & Basca, B. B. (2003). Helping students to grasp the underlying causal structures when learning about ecosystems: How does it impact understanding. *Journal of Biological Education, 38*(1), 16-29.

Grotzer, T. A., Kamarainen, A. M., Tutwiler, M. S., Metcalf, S., & Dede, C. (2013). Learning to Reason about Ecosystems Dynamics over Time: The Challenges of an Event-Based Causal Focus. *BioScience, 63*(4), 288-296.

Hakkarainen, K. (2003a). Emergence of progressive-inquiry culture in computer-supported collaborative learning. *Learning Environments Research, 6*(2), 199-220.

Hakkarainen, K. (2003b). Progressive inquiry in a computer-supported biology class. *Journal of Research in Science Teaching, 40*(10), 1072-1088.

Helldén, G. (2012). Studies of the development of students' understanding of ecological phenomena. In D. Jorde & J. Dillon (Eds.), *Science Education Research and Practice in Europe: Retrospective and Prospective*. The Netherlands: Sense Publishers

Hmelo-Silver, C., & Pfeffer, M. (2004). Comparing expert and novice understanding of a complex system from the perspective of structures, behaviors, and functions. *Cognitive Science, 28*(1), 127-138.

Hoadley, C. M. (2000). Teaching science through online, peer discussions: SpeakEasy in the Knowledge Integration Environment. *International Journal of Science Education, 22*(8), 839-857.

Hoadley, C. M. (2004). Fostering productive collaboration offline and online: Learning from each other. In M. C. Linn, E. A. Davis, & P. L. Bell (Eds.), *Internet environments for science education* (pp. 145-174). Mahwah, NJ: Lawrence Erlbaum.

Hodges, L., & Harvey, L. (2003). Evaluation of student learning in organic chemistry using the SOLO taxonomy. *Journal of Chemical Education, 80*(7), 785.

Howe, C., Tolmie, A., Greer, K., & Mackenzie, M. (1995). Peer collaboration and conceptual growth in physics: Task influences on children's understanding of heating and cooling. *Cognition and Instruction, 13*(4), 483-503.

IPCC. (2007). Summary for Policymakers. In Climate change 2007: the physical science basis. In S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (Ed.), *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*.

IPCC. (2013). Climate Change 2013: The Physical Science Basis. In T. Stocker, Q. Dahe, & G. Plattner (Eds.), *Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Summary for Policymakers (IPCC, 2013)*.

Kinchin, I. M., Hay, D. B., & Adams, A. (2000). How a qualitative approach to concept map analysis can be used to aid learning by illustrating patterns of conceptual development. *Educational Research, 42*(1), 43-57.

Korsager, M., Slotta, J. D., & Jorde, D. (2014). Global Climate Exchange: Peer collaboration in a "Global classroom". *Nordic Studies in Science Education, 1*(1), 105-120.

Krajcik, J., Slotta, J. D., McNeill, K. L., & Reiser, B. J. (2008). Designing learning environments to support students' integrated understanding. *Designing coherent science education: Implications for curriculum, instruction, and policy*, 39-64.

Kunnskapsdepartementet. (2012). *Kunnskap for en felles framtid. Revidert strategi for utdanning for bærekraftig utvikling 2012-2015*. Oslo: Retrieved from http://www.regjeringen.no/upload/KD/Vedlegg/UH/Rapporter_og_planer/Strategi_for_UBU.pdf.

Lake, D. (1999). Helping students to go SOLO: teaching critical numeracy in the biological sciences. *Journal of Biological Education, 33*, 191-198.

Leach, J., Driver, R., Scott, P., & Wood-Robinson, C. (1995). Children's ideas about ecology 1: theoretical background, design and methodology. *International Journal of Science Education, 17*(6), 721-732.

Leach, J., Driver, R., Scott, P., & Wood-Robinson, C. (1996a). Children's ideas about ecology 2: ideas found in children aged 5-16 about the cycling of matter. *International Journal of Science Education, 18*(1), 19-34.

Leach, J., Driver, R., Scott, P., & Wood-Robinson, C. (1996b). Children's ideas about ecology 3: Ideas found in children aged 5-16 about the interdependency of organisms. *International Journal of Science Education, 18*(2), 129-141.

Lee, H. S., Linn, M. C., Varma, K., & Liu, O. L. (2010). How do technology-enhanced inquiry science units impact classroom learning? *Journal of Research in Science Teaching, 47*(1), 71-90.

Leung, C. (2000). Assessment for learning: using SOLO taxonomy to measure design performance of design & technology students. *International Journal of Technology and Design Education, 10*(2), 149-161.

Levins, L. (1992). Students' understanding of concepts related to evaporation. *Research in science education, 22*(1), 263-272.

Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry based science instruction - what is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching, 47*(4), 474-496.

Mork, S., & Jorde, D. (2004). We know they love computers, but do they learn science? Using information technology for teaching about a socio-scientific controversy. *Themes in Education, 5*(1), 69–100.

Moser, S. C., & Dilling, L. (2004). Making climate hot. *Environment: Science and Policy for Sustainable Development, 46*(10), 32-46.

Myers, T. A., Maibach, E. W., Roser-Renouf, C., Akerlof, K., & Leiserowitz, A. A. (2013). The relationship between personal experience and belief in the reality of global warming. *Nature Climate Change, 3*(4), 343-347.

NASA. (2012). Global Climate Change. Retrieved 06.10, 2012, from http://climate.nasa.gov/

Palmer, J. (1998). *Environmental education in the 21st century: Theory, practice, progress and promise*: Psychology Press.

Papadimitriou, V. (2004). Prospective primary teachers' understanding of climate change, greenhouse effect, and ozone layer depletion. *Journal of Science Education and Technology, 13*(2), 299-307.

Perkins, D. N., & Grotzer, T. A. (2000). *Models and Moves: Focusing on Dimensions of Causal Complexity To Achieve Deeper Scientific Understanding*. Paper presented at the Annual Meeting of the American Educational Research Association, New Orleans.

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

Peters, V. L., & Slotta, J. D. (2010). Scaffolding knowledge communities in the classroom: New opportunities in the Web 2.0 era. *Designs for Learning Environments of the Future*, 205-232.

Rebich, S., & Gautier, C. (2005). Concept mapping to reveal prior knowledge and conceptual change in a mock summit course on global climate change. *Journal of geoscience education, 53*(4), 355.

Rojas-Drummond, S., & Mercer, N. (2003). Scaffolding the development of effective collaboration and learning. *International Journal of Educational Research, 39*(1–2), 99-111.

Rye, J. A., & Rubba, P. A. (2002). Scoring concept maps: An expert map-based scheme weighted for relationships. *School Science and Mathematics, 102*(1), 33-44.

Rye, J. A., Rubba, P. A., & Wiesenmayer, R. L. (1997). An investigation of middle school students' alternative conceptions of global warming. *International Journal of Science Education, 19*(5), 527-551.

Scardamalia, M., & Bereiter, C. (1993a). Computer support for knowledge-building communities. *Journal of the Learning Sciences*, 265-283.

Scardamalia, M., & Bereiter, C. (1993b). Technologies for knowledge-building discourse. *Communications of the ACM, 36*(5), 41.
Scardamalia, M., & Bereiter, C. (2003). Knowledge building environments: Extending the limits of the possible in education and knowledge work. *Encyclopedia of distributed learning*, 269-272.
Scardamalia, M., & Bereiter, C. (2006). Knowledge building: Theory, pedagogy, and technology. *The Cambridge handbook of the learning sciences. Cambridge University Press, Cambridge*, 97-115.
Shepardson, D. P., Roychoudhury, A., Hirsch, A., Niyogi, D., & Top, S. M. (2013). When the atmosphere warms it rains and ice melts: seventh grade students' conceptions of a climate system. *Environmental Education Research*(ahead-of-print), 1-21.
Slotta, J. D. (2009). *A forum for international peer exchange: Consequences and conversations* Paper presented at the the 13th Biennial Conference for the European Association for Research on Learning and Instruction (EARLI), Amsterdam, the Netherlands.
Slotta, J. D., & Jorde, D. (2010). Towards a design framework for international peer discusssions: Taking advantage of disparate perspectives on socio-scientific issues. *Research and Practice in Technology Enhanced Learning, 5*(3), 161–184.
Slotta, J. D., Jorde, D., & Holmes, J. (2005). *Learning from our peers in international exchanges: When is worth doing, and how can we help it succeed?* Paper presented at the Proceedings of the Fifth International ESERA Conference on Contributions of Research to Enhancing Students' Interest in Learning Science.
Slotta, J. D., & Linn, M. C. (2009). *WISE science: Web-based inquiry in the classroom*: Teachers College Press.
Slotta, J. D., & Najafi, H. (2010). Knowledge Communities in the Classroom. In P. Peterson, E. Baker, & B. McGaw (Eds.), *International Encyclopedia of Education* (Vol. 8, pp. 189-196). Oxford: Elsevier.
Stahl, G., Koschmann, T., & Suthers, D. (2006). *Computer-supported collaborative learning*: Cambridge handbook of the learning sciences. Cambridge, UK: Cambridge University Press.
Steffen, W., Rockström, J., Kubiszewski, I., & Costanza, R. (2013). 10. Planetary boundaries: using early warning signals for sustainable global governance1. *Globalisation, Economic Transition and the Environment: Forging a Path to Sustainable Development*, 259.
Tao, P. K. (1999). Conceptual change in science through collaborative learning at the computer. *International Journal of Science Education, 21*(1), 39-57.

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