Epistemic Agency and Patterns of Interaction in Computer-supported Inquiry

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Abstract

The problem addressed in the study was whether elementary school students, collaborating within a computer-supported classroom, would be able to productively participate in progressive discourse interaction focused on advancing their explanations. Technological infrastructure of the study was provided by the Computer-Supported Collaborative Learning Environments (CSILE). Methods of qualitative content analysis and social network analysis (SNA) were used to analyze written comments logged by 28 grade 5/6 students to CSILE’s database. The analysis indicated that the participants were engaged in an intensive progressive discourse, frequently sharing their explanatory theories and requesting each other to explicate their explanations. The progressive inquiry culture was rather uniform across the whole classroom in terms of all students producing the same type of comments. By relying on relational measures based in SNA, four levels of epistemic agency were identified from level 1 (pursuing mainly one’s own inquiry, 17 students), level 2 (communicating with one’s immediate peers, 4 students), level 3 (cognitively central participation in distributed regulation of inquiry, 4 students), to level 4 (taking of collective cognitive responsibility in terms of knowledge sharing, 3 students). The two highest levels of epistemic agency involved active efforts of socio-cognitive brokering. Expert evaluations by three philosophers of science confirmed the cognitive value of CSILE students’ peer interaction.

Keywords: computer-supported collaborative learning, progressive inquiry, social network analysis, distributed regulation of inquiry.

Introduction

In the present investigation, we analyze patterns of interaction between elementary-school students, collaborating within a computer-supported classroom. The purpose of the study is to examine whether elementary-school students are able to engage in progressive inquiry, involving a collaborative effort to advance their explanations. By ‘progressive inquiry’ the present investigators refer to the sustained processes of advancing and building of knowledge by pursuing the participants’ own research questions and explanations (Hakkarainen, 1998; Hakkarainen & Sintonen, 2002). Several, concurrent, cognitive research projects share a common goal of fostering such research-like processes of inquiry in education (Bereiter, 2002; Carey & Smith, 1995; Cognition and Technology Group at Vanderbilt University, 1997; Edelson, Gordin & Pea, 1999; Muukkonen, Lakkala, & Hakkarainen, 2005; Scardamalia & Bereiter, 1999; 2006). Inquiry involves generating one’s own tentative working theories for the phenomena being investigated (e.g., Carey & Smith, 1995; Scardamalia & Bereiter, 2006). Students’ own explanations or hy-
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Hypotheses are often ignored in science education, and students, often, without much reflection, adopt explanatory concepts and theories only as new facts or mechanical procedures. A critical aim of progressive inquiry is to practice using theories or models to advance, elaborate, and test ideas with which an agent is working (Bereiter, 2002; Carey & Smith, 1995). This may be facilitated by guiding the participants to externalize (write) and elaborate their intuitive conceptions and taking those as the objects of collaborative discussion (Bereiter, 2002). Sustained participation in progressive inquiry is likely to help students to see themselves as creators and contributors of knowledge, as prospective researchers (Scardamalia and Bereiter 1999; Xiadong et al., 1995).

From an epistemological perspective, inquiry appears to be an inter-subjective and dialogical process in nature (Paavola, Lipponen & Hakkarainen, 2004). Dialogue takes place in two directions. Firstly, the inquirer may engage in dialogue with the Nature by interrogating or asking questions through explorations and experimentation (Hintikka, 1999). Secondly, inquiry always takes place in dialogue with fellow inquirers (Sintonen, 1996; Hakkarainen & Sintonen, 2002). Questions and theories being explored have their societal histories and emerge in collective activity that involves interaction among inquirers. The progressive-inquiry approach aims at facilitating the same types of social processes that characterize progressive research teams and laboratories (Scardamalia & Bereiter, 1999). Databases of networked learning environments, such as Computer-supported Intentional Learning Environment CSILE/Knowledge Forum® (Scardamalia & Bereiter, 1999; 2006; Scardamalia, 2002), function as local space of cultural knowledge (Popper’s (1972) World 3) that allow the participants to pose their questions, advance their shared ideas, and engage in mutual interaction (Scardamalia & Bereiter, 2006). Advancement of inquiry is elicited by relying on socially distributed cognitive resources, emerging through interaction between the learners, and collaborative efforts to advance shared understanding (Pea, 1994). Through social interaction, contradictions, inconsistencies, and limitations of a student's explanations become available because it forces him or her to perceive conceptualizations from different points of view. Further, deep conceptual understanding is also fostered through explaining a problem to other inquirers (Hatano & Inagaki, 1992). Through this kind of process, inadequacies of one's understanding tend to become more salient.

The first author of the present study previously completed a series of studies in which he qualitatively analyzed the epistemological nature of 10-11 year-old CSILE students’ research questions and explanations, in order to examine whether these students engaged in the question-and-explanation-driven inquiry that characterizes scientific research. Table 1 presents a summary of these investigations, which are based on qualitative analyses of thousands of pages of CSILE students’ productions. Hakkarainen’s (2003a) study of CSILE students’ culture of inquiry in two Canadian CSILE classes (A and B) across three years indicated that a mature progressive-inquiry culture emerged in classroom A as an end result of several years’ development (see Hewitt, 2002; Hewitt & Scardamalia, 1998); initially, only a minority of the students produced knowledge that was at a high explanatory level, but gradually this practice became generalized and started to dominate the class (A). In another CSILE class (B) a corresponding progressive inquiry culture never emerged, even though the classroom was apparently moving to that direction. Further, Hakkarainen and his colleagues, in some subsequent studies, were unable to replicate the progressive-inquiry culture in Finnish elementary schools despite considerable efforts involving several teachers and schools (Hakkarainen, Lipponen, & Järvelä, 2002; Hakkarainen, Järvelä, Lipponen, & Lehtinen, 1998). CSILE-mediated discourse interaction in the same class-
room A -- in which the progressive-inquiry culture appeared to prevail -- is the focus of further analyses which constitute the present study. From now on we will refer to this classroom as “the CSILE class”.

Previous studies presented detailed qualitative analyses of the epistemology of CSILE students’ inquiry culture in classroom A. These studies indicated that knowledge produced by the CSILE class in question was at a very high explanatory level both in biology (Hakkarainen, 2003b) and physics (Hakkarainen, 2004). In accordance with knowledge produced by the participants, practically all research questions posed by them were explanation seeking in nature. Moreover, the students pursued their research questions in depth, following the pattern of interrogative activity (Hakkarainen & Sintonen, 2002). Accordingly, the students undertook their inquiry with initially very general and unspecific “big” questions and tentative working theories, and tried to solve the initial questions by searching for answers to a series of subordinate questions (Hintikka, 1999). This process was facilitated in the CSILE environment by provision of a special scaffold, the I-Need-to-Understand [INTU] question, for generation of subordinate questions. The analyses indicated, further, that the students made considerable conceptual progress (Hakkarainen, 2003a; 2004). Because the students’ progress was assessed by examining their written productions, the evidence of conceptual progress was not, however, conclusive, and there were some indications that the physical study projects (gravity, cosmology) were too complex for students to understand in depth.

The limitation of CSILE studies summarized in Table 1 was that the epistemology of inquiry was addressed by mainly examining the relative proportion of explanatory knowledge produced by individual students. While this approach allowed us to examine the general nature of knowledge produced by the participants, it did not provide detailed information about each student’s patterns of participating in collaborative process of inquiry or specific roles or types of agencies assumed by the participants. Agency is an inherently relational phenomenon that cannot be adequately understood by examining only individual attributes (Holland, Lachicotte, Skinner, & Cain, 1998; Lemke, 2001; Wertsch, Tulviste, & Hagstrom, 1993). Consequently, it does not simply arise from the psychological make-up of the participants, but emerges through participation in socio-cultural activities and is dependent of the nature of these activities (Wertsch et al., 1993).

We believe that progressive inquiry calls for specific type of agency of deliberately pursuing collective epistemic goals. This type of agency may be called epistemic agency (Scardamalia, 2002). Epistemic agency indicates that the students, working together, relate their personal ideas with those of others, monitor collective activities, solve emerging problems, and jointly assume responsibility of advancement of their collective knowledge (Scardamalia, 2002). Characteristic of epistemic agency is that the students take, perhaps for the first time in their studies, cognitive responsibility for advancement of their shared inquiry. A critical condition for success appears to be that the voices (Bakhtin, 1980; Wertsch, 1985) of participants of an inquiry community become socially recognized and respected. The concept of epistemic agency implies that participants of progressive inquiry are not only working for knowledge advancement, but “authoring” their selves as well (cf., Holland et al., 1998, p. 169).

In ordinary school classes, teachers and researchers struggle with a constant tendency of some students to avoid assuming of intellectual responsibility for their studies and be excessively
socially dependent on authority and acceptance of their teachers (Hakkarainen, Lipponen, Järvelä, & Niemivirta, 1999; Tapola, Hakkarainen, Syri, Lipponen, Palonen, & Niemivirta, 2001). Students learn very early in education that asking and answering questions is the teacher’s rather than students’ task, and that their own thinking and knowledge just do not count; there are hidden criteria for assessing validity of knowledge, invisible to students. The emergence of epistemic agency appears to be dependent on social transformations that help to put students’ own ideas and inquiries into the center rather than periphery of activities (Scardamalia, 1999). Characteristic of an emerging culture of progressive inquiry is creation of shared socio-cognitive norms and epistemic values – such as pursuit of collective rather than merely individual knowledge advancement, constructive rather than destructive criticism, and an epistemic commitment to sustained advancement of shared ideas (Scardamalia & Bereiter, 1999). The problem to be pursued in the present article is whether progressive inquiry supported by the CSILE environment elicited epistemic agency, and evidence of participants’ genuine commitments to collaboratively pursue their inquiries.

Individual agents function always within social networks of activities, which guide and constrain their epistemic activities. The history of cognitive socialization as well as diverse goals and activities produces discontinuities and boundaries within social communities (Wenger, 1998). If follows that school classes involve several informal communities (e.g., ‘jocks’ and ‘burnouts’) that constrain the students’ activities and partially follow gender-lines and academic orientation (Wenger, 1998; Eckert, 1998). As a consequence of internal boundaries, there emerge so-called structural holes (Burt, 1999) within communities. These are disconnections between actors that prevent the flow of relevant knowledge and competence. Actors functioning on different sides of the structural holes are often not aware of valuable epistemic resources that could be accessed through interaction and collaboration. Actors who mediate knowledge flow across structural holes or other boundaries may be called socio-cognitive ‘brokers’ or information ‘gatekeepers’ (see Burt, 1999; Moreland, 1999; Palonen, Hakkarainen, Talvitie, & Lehtinen, 2004). Crossing boundaries between communities or bridging structural holes is likely to be both intellectually and emotionally very demanding (Engeström, Engeström, & Kärkkäinen, 1995). It requires that the actors have metaknowledge concerning how relevant information can be found or a problem solved that is valuable across the overall network. The present investigators propose that the emergence of students who function in the role of socio-cognitive brokers can be regarded as evidence of strong forms of epistemic agency. It means clearly taking one step further from weaker forms of epistemic agency: pursuing one’s own epistemic goals or working with epistemic aims of one’s immediate social community, and committing oneself to advancement of the whole inquiry community. Evidence of emergence of such strong epistemic agency at the elementary-level of education would already be a significant achievement.

On the basis of the above considerations, it turned out to be necessary to partially re-do some of the investigations summarized in Table 1 because the qualitative methods employed mainly provided information about frequencies of certain types of events and attributes of individual actors, but did not allow the investigator to capture relational phenomena involved in epistemic agency. In order to overcome this limitation, we combined content analysis with social network analysis (SNA), which provides sophisticated statistical tools for examining relations between actors (Wasserman & Faust, 1994; Scott, 1991). SNA is a method for studying social relations among a group of actors, i.e., patterned sets of connections that link the actors to one another. These phenomena are often invisible when one uses standard statistical methods. Social
relations can be thought of as dyadic attributes, whereas mainstream psychological sciences are concerned with monadic attributes and corresponding statistical measures. The relations may, for instance, be kinship, social roles, affective or cognitive properties, actions, flows, distance or co-occurrence. The method is especially designed to facilitate the analysis of structural data (Scott, 1991; Wasserman & Faust, 1994). Knowledge communities appear to be formed through the accumulation of relations and influences among participants (Frank 1998). SNA modeling allows researchers to represent pairwise relational structures of social actors, where the relationships are defined by social interactions, e.g., commenting, collaborating, seeking for advice, mediating knowledge, and providing socio-emotional support. Access to knowledge and other resources is determined by the structural context of relationships, that is, to whom one is connected via direct or indirect links. Although the analysis of relational structures has its focus on the pattern of relationships between the actors involved, the relations are often strongly linked with the monadic attributes of the actors, such as age, gender, and academic achievements. The complexity of the situation is increased by the fact that it is often unclear, at the outset, which attributes influence the patterns of relationships. The present study focuses on examining the nature of CSILE students’ social network, especially to identify various degrees of epistemic agency assumed by the participants. The study is descriptive in nature; it focuses more on understanding various aspects of CSILE students’ inquiry than rigorously testing hypotheses about them.

Method

Participants and the Setting of the Study

The technical infrastructure for the study was provided by the Computer-supported Intentional Learning Environments, CSILE/Knowledge Forum® (Scardamalia & Bereiter, 1994; 1996; 1999; Scardamalia, in press). The study was 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 to the participants for producing, searching, classifying, commenting on, and linking knowledge together (Bereiter, 2002; Scardamalia & Bereiter, 2006). Several important aspects of progressive inquiry are implemented in the structure of the Computer-supported Intentional Learning Environment, CSILE, and corresponding cognitive practices. Participation in all aspects of the process of progressive inquiry is facilitated by use of CSILE’s thinking-type system of posting thoughts and ideas. The students are guided to categorize their computer entries in a way that corresponds to moves in the progressive-inquiry process, such as Problem, My Theory, New Information, I Need to Understand (subordinate question), Plan, and Comment.

The study material represented productions of 28 grade 5/6 students over an academic year at an inner-city public school in Toronto, Canada. A larger than normal proportion of children studying at the school came from middle-class and upper middle-class homes, but there were also a number of students from educationally disadvantaged homes. Patterns of CSILE students networking were analyzed in relation to their levels of school achievement and gender. Due to the nonexperimental context of the CSILE experiment, the students had been previously selected for the class as a part of normal school administration. Although assigning the students to the class was reported by the school to be random, the gender distribution of the students in the classroom was outside of what might be expected with sampling randomized by gender: Two-thirds of the students (n=19) were females and one-third (9) males. The students' school
achievement levels were assessed using the Canadian Test of Basic Skills (the CTBS); it allowed one to determine whether a student’s school achievement was below (1), average (2) or above average (3) of the corresponding age group. In what follows, the participants will be referred by giving student’s number (1-28), gender (m/f) and school achievement level -- below (1), average (2), and above average (3).

The teacher of the classroom investigated was a male in his late 50s and very experienced. He has Ph.D. in social anthropology, but not any academic degrees in science. He had been involved in CSILE project for several years and has a long experience of collaborating with researchers. Over those years he had perfected a special method of cultivating knowledge-building culture within his class in respect of guiding students to pursue their inquiries, follow their questions in depth, generate intuitive working theories as well as engage in constructive peer interaction. A significant aspect of his method was constituted by individual “rise above” (Scardamalia, 2002) sessions in which he personally guided the students’ contributions to CSILE’s database. His students produced hundreds of pages of text each year; he did not have time to read all of it, and preferred to do his coaching face to face. Whenever a student desired to “publish” her CSILE note in the database, the teacher looked over the note with the student and discussed it. Beyond being edited, revised, and grammatically correct, a note was required to offer a significant contribution to collaborative knowledge-building in CSILE’s database, to provide evidence of the student’s own thinking and cognitive effort. Improvements to the note were stimulated through indirect questioning, rather than direct pointing-out of weaknesses. Generous allowances for different levels of ability of the students were naturally made concerning required depth of inquiry. An important consideration was to guide students to build on other knowledge-building contributions prevailing in the database by exploring and commenting on other students’ notes. A student coming to show a working theory was asked whether there were other theories in the database concerning the same topic and how the theory in question related to them, whether those theories cohered or not. In many cases, the student did not know, and was asked to investigate the issue further, elaborate the theory accordingly, and constructively comment on the other theories.

On average, students worked with CSILE 40 minutes a day. The personal rise-above sessions took twice as much time as the actual working sessions with CSILE, according to the teacher’s estimate. The teacher got an opportunity to work with a much smaller group daily because the classroom was divided into two groups of equal size for studying French every day. He guided a half class personally at CSILE work while the other half studied French, and then the groups switched their activities. The teacher had, over years, succeeded in creating a classroom culture in which every activity supported progressive inquiry and channelled the students’ epistemetic resources accordingly (Hakkarainen, in press). The students were not, for instance, allowed to go to library to do research without defining the research question they were working on. Although the inquiry culture took several years to cultivate, new students adopted it early on. Since he had worked with a split class of grade 5 and 6 students, half the students had studied two years in his classroom. This allowed him to relatively quickly socialize new students to the sophisticated inquiry culture.

Qualitative Content Analysis

The study material represented data that arose naturally while the students worked with CSILE and carried out their study projects. The study involved qualitatively analyzing the partic-
ipants’ CSILE-mediated written comments in the context of three physics (Force, Cosmology, and Electricity) and one biology science project (Human Biology). The focus of the present analysis was to analyze CSILE-mediated discourse interaction; unlike the students’ questions and explanations, CSILE students comments are inherently relational in nature in respect of creating a link from the student commenting to the students commented on, and, thereby, suitable material for social network analysis. Although research questions and explanations, to a great extent, reflected the epistemological nature of the learning tasks being pursued and were strongly influenced by the teacher, comments appeared to be more open in nature and indicated how the students themselves saw their inquiry and what kind of agency they assumed. Both the content (what to say) and recipient (whose process to comment on) were decided by the student.

Each of the study projects took 4-6 weeks to complete and involved each student writing a long series of CSILE notes and comments by. The projects in question were Force (4 weeks, January-February), Electricity (6 weeks, April-May), and Cosmology (4 weeks, June) in physics and Human Biology (6 weeks, March-April). The purpose of the Force project was to explain the forms of force, especially gravity. In the Cosmology project, the students were asked to answer questions given by the teacher concerning what the universe was made of, how the universe changed, and how it will be in the future. In these three projects, the students worked in small groups consisting of 3-4 students. 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 common to all students, and every student was 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. The task of the students in the Human Biology project was to collaborate in small groups to understand biological processes in the human body. Four representative cases of CSILE students’ group-work in biology and physics are available at http://www.helsinki.fi/science/networkedlearning/material/csclmaterial.htm).

Qualitative content analysis (see, for example, Chi, 1997) was applied to analyze categories of CSILE students’ peer interaction; these categories were subsequently used to distinguish types of social networks. In order to make a reliable qualitative classification of the material possible, CSILE students’ comments were first partitioned into ideas (regarding segmentation of data for content analysis, see Chi, 1997). This was because some students gathered many ideas in a single comment whereas others scattered their ideas in many comments. The use of ideas rather than notes as a unit of analysis also helped to equalize the weight of short and long comments in the students’ interaction. The reliability of partitioning was assessed by asking two independent coders to segment 200 notes into ideas. The Pearson correlation between the numbers of ideas identified by the two coders was .94.

The object of cognitive activity determines, to a great extent, the psychological nature of inquiry (cf., Leontiev, 1978; Engeström, 1987). Accordingly, each communicative idea was analyzed in terms of the object of inquiry, i.e., whether it was about 1) linguistic form, 2) research questions, 3) research methods, 4) information, 5) explanation, and 6) other comments. Linguistic form was the object of communicative ideas that focused on linguistic form instead of content of ideas. Frequently these ideas contained a reference to spelling mistakes or other grammatical weaknesses of the note commented (“You have a lot of spelling mistakes”). Communicative ideas related to research questions were frequently general comments on research questions or re-
quests to set up specific research questions or keep focus on the research questions, for example: "You do not have very specific research questions." Some communicative ideas were related to practices and methods of inquiry. In these communicative ideas, students often requested reflection ("You should not copy information"), better collaboration ("You should work in collaboration with other members of your group"), or deepening inquiry ("You should do your inquiry in depth"). CSILE students’ communicative ideas frequently either explicitly or implicitly focused on searches for information. These communicative ideas concerned quantity ("Your note is good because you have a lot of information") or quality of information ("You have found very important pieces of information"). Explanation-related communicative ideas usually contained an explicit reference to explanation, as in the following examples: "I like your explanation because it helps me to understand electricity"; "You didn't explain your results." An explicit reference to explanation was not, however, a necessary condition for regarding an idea as explanation-related. Comments concerning how ideas were presented or might be understood, were regarded as explanatory: "Your note really helps me to understand how the brain works." Other communicative ideas referred, for instance, to technical aspects of CSILE use. These involved also a few of unspecified communicative ideas whose main object could not be specified even with respect to the object of comment ("Your note is excellent"). Table 2 provides instances of objects of inquiry in CSILE students’ comments.

Insert Table 2 about here

Each communicative idea was, further, analyzed according to type of comment, whether it was focused on a) distributed regulation of inquiry, b) sharing of knowledge or c) supporting the other. Distributed regulation of inquiry consisted of comments focused either on criticizing some aspect of inquiry of a student or requesting, in a neutral manner, that the student explicate some aspect of his or her inquiry, such as explanation. This category of interaction is called distributed regulation of inquiry (DRI) because these comments coming from other students of the class appeared to help a student to effectively regulate his or her inquiry and, particularly, facilitate engagement in deepening inquiry. Comments representing knowledge-sharing usually involved scientific information that was provided to the student commented on. Further, while students provided an answer to a question through the knowledge-sharing comments, they asked a question by the DRI comments. Comments in which students’ positively evaluated a particular note formed the third category of interaction. Each communicative idea was considered to represent only one of the above-mentioned categories. Two independent coders classified 300 communicative ideas; the analysis indicated that the reliability of classification was satisfactory; the agreement coefficient exceeded .74 across all variables reported.

Finally, the cognitive value of CSILE students’ interaction was assessed by using expert evaluations. The three internationally regarded philosophers of science from well-known Canadian and Finnish universities were asked to assess the cognitive value of CSILE students’ peer interaction in two cases of physics and two cases of biology (the four cases are available at http://www.helsinki.fi/science/networkedlearning/material/csclmaterial.htm). The rationale of using the philosophers of science as experts was that they were considered to be experts on inquiry (rather than learning) who would be able to appreciate young students’ conceptual problems involved in their first attempts to understand very complex physical and biological phenomena. The experts in question had themselves pursued research on the history of science or extensive cultural studies. This kind of expertise in research on actual doing of science was regarded as critical in assessing the cognitive value of CSILE students’ peer interaction.
Social Network Analysis

In the present investigation, CSILE students’ network structure was examined by relying on cohesion, i.e. the density and centralization of the networking linkage. Density provides a simple way to measure cohesion of networks: the more actors have connections with one another (here, in commenting on each other), the denser will be the network. Whereas density describes the general level of cohesion in a graph, centralization describes the extent to which this cohesion is organized around particular focal points (Wasserman and Faust, 1994, 169-219; Scott, 1991). Accordingly, the concepts of density and centralization focus on differing aspects of the overall compactness of a graph, and, therefore, provide complementary measures of network characteristics.

In studying centralization, it is possible to focus either on socio-cognitive centrality of an individual actor or centralization of a network structure (e.g., teams of students, school class). The centrality measures indicate the most central actors, who are in the middle of activity in contrast to the isolates, who are at the periphery of social network. One special centrality measure used in the study, Freeman’s degree – the amount of information and knowledge the participant provides for or receives from the other participants – can be treated as a rough estimate of socio-cognitive centrality (Burt, 1999; Stasser, 1999). As mentioned above, the centralization measures indicate the extent to which a whole graph has a centralized structure, being closely associated to individual centrality measures. Since Freemans’ degree has been chosen for centrality analysis, the centralization measure is based on indegree (i.e., number of incoming networking linkages) and outdegree (number of outgoing network linkages). Centralization of a whole network thus accounts for the variation in outdegrees or indegrees of the actors in a network.

Another centrality measure used in the study is Freeman’s betweenness (Borgatti et. al., 1996); it is a measure that allows one to examine the role of actors functioning as socio-cognitive brokers. The betweenness measure is based on the concept of path distance. Interactions between two actors of social network who are not in direct contact with one another, depend on the other actors who lie on the paths between these two. An actor who often lies on the path between two other actors who are not directly interacting with one another, has a high betweenness value (Wasserman & Faust, 1994, 188-192). To have a large "betweenness" centrality, the actor must be between many of the other actors by bridging structural holes in a network (Wasserman & Faust 1994, pp. 188-192). Actors with a high betweenness value often have metaknowledge of distribution of knowledge or competence within a social network that allows them both to find relevant information and recognize actors who would benefit from having this information (Nardi, Whittaker, & Schwarz, 2000). It is likely that socio-cognitive brokers also have diverse contacts beyond their immediate social network that allow them to channel relevant knowledge to the community. The present authors consider a high betweenness centrality to be an indicator of strong epistemic agency.

We analyzed the networking relations between actors by multidimensional scaling (MDS). Scaling methods, such as MDS, are used to transform the graph measures into more intuitive metric measures, in order to make the complex patterns of networking visible. MDS is a method of mapping path distances (the distance between two actors is the length of the shortest path -- a geodesic -- that connects them) to Euclidean distances. Intuitively, the more any two actors of social network are interacting with each other, the closer they are on MDS maps. The quality of a MDS map can be measured by the stress value; a low stress value implies that the
graph distances do not need to be forced to distances on a two-dimensional space. The aim of MDS analysis is to describe the phenomena being investigated in an appropriate degree of detail, avoiding both an excessive complexity and undesirable filtering of interesting phenomena (Wasserman & Faust, 1994, 187-289; Scott, 1991, 151-156).

Social-network analysis was used to examine the density and centralization of the students’ CSILE-mediated written comments to each other. The data consisted of the links between CSILE students' communicative ideas: who interacted with whom by constructing CSILE comments. The information was examined as a weighted and directed graph representing the structure of communication, in which the teacher and the pupils were viewed as nodes and the comments as vertices. All analyses were performed by using the UCINET program (Borgatti, Everett and Freeman 1996a; 1999).

**Results**

We begin by reporting the results of the first qualitative examination of the contents of CSILE students’ communicative ideas. The epistemic nature of two types of CSILE students’ networks (providing and requesting explanation) will be identified and examined in the subsequent sections. Next we will present an analysis of the density and centrality of CSILE students’ social network as well as an assessment of degrees of CSILE students’ epistemic agency using relational measures provided by SNA. Finally, we will report results of the expert evaluation of the cognitive value of CSILE students peer interaction.

**Epistemic Contents of CSILE Students’ Peer Interaction**

The CSILE students, taken together, produced 504 written communicative ideas; the teacher produced 32 such ideas. Because the receiver could not, in a few cases, be determined, the actual number of comments used in social network analyses was 493. On average, each student produced 17.6 (SD = 10.7) comments. Table 3 presents a frequency distribution of the most important categories of CSILE students’ comments.

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The analysis indicated that practically all comments generated by the students were inquiry-related, i.e., focused on some aspect of inquiry, such as formation of research questions, selection of methods, search for information or explanation (Table 3). It was particularly noticeable that explanation-related comments had so important a role in the students’ CSILE mediated interaction (f=330, 62%).

Three categories of interaction were separated in the analysis, i.e., comments focused on regulating collaborative inquiry, knowledge-sharing comments, and supportive comments. Approximately 48% (f=255) of the comments represented distributed regulation of inquiry (DRI), that helped the students addressed to engage in deepening inquiry either by direct criticism or by requesting explication of explanation. These comments involved all CSILE students’ critical comments (f=178, 70%) and their neutral comments that focused on requesting explication of explanatory relations (f=79, 30%). The second category of communication involved 29% (f=157) communicative ideas aimed at sharing knowledge, especially explanatory scientific information, with the student commented on. About a quarter of the communicative ideas (f=124) were supportive, i.e., focused on positive evaluation of this or that aspect of inquiry. Consistent with an assumption that the students engaged in explanation-oriented inquiry, the participants commented positively on the explanatory level of one another’s notes rather than merely, for in-
stance, the quantity of information. Only a few comments did not represent any of the abovementioned categories. While supportive comments are important for building a social community, those comments did not appear to have as essential a role in CSILE students’ inquiry as did the other two categories of commenting; consequently, the detailed analyses of comments focused on knowledge sharing and distributed regulation of inquiry.

An overall impression of the data is that CSILE students’ culture of inquiry was relatively homogeneous in nature; the objects of the students’ inquiry or the epistemological nature of comments produced did not vary significantly between the participants. The likely reason for the homogeneous culture of progressive discourse is the fact that the students’ inquiry took place within a public database with shared epistemic practices evolving under the strong guidance and support of the teacher.

CSILE Students’ Network of Knowledge Sharing

CSILE students shared knowledge in two ways. They were, firstly, working within a shared database that provided ample opportunities to build on ideas developed by their fellow students. This kind of knowledge sharing was, however, a somewhat invisible or an implicit aspect of their inquiry. The students frequently gave each other acknowledgement of ideas they found from the database. The second category of knowledge sharing was more active in nature; it consisted of comments focused on helping another student in pursuit of his or her inquiry (see Table 3 for the frequency distribution concerning the object of inquiry in the participants’ comments). The analysis indicated that whenever a student tried unsatisfactorily to explain a problem without having relevant scientific information, the other students systematically helped him or her by providing explanatory concepts or theories. Often a student in need of help was using a functional explanation—one referring to human purposes, goals or intentions—or an empirical explanation—one referring to the human perceptual world or its categories (Hakkarainen, 1998, submitted). Whatever the inadequacy, the helping students fostered articulation of each other’s conceptions by systematically proposing scientific types of explanation. However, the social support appeared to be dependent on a student’s own sustained effort to solve the problem in question.

According to our assessment, knowledge-sharing comments had a critical role in advancement of CSILE students’ inquiry; consequently, these comments were regarded as essential indicators of emerging epistemic agency. The key role of knowledge-sharing comments is highlighted by the fact that about 59% (f=92) of the knowledge-sharing comments represented theoretical concepts, explanatory theories or analogies (see the website for examples). In these comments, CSILE students provided each other with concepts, such as “electron”, “ionization” or “field”, that were critical for scientific explanation of the given research problems. For instance, in the context of the Electricity project, some students got stuck on empirical explanations and were not able to explain what makes one material a conductor and another material a non-conductor. A comment in which a student shared a theoretical explanation for conduction of electricity is a quite typical example of comments providing explanation:

[To 19f3], I found some information that will probably help you. In order for electricity to flow through a wire, electrons that are loosely bound to atoms are wrenched away (these electrons are called free electrons). This is called ionization. If ionization does not occur then electricity cannot flow through the wire. Electrons sometimes collide with other atoms
which causes them to slow down or stop. This sometimes appears as heat. Inside
the wire the electrons don't move very fast. (16f3, emphasis added)

In trying to explain the problem "how does electricity turn an iron spike into a magnet?", several students failed to make progress because they did not have a central explanatory concept of field (Nersessian 1989; Thagard, 1988). By introducing the concept of field, a student was able to push the whole group towards deepening inquiry:

NI [New Information]: I have found out how a wire turns an iron spike into a magnet. It is not the iron spike that is the magnet, but the wire. When we connect a wire to a battery we engage an electric force field. When we coil the wire we intensify the field. We can intensify it again when we wrap it around the iron spike. This creates a force field strong enough to pull other objects into its grasp. These force fields prefer to be in certain metals rather than air, so they might bend or extend themselves to be in metal. Then they go back into their normal pattern and pull that object with them. In answer to your comment on my note, I hope that the information above will help you to understand what an electromagnet is and how it works. (16f3, emphasis added)

By sharing explanatory scientific knowledge, the students fostered advancement of each other’s conceptual understanding. In some cases, a theory (e.g., that of gravity particles) introduced by one student considerably affected advancement of the whole learning community. Many of the comments providing explanation were rather detailed explanations concerning the problems being investigated; such as, what a stroke is or how a camera functions.

Knowledge-sharing comments do not always involve a high degree of epistemic agency; new information can mechanically be distributed to a large audience without tailoring it to the specific epistemic needs of the recipients. In the present case, however, knowledge-sharing comments clearly represented genuine mediated agency: Students providing knowledge-sharing comments appeared often to form representations of their own understanding, understanding of the students commented on as well as an interpretation of the shared knowledge object in question. This kind of mediated approach is evident in the following transcriptions:

14m3, I think that in order to understand it, first you have to understand what an atom does… (16f3)

Dear 20f2, I think that in order to understand how a battery does anything, you have to understand what a battery is, what it is made of and how it works… (19f3)

These examples indicate that knowledge-sharing comments involved metarepresentational expressions that provided evidence of how students engaging this kind of interaction conceived of their colleagues’ problems of understanding, especially in respect to the objects of their inquiry. Paavola and Hakkarainen (2003) have called this kind of mediated approach “trialogic” because it is not merely based on a dialogue between minds, but it is thoroughly mediated by the shared knowledge objects – so that there is the third, mediating element present. CSILE students’ knowledge-sharing comments were not randomly directed to a fellow student, but carefully anchored in specific problems and theories the addressed students worked with. This anchoring was indicated through expressions, such as “My theory on your problem is that…” (16f3); “I think I can help you with the problem you have in your first INTU” (16f3); “I have a theory on your problem: Why does the eye turn everything upside down” (7f3). The mediated nature of CSILE students’ peer interaction can also be seen from the fact that the participants’ reciprocal
criticism was focused on the theories their fellow students worked with rather than others’ personal attributes: “I disagree with your theory ...[rather than directly with you] (18f2); "26f1, I agree with your theory and I disagree with your New Information” (2f2).

CSILE Students’ Distributed Regulation of Inquiry

Distributed regulation of inquiry, in turn, consisted of 47.6% (f=255) of the communicative ideas (f=536) produced by the students. As mentioned above, two-thirds of these comments were critical and one third neutral in nature. The critical comments focused on criticizing weaknesses in fellow students’ research questions, research methods, information or explanation. The neutral comments did not explicitly criticize the note addressed, but requested explanations of various aspects of inquiry. The frequencies of all categories of comments representing DRI were not very high. We argue, however, that the power of social communication in a public domain is not based on the number of certain kinds of comments. Even one comment of a certain type may be enough to change the whole group’s practice of inquiry. Further, in the public database, merely reading about exchange of comments between student A and B may push student C to critically reflect on his or her own inquiry from the perspective of the others and thereby have a considerable effect on inquiry. In the following, some categories of interaction representing DRI are examined in a more detailed way, relying on transcriptions from CSILE students’ productions.

Comments in which the students’ commented on each other’s research questions formed a clearly distinguishable category of distributed regulation of inquiry. There were altogether 22 comments on research questions. In such comments, CSILE students were requesting each other to select manageable and specific research questions instead of general questions about the topic. Further, many comments were apparently intended to show that a student did not genuinely focus on his or her principal research question but wandered unproductively around peripheral areas of the topic. The problem of forming specific research questions was critical, for example, in the context of the Cosmology project in which many students constructed questions that were based on inadequate functional presuppositions concerning the centrality of human purposes in the universe. Through communicative ideas pointing out inadequate presuppositions, these students (and groups of students) were provided socially distributed metacognitive resources and guided to focus on more productive research questions, for example:

Dear 5f3,15f2, You said you thought that we would find more cures for diseases which is a very nice thought, but you didn't say why you thought this. Do you expect that just because our world will be more advanced we will be able to find cures? And what does it have to do with the universe? (3f3)

On your note, "How has the universe changed and how will it change?", I don't think you should be focusing so much on our planet with medicines and so on. I think you should focus more on the universe, because that's what your problem was in the first place. (10m3)

Moreover, pointing to an unanswered question was an important way of requesting deepening inquiry that was frequently used by the students:

In your INTU you said you need to understand what gravity and oxygen have in common. And in your NI you have not explained what gravity and oxygen have in common, you only said that without gravity and oxygen you would not be able to survive. (5f3)

An important aspect of distributed regulation of inquiry consisted of comments that focused on methods of collaborative process of inquiry. These comments concerned principles of
collaboration and communication, often requested reflectivity, and emphasized well-planned and organized inquiry:

Dear 15f2, I think that you have a good problem and good theories but you should put more new information in your note because 5f3 seems to be putting on all the information. I also think that 2f2 should comment on your note more. It also seems that 5f3 has been doing the whole last part of your note. (4f2)

After reading your comment … we decided that it did not really help [the student being commented]. If you don't think her note is good, then you should suggest some ways which you think would improve her note. For example some information that you found, or if there is something you don't agree with then you could tell her. (23M3)

These pieces of interaction appeared to have characteristics of metacommments: they concerned methods of carrying out the collaborative process of inquiry. They also represented gradually tightening epistemic norms of inquiry within this community, and appeared to contribute significantly to progress in the culture of communication. Many of the comments were focused on requesting fellow students to explicate, clarify, and further articulate their theories. A large number of these comments pointed to inadequate presuppositions or other weaknesses in theory (see website for examples). The participants were not satisfied with general descriptions of biological or physical phenomena, but requested a detailed theory of how the phenomenon in question operates. Some of the comments requesting explanation seemed to be metaconceptual in nature in the sense that they implicitly relied on criticism of the limited range or power of explanation, lack of simplicity or ad hoc assumptions (see Samarapungavan, 1992):

[to 28m2]: You are not being very specific to the reader in your MT. You say that some solutions conduct because they are like metal. In what way are they like metal? And you should write other substances that have other reasons besides being like metal. (21m2)

Dear 18f2, We do not quite understand some of the information that you have stated on your note. For instance, you said that "the universe is made out of a certain kind of air, and another "ingredient"." Even though this is your theory we think that you should go deeper into this topic and you will find out that the universe cannot be made out "a certain kind of air". Because we know that there are other gases in the Universe. (21m2 and 23m3)

There is some evidence that the distributed regulation of inquiry a pushed the student receiving the comment to do more research and find new information in order to further his or her conceptual understanding. In order to examine whether requests for explanation pushed students to deepen their inquiry, we conducted an analysis of the data for the Electricity project. The project, as mentioned above, was designed so that students worked individually to solve eight principal questions common to the whole group. In the analysis, we examined the depth of inquiry by calculating how many episodes of inquiry were conducted while solving each of the eight problems. (An episode of inquiry consisted of a cycle of producing a research question and one or several intuitive theories and pieces of scientific information.) The effects of requesting explanation were analyzed by comparing the mean depth of inquiry between a) processes of answering one of the electricity problems for which a student received a request for explanation, and b) processes for which he or she did not receive this kind of request. In the analysis, we included only those students (n=22) who received a comment requesting explanation. Because some of the students did not solve all eight problems, the comparison concerned 196 processes of solving one or another of the electricity problems across all students. The possibility that the processes com-
mented upon would have been necessarily longer because of receiving a request for explanation, was ruled out by comparing depth of those processes before receiving the request for explanation with processes that were not commented upon. The statistical analysis revealed that the mean depth of inquiry for the processes receiving comment did not differ from a student’s other processes.

A paired sample t-test was carried out in order to test whether the mean depth of inquiry was higher in those processes in which a student received a comment requesting explanation, than that of his or her other processes. The analysis indicated that a higher mean depth of inquiry was associated with receiving a request for explanation (t=-4.90, df=21, p<.001). The mean depth of inquiry was 1.7 (SD = .4) without requests for explanation and 2.7 (S.D. = .9) for those processes involving request for explanation. In the context of the episodes of inquiry in which other students asked for explication of explanatory relations, the students tended to conduct a larger number of episodes of inquiry than generally: i.e., a request for explanation, in many cases, started a new episode of inquiry by initiating generation of a new, more specific research question as well as search for new information. Therefore, one may conclude that requests of explanation were associated with a greater depth of inquiry, and, we would argue, had an essential role in pushing these students receiving comments to deepen their inquiry.

CSILE Students’ Social Network and Epistemic Agency

The intensity of CSILE students’ network-mediated interaction was examined by analyzing the density of their networking linkages. The density of a (binary) network is the number of observed links (i.e., network ties) divided by the number of all possible links (Borgatti et al., 1996, p. 78; Scott 1991, p. 74). For a binary matrix, the measure varies between 0 and 1. (If the value is 0, then the network is empty. If the value is 1, it indicates that everyone is directly interacting with everyone else.) The analysis indicated that CSILE students’ network of interaction was rather dense; the density was 41% for symmetrized data, i.e., a matrix in which the direction of commenting was ignored. In the case of the asymmetric graph based both on sent and received comments, the measure was 28% of the possible links between participants. The data set was dichotomized in these analyses (cut off point = 0). Thus, in order to analyze the network of CSILE students’ interaction as a whole, we abstracted from the number of comments and investigated whether there existed a networking linkage at all (1) or not (0).

Further, we examined the extent to which a whole graph, representing CSILE students' interaction, had a centralized structure. A centrality value is calculated for each student in order to find the most active and visible actors in the community; we used Freeman's degree (i.e., number of sent and received comments, see Appendix). The results of the analysis indicated that the CSILE students' interaction was not very centralized (24% and 28% in the case of sent and received comments, respectively); CSILE students' communicative efforts were distributed among a relatively large number of students who actively engaged in peer interaction.

The Appendix presents the centrality of each student’s participation in the overall social network as a function of gender and school achievement level of the participants, and includes information concerning the size of the participants’ network, such as number of partners of interaction, number of dialogue partners (reciprocal interaction), and the overall indegree value (number of received comments). The participants’ social network was further examined in terms of two epistemic networks of interaction, i.e., networks of knowledge-sharing and distributed regulation of inquiry. For these networks we calculated outdegrees (number of sent comments)
and betweenness values. If we think of CSILE students' communication as an information flow consisting of the individual comments, Freeman's 'betweenness' value for a given student shows how often that student is found in the shortest path between two other students. The betweenness values are calculated by using dichotomized matrix, i.e., abstracting from the number of comments among the participants. Apparently, there were drastic differences in the number of comments, particularly knowledge-sharing ones, generated by CSILE students, the size of students' network of interaction, and students' positions in the epistemic networks in question, as indicated by the betweenness values.

Whereas all CSILE students, except one male student (1m1), engaged in a seemingly very advanced progressive discourse focused on advancing their explanations, there were significant between-student differences in the level of assumed epistemic agency. Relational measures of CSILE students' networking practices were used to classify CSILE students into homogeneous subgroups, using a 4-means cluster analysis. As mentioned above, epistemic agency was considered to be a relational phenomenon that emerges between rather than within people. Consequently, epistemic agency was assessed with corresponding relational measures of SNA, such as betweenness of knowledge sharing and betweenness of distributed regulation of inquiry. In addition, we used measures that appeared to reflect each participant's own active networking efforts, such as outdegree of knowledge sharing, outdegree of distributed regulation of inquiry, and the number of dialogue partners (rather than incoming comments that indicate popularity within a social network). The final cluster centers are presented in Table 4; the membership of each student in clusters representing level of epistemic agency is presented in the Appendix.

All CSILE students’ indicated at least some level of epistemic agency in respect of posing their questions and pursuing their explanations; this is a significant improvement in relation to conventional educational practices. The analysis indicated, however, that there were four distinguishable level of epistemic agency, that is to say, of taking collective responsibility for their inquiry-community’s advancement (see Scardamalia, 2002). We now describe these levels of epistemic agency.

**Level 1 epistemic agency:** The analysis indicated that 17 students mainly took responsibility for advancing their own inquiry. These participants produced relatively small numbers of knowledge-sharing comments, and they had only a few dialogue partners, communicating mostly with their immediate peers. They did not mediate interaction and knowledge flow between other students of the class, as indicated by extremely low betweenness values. The teacher of the CSILE class was classified in this group because he did on engage in CSILE-mediated dialogue beyond requesting explication of explanatory relations (i.e., he did not mediate knowledge flows between students, but encouraged students to do it themselves).

**Level 2 epistemic agency.** Four students engaged in relatively intensive peer interaction as indicated by a larger number of knowledge-sharing comments and dialogue partners than the former group of students. They had substantially higher betweenness of both knowledge sharing and distributed regulation of inquiry than the former group of students, indicating that they went beyond taking responsibility solely for their own inquiry to communicate with a number of other students. They appeared, however, to be mostly interacting with other members of their respective gender groups.
Level 3 epistemic agency. The third group identified in the analysis consisted of four students who had a very high cognitive centrality both in networks of knowledge sharing and distributed regulation of inquiry. Their extremely high betweenness centrality of distributed regulation of inquiry indicated that they were particularly focused on pursuing distributed regulation of inquiry by way of systematically asking their fellow students to engage in deepening inquiry and explicate their explanations. Actually, these students had the highest number of dialogue partners, implying that their network of interaction covered practically all students within the class. They had also a relatively high number of knowledge-sharing comments.

Level 4 epistemic agency. We consider, however, the final group of three students (14m3; 16f3; 19m3) to have demonstrated an exceptionally high level of epistemic agency in respect of assuming the role of socio-cognitive brokers of CSILE students’ knowledge-sharing network. These students shared their knowledge and achievements by crossing boundaries between male and female students, as well as less and more advanced students. Knowledge sharing appears to require an actor to know a great deal about the other actors with whom knowledge is being shared. It appeared to be characteristic of the students representing level 4 epistemic agency to acquire metaknowledge of the other students’ knowledge across boundaries of gender and achievement level.

Students representing both level 3 and 4 epistemic agency, broke the boundaries of their own networks and became outstanding examples of epistemic agency in the CSILE students’ overall social network. Students representing level four epistemic agency contributed significantly to advancement of their fellow students’ inquiry in terms of sharing epistemologically significant explanatory knowledge with their fellow students; thereby, these students assumed epistemic responsibility of the advancement of the whole community’s rather than only their own inquiry. In the present case, this appeared to crucially affect the progress of CSILE students’ inquiry community. Distributed regulation of inquiry may have a crucial role in collaborative inquiry. Simultaneously, it leaves the responsibility of advancement of inquiry to the students involved. Both types of interaction are needed, but in terms of epistemic agency, a sophisticated knowledge-sharing approach appears to indicate a higher-level epistemic commitment.

For a closer look at relations between CSILE students’ epistemic networks of interaction, we performed MDS analyses. The more messages any two students sent or received from each other, the closer they are situated in the MDS maps. The stress values, measures of the quality of the MDS map, for networks of distributed regulation of inquiry and knowledge sharing were at a satisfactory level (0.125 and 0.079, respectively). Figures 1 and 2 present MDS maps for networks of distributed regulation of inquiry and knowledge sharing.

The MDS analyses indicated clearly that CSILE students’ network of regulating inquiry was relatively homogenous across their community of inquiry. In other words, all students except one produced this type of comment; this student had to be left out of the analysis. Most students were grouped together into a relatively small area except for two (1m1 and 23m3), who produced only two or three comments of this type. Gender appears to have strongly influenced interaction; all male students formed a cohesive area without any girls. The male students are located in the upper right part of Figure 1 and females to the left, with very little overlap between the groups. Students with levels 3 and 4 epistemic agency are located in the middle of the figure, and no easily interpretable pattern has been found.
Intensity of participation in the knowledge-sharing network varied more among the participants than did distributed regulation of inquiry. An examination of the MDS for knowledge-sharing network indicated that two or three male actors (1m1, 6m3, 28m2) and female actors (15f2, 13f3, 9f3) were separated from the others. These students either produced no or only a few knowledge-sharing comments and, correspondingly, had very low betweenness values. Three out of the four isolated students were males. In the middle of the map are located seven students with level 3 or 4 epistemic agency and, correspondingly, the highest betweenness values, for example 5f3 (98), 16f3 (104), 18f2 (102), and 19f3 (159). Student 14m3 is located at the upper left boundary of closely grouped students (and towards the isolated male participants), indicating that his communication crossed internal boundaries of the social network; this explains his high betweenness value (129). The male and female participants did not form their own cohesive areas, indicating that knowledge sharing took place also across the gender boundary of the classroom. To summarize, the MDS map reveals that some students were separated from the knowledge-sharing network of the CSILE class indicating that they did not actively participate in this network. The CSILE students with the highest levels of epistemic agency formed a knowledge-sharing network crossing the internal dividing lines within the classroom in question.

Expert Evaluation of the Cognitive Value of CSILE Students’ Peer Interaction

In order to confirm the cognitive value of CSILE students’ interaction, we asked three highly regarded philosophers of science to assess the cognitive value of the peer interaction. As explained above, the experts assessed four cases of CSILE students’ inquiry involving students’ research questions, intuitive theories, scientific information found by them, as well as their peer interaction (see http://www.helsinki.fi/science/networkedlearning/material/csclmaterial.htm). The evaluation of the experts corroborated that interaction mediated by the CSILE network was likely or highly likely to facilitate advancement of CSILE students’ inquiry. All of the experts agreed that comments generated by the students were quite good and facilitated advancement of inquiry. The following analysis draws on expert A’s and B’s evaluations because expert C’s evaluation remained at a very cursory level. Expert C did not go beyond very general remarks according to which there was “good discussion” between students, interaction between students worked “to some extent” or that comments from other students in the class were “quite good.”

Expert A stated, as an overall assessment, that throughout the cases discourse interaction between students was “highly useful. Absolutely!” Experts A and B were particularly impressed with CSILE students’ consistent and forceful way of asking each other to clarify or explicate their explanations. They also judged that comments providing explanatory scientific information were critical for advancement of students’ inquiry. Particularly important for furtherance of inquiry was the provision of analogies that made new conceptual points of view available to the students receiving comments. In assessing the case of a small group that tried to explain how the eye functions, expert A stated,“

... I think the interaction goes along all right. I mean having comments from somebody else who has actually done some homework on the cameras, helps to bring out an analogy, which I think is a useful way of approaching anything. An analogy, of course, helps and that surely does aim to progress, progressiveness of the process of inquiry. I really do think there is progress of inquiry.”
Expert B asserted that analogies are useful for understanding due to increased coherence with other things that are better understood, but they do not always facilitate explanatory unification. He concluded that the students moved towards the unifying level of coherence both in the Cosmology and How-the-Eye-Function cases. He assessed that the students were “... likely to be able to gain from this [interaction] and to get more information passing around. In this case peer-interaction definitely was useful.” He stated that, although it was difficult to assess how much conceptual change was achieved by the students “here [there] does seem to be [occurring ] the sort of things in which peer-collaboration is likely to foster conceptual change.”

Expert A very much appreciated a comment given by one of the students in the class that the Cosmology group should organize their work better and go deeper into the topic: “This a kind of metacomment on the way they work. ... commentary on methodology, how they work and organize, which is nice.” He concluded by stating, “This is highly interesting here. ... Because there are a number of extremely useful interactions from the audience, like this question, ‘OK, come on guys, get back to business’, and ... also there are metacomments on the process.”

The cognitive value of CSILE students’ communicative ideas was associated with the expert’s corresponding appreciation of their explanations as well as their research questions that appeared to advance their inquiry (see Hakkarainen, 2003b and 2004 for further analysis of CSILE students’ explanations). Even though CSILE students’ intuitive conceptions were in many cases mistaken and based on functional and other kinds of misleading presuppositions, they often succeeded in overcoming these limitations when relevant scientific knowledge was available. According to the experts’ overall evaluation, CSILE students’ research questions were generally at a high level of sophistication, and, if successfully answered, were likely to produce new conceptual understanding. Moreover, they noticed that CSILE students did not move randomly from one to another research question; the student-generated research questions formed a pattern that allowed the students to answer their main research questions by generating a series of more specific questions (for a further analysis of CSILE students’ pursuit of research questions, see Hakkarainen & Sintonen, 2002).

Discussion

The present study aimed at understanding to what extent elementary school students are able to participate in progressive discourse interaction in computer-supported inquiry and develop corresponding epistemic agency. The evidence presented indicates that it is entirely possible for young students in the educational system to engage in progressive discourse focused on advancing their explanations. An explanation-oriented discourse interaction played a crucial role in CSILE students’ inquiry and the participants were clearly able to give meaningful input to their fellow students’ explanations. This alone is an unusual achievement because elementary school students so easily focus on mere social correspondence and fact-centered discussion (Feldman, Konold, Coulter, Conroy, Hutchinson, & London, 2000; Hakkarainen, Järvelä, & Lipponen, 2002; Lipponen, 2000; Lipponen, Rahikainen, Lallimo, Hakkarainen, 2003). The study furnished evidence that children can be successfully encouraged, given both CSILE and appropriate teacher guidance, to pursue progressive discourse and think with deeper levels of explanation than is generally believed possible.

The methods of SNA helped us to overcome weaknesses of earlier studies based on qualitative content analyses and provided relational information about CSILE students’ participation: Findings regarding epistemic agency presented several intriguing features concerning patterned
sets of connections that linked the students to one another. The analysis indicated that
while the contents of CSILE students’ comments were relatively homogeneous across the stu-
dents, the participants appeared to represent varying degrees of epistemic agency. Four levels of
epistemic agency were distinguished in the analysis. Characteristics of level 1 epistemic agency
was taking responsibility mainly for one’s own immediate inquiry without mediat-
ing interaction between other students or engaging in CSILE-mediated dialogue. Level 2 epistemic agency, in
contrast, was associated with working within a larger group of peers and having a higher be-
tweenness of knowledge sharing and distributed regulation of inquiry. It was typical of level 3
epistemic agency to have a cognitively central role among the CSILE users’ network of distrib-
uted regulation of inquiry as well as engage in dialogue with a large number of partners. Finally,
students represented level 4 epistemic agency in terms of sharing their explanatory knowledge
with their fellow students. Students representing the two highest levels become originating points
of epistemic agency within the students’ overall social network in terms of crossing boundaries
between groups of students.

The results of the study revealed that average and high-achieving female students’ pa-
rticipated very actively in interaction within CSILE students’ inquiry community. Only some of the
male students engaged equally actively in CSILE-mediated communication. The male and fe-
male students appeared, further, to prefer communication within their respective gender groups;
indeed, the MDS analyses indicated that male and female students formed two relatively distinct
subcultures of peer interaction. Many earlier CSILE studies, insofar as they did not investigate
heterogeneity, were implicitly or explicitly based on an assumption that the students’ culture of
inquiry was more or less homogeneous across students (e.g., Scardamalia & Bereiter, 1999;
Hakkarainen, 1998). Due to the biased gender distribution of the investigated classroom, it is,
however, difficult to make definite conclusions of the observed patterns of participation (for a
more detailed examination of the gender issue see Hakkarainen & Palonen 2003, which involves
a comparative analysis of two CSILE classes).

Several students, representing both level 3 and level 4 epistemic agency, appeared to be
working as socio-cognitive brokers in CSILE students’ inquiry community. Socio-cognitive bro-
kring can be interpreted very broadly as the acts of creating connections and establishing net-
works between agents, knowledge-laden artifacts, and other kinds of resources (Sverrisson,
2001). Socio-cognitive brokerage not only provides access to knowledge resources, but also is a
process of conceptual bridging and translation (Latour, 1999). Bridging the structural holes --
those gaps between or among groups of students representing different gender and ability levels -
- appeared to facilitate the advancement of the whole community’s knowledge and inquiry. The
students who functioned as socio-cognitive brokers of the CSILE students’ social network as-
sumed collective responsibility for the advancement of the whole community’s rather than solely
for their own inquiry (Scardamalia, 2002). Rather than subsuming their thinking under the teach-
ers’ epistemic authority, these students took responsibility for their own thinking and problem
solving. This kind of epistemic agency is regarded as an important indication of the emergence
of authentic knowledge-building culture (Scardamalia, 2002). An interview of the teacher indi-
cated that he was full of respect for his students’ ideas and personal voices and was convinced
that the students “ran the curriculum” during the period investigated, rather than himself.

Socio-cognitive brokers of knowledge-sharing network appeared to have more developed
cultural resources for independently searching and obtaining new scientific information, and
have metaknowledge of the relevance of explanatory knowledge. They were ready to share
emerging knowledge and understanding with the other students. These students appeared to focus on encouraging participation of others who did not themselves have equally strong academic skills. Rather than having solely functional skills needed for academic studies, these students appeared to have developed relational skills involving metaknowledge of other persons’ and communities’ skills and competencies within the inquiry community (c.f., Nishiguchi, 2001). These skills appeared to help students use the intellectual resources of the inquiry community in question by knowing “who know what, who can and is willing to be helpful in what”, and who is in need of new knowledge (p. 216). These skills that constitute the core of networked expertise emerge through intensive interaction between a person and the social environment of his or her activity (Hakkarainen, Palonen, & Paavola, & Lehtinen, 2004).

The students used socially distributed resources mediated by the CSILE environment extensively in articulation of their theories. In this collaboratively functioning learning community, participants fostered "distributed conceptual advancement" by sharing theories or theoretical concepts learned by individual members of the group. Thus, the students appeared genuinely to engage in collaborative effort to advance their explanations. This collaborative process of building knowledge happened at several levels. CSILE’s database provided each student with access to other students' productions, and this public forum provided ample opportunities for sharing knowledge. By sharing explanatory knowledge, the students fostered development of each other’s conceptual understanding. Fellow students' comments formed an important source of development of each student's own theories and helped him or her to overcome conceptual difficulties regarding physical and biological phenomena and facilitate conceptual advancement.

By participating in a socially distributed process of progressive inquiry, the students were taking some responsibility for controlling each other's process of inquiry, a task that has traditionally been carried out exclusively by the teacher (Bereiter & Scardamalia, 1987). The epistemic value of comments requesting for explication is presumably based on the fact that weaknesses in conceptions of one student are more easily available and salient to another who is considering the problem from a different point of view. In many cases, inadequate initial assumptions or wrong presuppositions prevented a student from progressing in his or her project. In these cases, the successful process of inquiry was critically dependent on social interaction, which often helped students to focus on specific manageable problems and distribute limited intellectual resources more effectively.

Nevertheless, CSILE material suggests that even very young children are able to take much larger social responsibility for their inquiry than has generally been assumed. Moreover, the students were able to encourage one another to engage in in-depth inquiry. C. S. Peirce's Principle of Economy of Inquiry implies that an agent considers a belief to be true when inquiry "is carried sufficiently far", as far as it turns out to be "fruitful"; hence the pursuit of truth is pragmatically constrained (see Misak, 1991; Rescher, 1978). Conceptual change research has shown that, in an educational context, inquiry is often not carried very far – students frequently give up after a few minutes' unsuccessful efforts (see, e.g., Schoenfeld 1983). The epistemic value of CSILE students' socially distributed inquiry appeared partially to be based on a process in which social communication changed the level of what students interpreted to be "sufficiently far". Comments from colleagues apparently pushed a student to go further than he or she, originally, would have been ready to go, which we take to be clear evidence of emerging epistemic agency among the CSILE students.
Epistemic agency appears to be distributed between the participants and the social system of their learning environment rather than carried out by the participants or technology-based learning used by them alone (cf., Lemke, 2001). The inquiry culture investigated represented the end result of an extended process of cultural learning across several years, characteristic of which was that the teacher in question assessed, together with researchers, achievements of his students every year and developed methods and practices that allowed the community to overcome emerging tensions, disturbances and weaknesses of progressive inquiry (see Hewitt, 2002; Hewitt & Scardamalia, 1998). In this regard, CSILE students’ inquiry community resembled boundary-crossing laboratory discussed by Engeström and his colleagues (1995). It appears that inquiry is not just an epistemic process, but it is deeply rooted in routine and prescribed activity patterns (Kolodner & Crey, 2002) that guide the participants in pursuing their questions, articulating their working theories, and commenting on each other’s ideas. Accordingly, knowledge-building communities (organized around shared conceptual artifacts, Bereiter, 2002) and expansive-learning communities (focused on transforming social practices, Engeström, 1999) appear to be very close to each other (Hakkarainen, 2003b; 2004; 2009; Hakkarainen, Bollström-Huttunen, & Hoffman, 2008; Paavola, Lipponen, & Hakkarainen, 2004). During the present study, we were concerned mainly with knowledge produced by the participants; the social practices on which knowledge-building efforts were anchored remained invisible to us, and, consequently, were never adequately documented. The conclusion of the present investigation—the mutual dependency of knowledge building and expansive learning—has important methodological implications, such as the necessity of addressing actual classroom activities beyond analyzing CSILE postings (Hakkarainen, 2009).

Contributions made by the authors: Kai Hakkarainen designed and carried out the qualitative content analysis of CSILE students’ inquiry process. Tuire Palonen performed the social-network analyses of CSILE students’ peer interaction and wrote corresponding parts of the present article. Hakkarainen was centrally involved in theoretical framing of the study. The article was finished and revised together according to the anonymous referees’ comments. We are very grateful for Carl Bereiter, Marlene Scardamalia, and other people from IKIT for their guidance and support while performing the study.
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