
RUNNING HEAD: Pursuit of explanation

A draft of “Pursuit of explanation within a computer-supported classroom”


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Pursuit of explanation within a computer-supported classroom

Abstract

The problem addressed in the study was whether 10- and 11-year-old children, collaborating within a computer-supported classroom, learned an explanation-driven process of inquiry that had characteristics of the progressive nature of scientific inquiry. Technical infrastructure for the study was provided by the Computer-Supported Intentional Learning Environments, CSILE. The study was based on qualitative content analysis of students’ written productions in physics posted to CSILE’s database in three investigative projects. The study indicated that some young students do engage in epistemic agency and genuinely pursue explanation-driven inquiry. Students’ intuitive explanations were often functional (referring to human agency) and empirical (in terms of observables) in nature. Provided that understandable explanations were available, some of the students moved towards theoretical scientific explanations.
Introduction

The purpose of the study is to analyse whether elementary school children, collaborating within a computer-supported classroom, may profitably participate in research-like processes of inquiry that characterize practices of scientific research. The problem addressed in the study is whether 10- and 11-year-old children, in appropriate circumstances, engage in working with knowledge at a deep level of explanation instead of processing only factual and descriptive knowledge. Computer-supported Intentional Learning Environments, CSILE/Knowledge Forum®, that provide a shared space for students to articulate their conception together, have furnished the technical infrastructure for the study (Scardamalia and Bereiter 1993; Scardamalia, in press).

In the present study, I use the concept of ‘progressive inquiry’ to refer to the sustained processes of advancing and building of knowledge characteristic of scientific inquiry (Hakkarainen 1998; Hakkarainen and Sintonen 2002). Fostering such research-like processes of inquiry in education is the goal of several, concurrent, cognitive research projects (Carey and Smith 1995; Hakkarainen and Sintonen 2002; Perkins, Crismond, Simmons, and Unger 1995; Scardamalia and Bereiter 1993; 1999; The Cognition and Technology Group at Vanderbilt 1997). Characteristic of progressive inquiry is that scientific knowledge is not passively transmitted to students but appropriated through solving problems of understanding. An essential aspect of this kind of inquiry is to jointly engage in progressively improving shared conceptual artefacts, such as questions and explanations (Bereiter, 2002).

An important aspect of inquiry is generation of one’s own tentative explanations or working theories for the phenomena being investigated (Carey and Smith 1995; Hakkarainen & Sintonen, 2002; Perkins et al., 1995; Scardamalia and Bereiter 1993). From the intimate link between explanation and understanding, it follows that explanation should have an essential role in science education. Studies of the self-explanation effect in physics learning indicate that students who explain examples to themselves achieve better learning results than students having identical, separately measured, declarative knowledge (Chi, Bassok, Lewis, Reiman, and Glaser 1989). Explaining a problem to other inquirers is likely to make the inadequacies of one’s understanding more salient, as well as facilitate deep conceptual understanding (Hatano and Inagaki, 1992).

The purpose of the present study is to explore whether and to what extent elementary school students, in appropriate circumstances, engage in generating and improving their own intuitive theories while working on such topics of physics as gravity and cosmology. When examining the nature of the intuitive theories and scientific knowledge students work with, it is useful to make distinctions between functional and physical as well as empirical and theoretical explanations. Mackor (1995; see also Millikan 1984; Brewer, Chinn, and Samarapungavan, 2000) distinguished between physical and functional explanations. Functional explanations categorize things according to their actual or potential functions, often containing a reference to whether an object is working properly, fulfilling its function. The human body is an example of the kind of system that does not necessarily always work properly. Physical explanations, in contrast, do not attribute any purposes or goals to
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physical systems. Physical explanations are descriptions about what physical systems do or have a disposition to do. For example, a description of a system’s microstructure is a kind of physical explanation. About a physical system, one cannot say that it is or is not working properly; physical systems just exist and are determined by causal laws or regularities. According to Millikan (1984), the phenomena accounted for by functional and physical explanations represent different ontological categories. Accordingly, functional explanations referring to intentions, goals and purposes can be contrasted with physical explanations, which do not contain any reference to these kinds of processes, such as correct functioning or malfunctioning.

Salmon (1984) argued that science can give us not only descriptive knowledge but also explanatory knowledge that provides understanding of the world. Scientific change happens by articulating theoretical knowledge of hidden mechanisms of the world (Salmon 1984). The role of theoretical concepts, which refer to unobservable theoretical entities, is crucial in this process. Theoretical concepts constitute the core of theories; theoretical concepts explain relations between observable concepts by postulating underlying entities, common causes, and mechanisms (Salmon 1984; Tuomela 1985). Theoretical explanations refer to non-observable entities that allow the explanation of a wide variety of complex events, and make these events more understandable. The fundamental epistemic value of theoretical concepts is based on the explanatory unification provided by them (Salmon 1984; see also Kitcher 1989; Thagard 1988). Theoretical explanations may be contrasted with empirical explanations based on empirical generalizations across observables. According to Sellars (1963, see also Tuomela 1985), empirical or everyday concepts refer to the manifest image whereas scientific concepts refer to the scientific image. The manifest image represents humans’ phenomenal everyday world, which primarily consists of perceptual middle-sized objects, which serve our practical purposes as human beings. The scientific image, in contrast, refers to ontologically different microphysical processes (Tuomela 1985). A transition from explaining a given phenomenon on the basis of empirical concepts to explaining it theoretically is a crucial step in advancement of conceptual understanding. Often it is not possible to identify and understand a phenomenon without appropriate theoretical concepts, for example, that of ‘field’ (Nersessian 1989; Thagard 1988).

The present study is entirely based on a conceptual as well as qualitative and quantitative analysis of students’ written productions from posted to and recorded in CSILE’s database, and, therefore, we are not seeking direct information about psychological processes involved in CSILE use. The study was a part of pedagogical design experiment that focuses on putting ideas generated by the students themselves into the foci of education (Scardamalia, 1999). Accordingly, it focuses on analysing the students’ externalised conceptions posted to CSILE’s database. These conceptions were interpreted to represent conceptual artefacts created by the students for their local world of cultural knowledge -- Popper’s (1972) World 3 -- constituted by CSILE’s database (Bereiter, 2002; Scardamalia, Bereiter, & Lamon, 1994).

The problem addressed in the present study is whether CSILE students are profitably able to profitably engage, even in a rudimentary form, in an explanation-driven process of inquiry. CSILE is designed to engage students with an extensive
process of setting up research questions, generating and improving their own intuitive explanations, and searching for scientific information. The present investigator has analysed the nature of students’ explanations and whether they were able to commit themselves to progressive improvement of their ideas.

Method

Participants and the Setting of Study

The study is based on an analysis of CSILE students’ written productions, posted to CSILE’s database. CSILE is a networked learning environment that provides a shared space for the participants to solve problems and build knowledge together. The system facilitates sharing of cognitive achievements by providing each student access to all notes produced by their fellow students. Students use CSILE by writing notes, creating charts, and reading and commenting on each other’s productions in various domains of knowledge, such as physics.

The study material represents productions of 28 grade 5/6 students over an academic year at an inner-city public school in Toronto, Canada. In the school studied, a larger than normal proportion of children came from middle-class and upper middle-class homes, but the school also involved a number of students from educationally disadvantaged homes. The study material represents data occurring while the students carry out their study projects, working with CSILE. A study project takes 4-6 weeks and involves writing of a long series of written CSILE notes and comments by each student. On average, students are to work with CSILE 40 minutes a day.

The teacher of the classroom was very experienced male teacher in his 50s. He had participated in CSILE project from the beginning and collaborated closely with researchers, many of them working within his classroom. He has a Ph.D. in social anthropology, but not any academic degrees in science. Over the years he had developed a special method of cultivating knowledge-building culture within his class in terms of involving students with their own inquiries, pursuing their own research questions and intuitive working theories in sciences. Whenever a student wanted to “publish” a CSILE note, the teacher discussed the note with her so as to ensure that beyond being edited, revised, and grammatically correct, it made a significant contribution to collaborative knowledge-building in CSILE’s database, i.e., provided evidence of the students own thinking and cognitive effort. The fact that the classroom was divided into two groups of equal size for studying French every day, provided the teacher an opportunity to work with a much smaller group. While one half of the classroom studied French, the teacher guided the other students’ CSILE work; and then group switched their activities. The teacher wanted each note to make a real contribution to the database, but made, normally, generous allowances for levels of ability of the students. According to the teacher’s estimate, these kinds of oral knowledge-building discussions took twice as much time as the actual work with CSILE.

For years the teacher had attempted to create a classroom culture in which everything they did relied on progressive inquiry and supported it. The students were not, for instance, allowed to go to a library to do research without being able to define...
the research question they were working on. While the inquiry culture took several years to develop, new students adopted it quite soon after entering the classes. The fact that he worked with a split class of grade 5 and 6 students, and half of the students studied two years in the classroom, allowed him to quickly integrate new students into the sophisticated inquiry culture developed over years.

**Study Material: CSILE’s Database**

The study material consisted of written productions posted by the students to CSILE's database across three projects, Force (4 weeks, January-February), Electricity (6 weeks, April-May), and Cosmology (4 weeks, June) in physics. Altogether, the participating students produced, during these projects, 77, 195, and 55 pages of single-spaced text, respectively. The purpose of the Force project was to explain various forms of force, especially gravity. In the Cosmology project, the students were asked to answer the teacher’s questions concerning what the universe was made of, how the universe changed, and how it will be in the future. The Electricity project was based on eight explanation-seeking questions given by the teacher, such as ‘What happens inside a wire when electric current passes through it?’ or ‘What makes one material a conductor of electricity and another material a non-conductor of electricity?’ These questions were addressed by all students, and students were expected to answer the questions by working independently. Further, the students carried out some classroom experiments with circuits, electrolytes, and static electricity during the project.

As stated above, the students were systematically guided by their teacher to generate their own hypotheses, conjectures, and theories about the physical phenomena being investigated. The teacher did not, however, expressly correct the students’ wrong theories but tried to guide the participants themselves to improve their theories through the personal knowledge-building discussions. This pedagogical design allowed analysis of the nature and development of students' intuitive theories, particularly whether all basic types of explanation, such as functional, physical or theoretical explanation, were represented in these students' productions.

**Qualitative Classification of CSILE Students’ Explanations**

CSILE students’ productions (research questions, intuitive and scientific explanations, written comments) were analysed at multiple levels by using qualitative content analysis (see Chi 1997). The participants’ postings to CSILE’s database were partitioned into ideas – corresponding elements of progressive inquiry, such as questions, working theories, (authoritative) scientific information -- in order to increase reliability of classification. This partition was necessary because some students presented many ideas (e.g., several research questions) in a single note. Two independent coders segmented 200 notes into ideas, and the reliability of partitioning was .94.

The students produced a series of written comments that were analysed according to the object of comment; i.e., what aspect of inquiry (problem, method, information, explanation, or other) the comment was about. Further, the epistemological nature of the students’ research questions was analysed by classifying each research question according to whether it was fact- or explanation-seeking in
nature. Why and how questions are typical explanation-seeking questions and cannot be satisfactorily answered without elaborating an explanation. Further, many indirect questions can be transformed into explanation-seeking why or how questions.

In answering their research questions, CSILE students searched for several kinds of scientific information and generated their own intuitive explanations and theories. Each knowledge idea was classified according to type of knowledge, i.e., whether its main content represented a) new scientific information or b) the student’s own intuitive explanation. ‘Scientific information’ means that a student reviewed or introduced pieces of new scientific facts or theories; introduction of new scientific information was usually explicitly categorized by using the “New Information” scaffold or by referring to authoritative scientific sources. ‘Intuitive explanations’ refers to notes in which a student generated his or her own working theory about the phenomenon in question. These types of contributions were categorized by using the “My Theory” scaffold or otherwise talking about “my theory”.

Further, in order to examine contents of the explanations generated by the CSILE students more closely, occurrences of explanatory concepts used by CSILE students to construct and warrant their explanations were coded. Adoption of these explanatory, theoretical concepts is crucial for deep conceptual understanding of the problems being investigated. From each explanation, only one and the most important explanatory concept was coded.

Frequencies of CSILE students’ explanations were analysed based upon qualitative analysis of content. The textnotes of students representing an intuitive theory or explanatory scientific information were analysed according to the nature of explanation. The nature of explanation consisted in three categories, i.e., functional, empirical-physical, and theoretical-physical explanation. Functional explanations refer to and are grounded on human intentions, purposes and goals, whereas physical explanations do not use human agency as a basis of explanation. All explanations containing an explicit reference to human agency (goal, purposes or intentions) or considering the problem on the basis of human needs were regarded as functional. These included explanations that referred to how something is working properly or malfunctioning. Anthropomorphic and animistic explanations, which relied on some kind of agency in explaining physical phenomena, were also regarded as functional.

MT [My Theory]: I think gravity is a force that holds everything down to a surface. Without gravity, we wouldn't be able to sit down on a surface because you would be floating around. I also think that without gravity, we wouldn't be able to live because the air is held down by gravity. (S18)

Physical explanations, in contrast, explain physical relations and processes as such without reference to human agency. Empirical-physical explanations refer to observable empirical phenomena and phenomenal properties of reality.

MT: (gravity) My theory is related to the Earth's core because I think it is like a magnet and it pulls you down to the ground. That is why gravity is not as strong on the moon because the core is not as strong as the Earth's core. (S1)
Theoretical-physical explanations refer to unobservable theoretical entities constructed for purposes of explanation. Occurrence of theoretical concepts, such as atom or particle, was regarded as an indication of theoretical-physical explanations.

MT: I think it has to do with the size and spin of force particles, and the fact that all matter emits gravity. But I think one force can block another force. If all matter particles emit force particles then antiparticles must emit antigravity force particles (antigravity). So I think that antigravity could block gravity. But, if an antiparticle meets a particle they will destroy each other. So it would be impossible to have an antigravity chamber made out of antiparticle matter in a nonantiparticle universe. (S22)

The agreement coefficients for the variables analysed are presented in table 1. The reliability of determining the explanatory concepts used by the students was not, however, assessed. Disagreements were discussed after the reliability analysis, and those ideas that were classified differently by the two coders were discussed and coded according to mutual agreement.

In addition, each student’s process of inquiry was assessed as a whole by using the degree of deepening explanation scale. The purpose of the scale was to assess whether a student progressed in the search of new explanatory scientific knowledge in the course of his or her inquiry. The scoring for the scale was based on the following guidelines:

1) **No advancement.** A rating of 1 was assigned to a student’s process of inquiry if he or she did not succeed in finding new explanatory scientific information and, therefore, did not advance in his or her inquiry.

2) **Small advancement.** A rating of 2 was assigned if a student found some pieces of new explanatory scientific information. This information, however, left a major part of the students’ research questions unanswered and did not have a very high explanatory value. There was only a small likelihood that the new information would have considerably facilitated the student’s conceptual understanding.

3) **Moderate advancement.** A rating of 3 was assigned if a student found several significant pieces of explanatory scientific information and clearly made progress in his or her inquiry. These pieces of new information provided answers to some of his or her main research questions, and were likely to facilitate his or her conceptual understanding. However, the explanatory value of new pieces of information found by the student was only moderate; i.e., the concepts introduced were not central from the viewpoint of problems studied or already introduced by other students in the class.

4) **Strong advancement.** A rating of 4 was assigned if a student found substantial pieces of new explanatory scientific information, particularly introducing new theoretical concepts or explanatory theories that provided answers to his or her most important research questions. These pieces of information were not only highly
likely to facilitate the student’s conceptual understanding but also had a potential for significantly contributing to advancement of the whole group.

Degree of deepening explanation refers to in-depth advancement in a student’s search for explanatory scientific information. Deepening explanation entails that knowledge produced by a student becomes increasingly sophisticated and articulated in the course or inquiry through adoption of explanatory scientific concepts and theories. Strong deepening of explanation entails that a student succeeds in answering his or her research questions by finding significant pieces of explanatory scientific information. The degree of deepening of explanation appeared to be associated with, but partially independent of a students’ reliance on functional and empirical explanations. While depth of explanation represented the degree to which a student explicated his or her own intuitive framework, deepening of explanation was associated with in-depth search for new explanatory scientific information. Many CSILE students started their inquiry from physical or even theoretical scientific explanations so that, in their cases, the nature of explanation did not change. However, these students advanced considerably through seeking and introducing new explanatory concepts and theories, and deepened their explanations. The reliability of the scale was assessed by asking two independent coders to evaluate the students’ conceptual advancement in two projects. The correlation between the scores for the two coders was .85 for the deepening of explanation scale.

Construction of Inquiry-Structure Graphs

The analysis of frequencies of CSILE students’ questions and explanations did not provide detailed information on the process of their inquiry. In order to analyze the students’ strategies of inquiry, the present author constructed graphic descriptions -- inquiry-structure graphs -- for their inquiry in the Electricity and Force projects. Their inquiry consisted of research problems, theories, new information, and comments that were regarded as elements of inquiry. Identification of the elements of inquiry was based on the qualitative analysis of content, as explained above. An episode of inquiry consists of a process of articulating a research question, searching for new information, and construction of an explanation. Articulation of a new research question involves beginning another episode of inquiry. Each step in a process was assumed to move a student from one epistemic state to another. Epistemic change is a process of moving from one epistemic state to another. In the present study, epistemic change does not entail any particular change in an agent’s mental state (that cannot be inferred on the basis of a written document), but rather a change in an agent’s externalized knowledge that is in the form of written notes. Interrogative moves such as asking a question, obtaining of new information or explicating one’s presuppositions by generating a theory change a student’s manifest epistemic state.

During their study projects, the classroom A students were working in small groups, jointly to solve a set of research questions, except in the Electricity project which they carried out by working individually to solve eight research questions common to the whole class. Although the students were working in close collaboration, an individual student’s contribution was identifiable. Although each student was responsible for investigating at least one particular problem, all members of the study group were required to support him or her by generating theories to
explain the student's problem and articulate new research questions as well as introduce new information and participate in commenting. In order to handle the complexity of the material and assess individual students’ strategies of inquiry, inquiry-structure graphs were constructed by the present author, for each student separately from the functioning of other members of his or her study group. The reliability for identified characteristics of the inquiry-structure graphs was examined by asking two independent coders to classify the graphs, representing the Electricity project, according to their structural characteristics. The agreement coefficient was .84.

The main elements of inquiry abstracted in the study were research problems (Pn), theories (T), information (I), and comments (C). These elements contained further subdivisions such as subordinate questions (Ps), functional (Tfu), empirical-physical (Tep) and theoretical-physical (Ttp) intuitive theories, empirical-physical (Iep) and theoretical-physical (Itp) scientific information. In addition, the coders analyzed comments requesting information (Cre) or comments providing information (Cep, Ctp).

Results

The Nature of Intuitive Explanation

Examination of CSILE’s database indicated that the students produced 1007 intuitive or scientific explanations and 141 pieces of factual information in physics. About 56% (f=565) of the explanations represented the students’ intuitive theories, and 44% (f=441) involved scientific theories found by them. The students produced 226 (M=10, SD=7) intuitive explanations and scientific theories in the Force project and 213 (M=9, SD=6) in Cosmology; they produced 567 explanations in the Electricity project (M=22, SD=10). A frequency distribution of CSILE students’ explanations across physical study projects is presented in table 2.

CSILE students produced a large number of intuitive working theories in their study projects. Table 2 indicates that the students’ intuitive theories were frequently functional or empirical in nature. However, some of the working theories generated by CSILE students, those referring to unobservable theoretical entities, were regarded as theoretical-physical. These were frequently scientific explanations adopted by CSILE students as their own theories, and the students made use of such explanations in their subsequent processes of inquiry. Further, some scientific explanations concerning how physical artefacts (e.g., spacecraft) can be used, or referred to observable physical phenomena, and were regarded as functional or empirical-physical in nature.

Two cases of CSILE students’ group work in the Force and Cosmology projects are presented at http://www.helsinki.fi/science/networkedlearning/material/csclmaterial.htm. An examination of these cases indicates that a significant number of students explained physical phenomenon by referring to human intentions, purposes and goals. Many students explained gravity by contrasting it with a situation in which gravity would not ‘function properly’. Some of the questions generated by
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the students appeared to encourage functional explanations such as the question, ‘why do you need gravity and where does it live?’ (S2). Functional explanations in the Cosmology projects particularly concerned the questions ‘What will the universe be like in the future?’ and ‘How has the universe changed and how will it change?’ In the functional explanations, the Earth as well as human needs and future were given a central position.

Further, the students tried frequently to explain physical phenomena by using their intuitive knowledge concerning how things work in nature. Examination of the students’ intuitive conceptions revealed that they tended to use empirical categories representing the perceptual world to explain something outside direct perception. The students used frequently empirical concepts such as magnetism (f=27), ground (f=26), core of earth (f=14) to explain gravity. As in the Force project, CSILE students’ intuitive explanations concerning cosmology were based on certain basic empirical categories. They used a wide variety of empirical concepts such as ‘rock’ or ‘land’ (f=6), gas (f=6), ‘atmosphere’ (f=2), ‘water’ (f=2), or ‘explosion’ (f=3) for explanatory purposes:

My theory on how the universe begin is this. A VERY long time ago, there were extremely big rocks floating around in space. Then, after a very long time, the rocks started to bang into each other, until there was one big rock, still floating around in space. This happened a few times in different places until there were very many, but not all of them were as big as others. Some were little ones, called moons, circling the big ones. (S13, explanatory concept used highlighted by the present author)

Further, explanations of how electricity works also were often empirical-physical in nature. Concepts like ‘metal’ (f=13), ‘iron’ (f=3), ‘material’ (f=6) ‘gas’ (f=5), ‘ingredient’ (f=2) or ‘magnet’, ‘grain’, ‘power’ or ‘substance’ (f=9) were used to explain electricity:

I think that in some materials there might be a certain grain, like the grain in wood, that stops electricity or does not let it go by in it, but this ‘grain’ is only in a few materials so the other materials would conduct electricity. I also think that if materials don’t conduct electricity very well then they have a little a bit of this grain in them but not enough to stop electricity totally. (S7, explanatory concept used highlighted by the present author).

CSILE Students’ Conceptual Advancement

The study projects differed from each other considerably in terms of intuitive explanations. The students were more likely to use functional and empirical explanations in the context of Force and Cosmology than Electricity project. Most of the students went beyond their initial functional explanations and moved towards physical explanations in the course of their inquiry, regardless of the projects. Many students, however, remained at the level of empirical-physical explanations without success in finding understandable theoretical-physical explanations.

The analysis indicated, further, that there were gender-related differences concerning externalisation of their intuitive explanations. An independent sample t-
test was performed to analyse whether the mean proportion of functional explanation differed according to gender of the students. The analysis indicated that the proportion of functional explanations was lower in the case of male students ($M = .13$, $SD = .04$) than female students ($M = .25$, $SD = .10$) ($t=-3.3$, $df=26$, $p<.003$). This phenomenon appeared to be due to the fact that some male students were already more familiar with physical scientific theories as well as somewhat reluctant to externalise their intuitive conceptions. In some cases they started by reporting authoritative knowledge rather than their own ideas; they resumed efforts to clarify the meaning of the scientific conceptions in question only later on in the course of their inquiry. The female students produced more functional theories, but achieved the same level of explanation as the male students.

During their process of inquiry many CSILE students found explanatory scientific information in the Force, Cosmology, and Electricity projects as indicated by degree of deepening explanation (table 3). These distributions provide a conservative estimate of deepening of CSILE students’ explanations because they were based on evaluation of individual students’ explanations. The students were, however, working in small groups, and a group as a whole often succeeded in solving its principal research questions even if an individual member did not. Further, if a student introduced advanced explanation to the group, the other members of the group usually did not repeat the same information in their own notes. As a consequence, only the student who first introduced an explanation appeared to have advanced although the others could have adopted and understood the same information.

[Insert table 3 about here]

The students found several important explanatory concepts in the domains of physics being investigated. For instance, a student, S27, answered the question ‘Why does the Earth have gravity?’ by arguing that ‘the reason the Earth has gravity is the same reason everything has gravity’ (S27), and introduced the particle theory of gravity to the group, together with S22. In the Cosmology project, the students were also able to find relevant theoretical-physical explanations. Studying scientific theories concerning the future of the universe led to articulation of more physical and theoretical conceptions. Theoretical concepts such as electron or field are critical for explaining and understanding electricity. Remarkably, the concept of electron was used for explanatory purposes in 28.7% ($f=163$) out of 567 explanations produced in Electricity project; 26 out of 28 students used the concept of electron for explanatory purposes in some of the notes, and practically all students achieved some sort of theoretical understanding of electricity.

Availability of understandable theoretical knowledge, however, appeared to constrain the students’ advancement. In the Force project only 4 out of 28 students succeeded in finding adequate theoretical-physical explanations of gravity. Genuine explanations of many physical phenomena are so complex that they cannot be understood without the background of a large body of scientific knowledge, a problem acknowledged by some of the students:

I need to understand how Gravity works. I know that Gravity pulls you down and keeps you on the ground but I still don't understand how Gravity works! (S4)
A CSILE student expressed the problem of understanding theoretical-physical explanations in the following way:

I would need to understand what the weak nuclear force is, but even if I find good information I wouldn't be able to understand it in my own words. (S19)

Sources of Conceptual Advancement

In order to appreciate CSILE students’ pursuit of genuine inquiry, it is essential to examine the sources of their conceptual advancement. The participants guided their inquiry by generating a series of research questions. About 35% (f=258) out of the questions were given by the teacher to pre-structure students’ inquiry, while the others (65%, f=478) were generated by the students themselves. In accordance with the nature of students written productions that involved various types of explanations, about 94% (f=687) of the questions guided students to pursue explanatory rather than factual information. It was noticed that within each topic, the students answered their principal questions (e.g., what is gravity?) by generating a series of subordinate questions. Generation of a large number of more specific, research problems appeared to carry the process of inquiry to a deeper level (for a detailed description of this phenomenon, see Hakkarainen and Sintonen, 2002).

Further, comparisons between intuitive and scientific theories appeared to be an important source of the conceptual advancement for students. Although the students did not ground their explanations on experimentation or experimental facts, they were able to change their conceptions when they confronted new scientific information that contradicted their intuitive conceptions. In many cases, the students noticed that their explanations did not fit a generally accepted scientific view, and had only a limited range and power of explanation. Some students were even able to recognize inadequate presuppositions of their questions:

I found that my theory was wrong, and in a way so was my problem. I began my problem assuming that the planets evolved from pieces of rocks but as you see it is much different, I also said my problem was ruffly [roughly] universe evolution when what I’ve actually been doing is the solar system. (S3)

I know that my beginning theory was wrong because only the first few things on my list of things that can conduct electricity have metal in them, the rest don’t. (S5)

Finally, CSILE students’ peer interaction appeared to contribute significantly on their conceptual advancement. The students produced 353 written comments in the context of their three study projects in physics. About 56% (f=198) of these comments concerned explanations, 29% (f=102) information, 7% (f=25) methods, and 4.5% (16) research questions. In their comments, the students provided explanations (see the gravity example above), requested explication of explanatory relations and pointed out inadequate presuppositions of one’s theory. They appeared, further, to be able, spontaneously, to use metaconceptual criteria for evaluation explanations (Samarapungavan 1992). For a question ‘How has the universe changed and how will it change?’ students S5 generated a functional explanation concerning how we humans will have advanced medicines and a lot of knowledge. These kinds
of functionally oriented theories were challenged and the process of inquiry redirected by comments requesting people to talk less about the future of humans and more about the universe, which was the actual topic. Moreover, pointing to an unanswered question was an important way of requesting deepening inquiry, which was frequently used by the students:

I think that your note is a good note except for 1 thing, S27, in your first INTU [I Need To Understand], you said that you wanted to find out how gravity works, where gravity comes from and what causes gravity. So I was wondering, did you find out what causes gravity, I saw that you have the other two things that you mentioned in your note. (S7)

Analyses reported elsewhere revealed that CSILE students’ written comments in general and requests of explication of explanation embedded in these comments, were associated with their conceptual advancement (Hakkarainen, 1998). It was observed, particularly in Electricity project that students pursued their inquiry more deeply when they received a comment requesting explication of explanation from their fellow students.

Strategies of CSILE Students’ Inquiry

Examination of the inquiry-structure graphs revealed that CSILE students’ basic strategies of inquiry seemed to be closely associated with their practices of question transformation; generation of a large number of more specific, research problems appeared to carry the process of inquiry to a deeper level (see Hakkarainen & Sintonen, 2002). The analysis indicated that the students followed three basic strategies of inquiry:

a) **Truncated inquiry** entails that the process ended when a first plausible theory was generated or a relevant piece of information found. It means that there was usually not more than one episode of inquiry in the context of a given, principal research question, without generating subordinate questions or carrying out in-depth searches for new scientific information. Sometimes a student just stated a principal question without pursuing it at all (see figure 1);

b) Typical of **extensive inquiry** was the production of several, principal research questions without carrying out in-depth searches in the context of a particular problem. Accordingly, student moved to conceptually unrelated problems after some episodes of inquiry without articulating more than a few subordinate questions or without in-depth search for new information. It was, however, typical for the strategy of extensive inquiry to produce relatively more CSILE notes than it was for truncated inquiry;

b) **Intensive inquiry**, by contrast, characterized a process in which a student went more deeply into the problem by articulating a series of new specific research questions and carrying out several in-depth searches in the context of each principal research question (figure 1). These subordinate questions were closely related conceptually to
the principal question, leading to a deeper level of inquiry. Frequently, however, engagement in intensive inquiry meant that the student also worked with several principal questions so that inquiry was often carried out both in depth and in breadth.

[Insert figure 1 about here]

These strategies of inquiry were abstracted from the inquiry-structure graphs, and there were some processes that represented intermediate states. Strategies of CSILE students’ inquiry seemed to be closely associated with their cognitive achievement. Figure 2 presents the 95% confidence intervals for strategy of inquiry and the degree of deepening of explanation in the Electricity project. The figure indicates that students engaged in intensive inquiry achieved a significantly higher degree of deepening of explanation than students participating in truncated inquiry. This expected relationship provides evidence that the patterns of the students’ inquiry were not accidental, but represented an important aspect of their inquiry.

[Insert figure 2 about here]

Discussion

The purpose of the study was to analyse elementary school children’s process of collaborative knowledge building within a computer-supported classroom. I conducted epistemological and qualitative analysis of students’ productions. The material gave detailed information about the students’ process of inquiry, but did not provide direct information about actual psychological processes involved. The analysis indicated that the students genuinely engaged in inquiry demonstrating an impressive degree of epistemic agency (Scardamalia, 2002). They systematically generated their own intuitive theories and searched for explanatory scientific information to answer their research questions. Thus, the results furnished evidence, within specific topic areas, that children in appropriate conditions are indeed able to go beyond the surface-level phenomena through generating explanations.

Analysis of CSILE students’ intuitive explanations of physical phenomena indicated that these were frequently functional in nature, referring to human purposes, goals or intentions as the basis of explanation. Moreover, the students often constructed empirical-physical explanations to explain physical phenomena, i.e., their intuitive explanations were based on generalizations of the properties of our perceptual world to explain something outside direct perception (DiSessa, 1983; 1988). In the course of the study projects, however, some of the participating students went beyond their intuitive conceptions and adopted very advanced scientific explanations, provided that an understandable scientific explanation was available. Although a number of students were able to overcome the functional and empirical approaches in their intuitive conceptions, only a few students were able to arrive at well-articulated theoretical-physical explanations of the problems being investigated. Although strong conceptual advancement was achieved only by 4 students in Force and 8 students in Cosmology project, 15 students succeeded in doing it in the context of the Electricity project. The gravity and cosmology topics appeared to have been too demanding for the students to achieve in-depth conceptual understanding -- regardless of their apparent engagement and interest.
In spite of the functional or empirical nature of CSILE students’ intuitive explanations, their conceptions did not appear to be trivial. Many of the students’ intuitive conceptions represented a genuine attempt to find a general principle, or common element, which would explain a wide variety of empirical phenomena. Even if their conceptions were empirically bounded, in most cases they focused on some general aspect of the objects of the world. In the context of cosmology, conceptions surprisingly resembled the four elements (e.g., earth, air, fire, water), which formed the basis of ancient cosmologies or natural philosophies. Reliance on these basic empirical categories seemed to represent a sort of content recapitulation (Thagard 1992) in relation to the history of science (see Wiser & Carey, 1983 for a corresponding observation in the domain of thermodynamics). Naturally, CSILE students’ intuitive explanations lacked generality, and the range of their explanations was quite limited.

The results of the present study indicate that science educators may achieve good results from guiding their students to work systematically to develop their own theories and ideas (Bereiter, 2002). There were, however, many contextual factors that affected the results of the present study, including the teacher’s exceptional efforts, his close involvement in CSILE project over many years, as well as researchers’ strong support for pedagogical design of the projects in question. Consequently, the present investigation cannot simply be said to reveal advantages of the present pedagogical approach as such – its productivity depends on many contextual factors that are neither very well known or under control. It simply provided evidence that, in advantageous conditions, it is entirely possible for young children, collaborating within a computer-supported classroom, to engage in explanation-driven processes of inquiry.

Facilitation of genuine inquiry is a central challenge of science education. It appears that students’ inquiry, especially when dealing with complex, physics topics, may benefit from systematic instruction and organizing, for instance, through benchmark lessons (DiSessa & Minstrell, 2000). These kinds of lessons, grounded on classroom experimentation, are likely to facilitate students’ conceptual understanding without decreasing their ownership of the knowledge-building process. An explanation-oriented culture of inquiry, as stated above, does not emerge spontaneously, but has to be intentionally cultivated (Brown & Campione, 1994; Cohen & Ball, 2001; Cole, 1995; Lambert, 1995), a process in which innovative learning environments and corresponding social practices evolve together (Lipponen, 2002).
References


Pursuit of Explanation

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### Study project

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TABLE CAPTIONS

Table 1.
Agreement Coefficients in Classifying CSILE Students’ Communicative and Knowledge Ideas

Table 2.
Frequency Distribution of Intuitive and Scientific Explanations in CSILE Students’ Study Projects

Table 3.
Number of Students Representing Different Degrees of Conceptual Advancement in Physics Study Projects
Pursuit of Explanation

Truncated Inquiry

Extensive Inquiry

Intensive Inquiry
Pursuit of Explanation

Degree of Deepening Explanation

Strategy of inquiry

N = 5

Truncated Inquiry

Extensive Inquiry

Intensive Inquiry

N = 10

N = 13
Figure captions

Figure 1.
Abstract descriptions of CSILE students’ strategies of inquiry

Figure 2.
Strategy of inquiry and 95% confidence intervals for mean scores of deepening of explanation in the Electricity project.