
RUNNING HEAD: Progressive Inquiry in Biology…

DRAFT OF “PROGRESSIVE INQUIRY IN A COMPUTER-SUPPORTED BIOLOGY CLASS”

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Abstract

The problem addressed in the study was whether 10- and 11-year-old children, collaborating within a computer-supported classroom, could engage in progressive inquiry that exhibit an essential principal feature of mature scientific inquiry, namely engagement in increasingly deep levels of explanation. Technical infrastructure for the study was provided by the Computer-Supported Intentional Learning Environments, CSILE. The study was carried out by qualitatively analyzing written notes logged by 28 grade 5/6 students to CSILE’s database. Results of the study indicated that with teacher’s guidance the students were able to produce meaningful intuitive explanations about biological phenomena, guide this process by pursuing their own research questions, and engage in constructive peer interaction that helped them to go beyond their intuitive explanations and towards theoretical scientific explanations. Expert evaluations of three widely recognized philosophers of science confirmed the progressive nature of the students’ inquiry.
Introduction

The purpose of the study was to analyze elementary school students’ process of inquiry in computer-supported collaborative learning. The problem addressed in the study was 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 study focused on examining whether 10- and 11-year-old children are capable of engaging in processing of knowledge at a deep level of explanation instead of being bound to surface-level phenomena. This kind of explanation-driven inquiry appears to be both an essential aspect of pursuing scientific research and within the pragmatic limits of school children’s cognitive resources.

Technical infrastructure for the study was provided by the Computer-supported Intentional Learning Environments, CSILE / Knowledge Forum® (Scardamalia and Bereiter 1994; 1996; Scardamalia, in press). CSILE is a networked learning environment for fostering higher-level processes of inquiry in elementary education. A central part of the system is a shared virtual space for producing, searching, classifying, and linking knowledge. Students use CSILE by writing notes, creating charts, and reading and commenting on each other's productions in the context of such domains of knowledge as mathematics, physics, biology, and history.

In the present study, the sustained processes of advancing of knowledge characteristic of scientific inquiry are called progressive inquiry (Hakkarainen, 1998; Hakkarainen & Sintonen, 2002). Facilitation of this kind of inquiry is an aim of
several, concurrent, cognitive research projects (Brown & Campione, 1996; Carey & Smith, 1995; Perkins, Crismond, Simmons, & Unger, 1995; Scardamalia & Bereiter, 1994; The Cognition and Technology Group at Vanderbilt, 1997). Progressive inquiry entails that by imitating practices of scientific research communities, students are guided to participate in extended processes of pursuing their own questions and explanations. Progressive inquiry is closely associated with Scardamalia’s and Bereiter’s (1994; Bereiter, 2002) knowledge-building approach and Jaakko Hintikka’s (1985; 1999) interrogative model of inquiry (see Hakkarainen & Sintonen, 2002). Accordingly, an important aspect of progressive inquiry is to guide students to set up their own research questions and working theories. Participation in progressive inquiry can be facilitated through computer-supported collaborative learning environments that provide sophisticated tools for supporting inquiry process as well as sharing of knowledge and expertise.

An essential aspect of progressive inquiry is to set up questions or problems that guide the process of inquiry. Without a research question there cannot be a genuine process of inquiry although traditional teaching often takes place without any questions whatsoever. Cognitive goals determine what kinds of questions are generated, and, thereby, guide and regulate the process of inquiry. Questions that arise from students' own need to understand, have a special value in the process of inquiry (Scardamalia & Bereiter, 1992). Explanation-seeking why and how questions are especially valuable in progressive inquiry while fact-seeking questions that are not embedded in genuine inquiry tend to produce fragmented pieces of knowledge. Advancement of understanding often emerges through solving conceptual problems, i.e., problems arising from gaps of knowledge, conflicting theories or unexpected
phenomenon (Laudan, 1977). Although a teacher needs to set up general frame of investigation, it appears to be essential to engage students themselves in a process of question generation.

An important aspect of inquiry is generation of one’s own explanations, hypotheses or conjectures for the phenomena being investigated (e.g., Carey & Smith, 1995; Perkins, et. al., 1995; Scardamalia & Bereiter, 1994). According to Thagard (1988, p. 44), explanation can be seen as a cognitive process of providing or achieving understanding: demonstrate their understanding by offering explanations. Explanation in everyday life and in science has a corresponding epistemic role, and in this sense, good everyday explanations resemble scientific explanations (Sintonen, 1989, p. 254). Generation of an agent’s own intuitive working theories is a substantial aspect of the process of inquiry. Yet students’ own explanations or hypotheses do not have a significant role in current practices of science education. Students often, without reflections, adopt explanatory concepts and theories only as new facts or mechanical procedures. In order to overcome his limitation, science education should focus on practicing how theories or models can be used to develop, extend, and test ideas (Carey & Smith, 1995). Such focus would provide students a basis for applying the process skills to construct, explore, and evaluate their own ideas about natural phenomena.

Keil’s (1989) analysis supported the contention that children construct theories or other explanatory systems in order to justify what features or dimensions are important for organizing a domain and what ones are not (p. 254). Further, he argued that the role of theoretical and explanatory knowledge is to provide coherence
and explanation for observed the correlations and frequencies. Chi, Bassok, Lewis, Reiman, and Glaser (1989) found out that students who explained examples to themselves achieved better learning results than other students having identical, separately measured, declarative knowledge. Progressive inquiry is aimed facilitating explication and externalization of these intuitive conceptions (through guiding students, for instance, to write about their ideas) and taking them as the object of collaborative discussion (Bereiter, 2002).

The question-driven process of inquiry provides heuristic guidance in the search for new scientific information. Considerable advancement of inquiry cannot be made without obtaining new information either by conducting experiments, collecting data or using literature. Brown and Campione (1996) emphasized the importance of connecting collaborative learning with domain-specific “deep principles”, or “generative ideas” fostering advancement toward higher levels of abstraction. In the biological domain such principles are, for example, interdependence, biodiversity, evolution, and adaptation, i.e., explanatory concepts and theories that facilitate organized thought and analogical inferences. However, a theoretical explanation may have more significant influence on advancement of one’s conceptual understanding when it is adopted in a process of knowledge-seeking inquiry and provides an understandable answer to an agent’s own research question.

Hakkarainen and Sintonen (2002) argued that, in an appropriate environment, it is entirely possible for young students, with computer-support for collaborative learning, to engage in sophisticated interrogative process of inquiry (Hintikka, 1999) analogous to scientific inquiry. In pragmatic problem-solving situations an agent has
to start generating questions and theories before all necessary information is available. As a consequence, the process of inquiry often has to start with initially very general and unspecific questions and tentative working theories. The agent tries to solve the initial big question through using his or her existing knowledge and new information that provide answers to a series of subordinate questions (Hintikka, 1985; 1999). According to the model, this kind of theory may function as a tool of inquiry in spite of gaps, weaknesses, unclarities or other limitations. A critical condition for progress is that the agent focuses on improving his or her theory by generating more specific questions and searching for new information. The dynamic nature of inquiry is, further, based on the fact that new questions emerge in the process of inquiry that cannot be anticipated when the principal question is generated. That new questions are generated from one's original question in a successful process of inquiry has been pointed out by several cognitive researchers (Ram, 1991; Scardamalia & Bereiter, 1992; Simon, 1977).

Advancement of inquiry can be substantially elicited by relying on socially distributed cognitive resources, emerging through social interaction between the learners, and collaborative efforts to advance shared understanding (Scardamalia & Bereiter, 1994; 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 (Miyake, 1986). 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 purpose of the study was to investigate whether young children are able to participate, even in an elementary form, in the same sort of progressive inquiry that characterizes scientific research. Essential aspects of progressive inquiry examined in the present investigation are research questions generated by the students themselves, their intuitive theories, scientific information sought by them as well as comments between the participants focused on facilitating advancement of inquiry. Several important aspects of progressive inquiry mentioned above are implemented in the structure of the Computer-supported Intentional Learning Environment, CSILE, and corresponding cognitive practices. CSILE is designed to engage students in question-driven inquiry and generating and improving their own intuitive explanations and searching for scientific information. 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 were guided to categorize their computer entries a way that corresponds to moves in the knowledge-seeking or interrogative process, such as Problem, My Theory, New Information, I Need to Understand (subordinate question), Plan, and Comment.

Method

The study was based on an analysis of CSILE students’ written productions, posted to CSILE’s database. CSILE has been used as a part of normal education by these elementary school students. The study material represented data occurring naturally while the students carried out their study projects, working with CSILE. The study material represented productions of 28 grade 5/6 students over a period of one academic year at an inner-city public school in Toronto, Canada. The study was
entirely based on a conceptual as well as qualitative and quantitative analysis of students’ written productions from CSILE’s database, and, therefore, it did not give direct information about psychological processes involved in CSILE use. The rationale of the study was that CSILE enables analysis of sustained processes of inquiry in authentic school environment, processes which are very difficult to study by using traditional experimental designs.

The study was intended to analyze CSILE students’ inquiry through examining the nature of intuitive explanations generated and scientific information sought by the students. The students were engaged in studying human biology, such as how cells or the circulatory system function. They were systematically guided by their teacher to generate their own hypotheses, conjectures, and theories about the biological phenomena being investigated. The intuitive theories generated by the students did not generally represent accepted scientific views. The teacher did not, however, expressly correct the students’ wrong theories or misconceptions but tried to guide the students themselves to improve their theories. This pedagogical design allowed analysis of the nature and development of students' intuitive theories.

**Qualitative Classification of CSILE Students’ Explanations**

CSILE students’ productions (research questions, intuitive and scientific explanations, written comments) were analyzed at multiple levels by using qualitative content analysis (see Chi, 1997). The participants’ postings to CSILE’s database (notes) 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 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 main categories of CSILE students’ knowledge – their research questions and knowledge ideas – were classified independently from each other. Research questions were separated from the students’ postings by following explicit labeling such as “Problem” or “I Need to Understand”. Knowledge ideas consisted in intuitive knowledge and scientific information generated by the students. The Inter-coder reliabilities of the classification were satisfactory so that the agreement coefficient exceeded .70 across all variables to be reported here.

The epistemological nature of the students’ research questions was analyzed 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 many cases also what questions require articulation of explanation; e.g., “what is inside a cell?”

In answering their research questions, CSILE students searched for different 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; i.e., provided information that he
or she or the group as a whole was not yet familiar with. “Intuitive explanations” refers to notes in which a student generated his or her own working theory about the phenomenon in question.

In order to analyze the epistemological nature of knowledge produced by the CSILE students, mean level of explanation was analyzed across students’ productions representing their intuitive conceptions and scientific information sought by them. Each knowledge idea constructed by the students to answer their research questions was classified using a five-step scale starting from (1) separated pieces of facts to (5) explanation. The actual material utilized while developing this assessment instrument was much larger that reported here. It included also productions of another CSILE class in which students worked with biology and produced knowledge that was at a lower explanatory level than in the case of the present class (see Hakkarainen, Lipponen, & Järvelä, 2002; Hakkarainen & Palonen, in press).

**Level 1. Separated pieces of facts.** A rating of 1 was assigned to CSILE students’ knowledge ideas representing either simple statements of facts or lists of facts with hardly any connecting linkages that would have provided some coherence or integration. Ideas representing separated pieces of facts usually represented answers to corresponding fact-seeking questions, for example,

Some realated (sic!) animals are, Sponges, Venusus Flower basket, Portuges man of war, Sea Anomes, Jelly Fish and Hydra (Student 29).

**Level 2. Partially organized facts.** A rating of 2 was given to ideas that represented loosely connected pieces of factual information. These ideas can be
separated from level 1 ideas because the former represented more organized descriptions about empirical phenomena and certain linkages were provided to connect pieces of facts together. The following example demonstrates how lists of facts were connected with more general background ideas such as functions of cells or structures of simple-celled animals. Nevertheless, at this level information was still produced in a list-like fashion, for example,

MT: I think that there are many different kinds of cells with totally different functions. I only know the names of some cells, the red blood cell, white blood cells, muscle cells and nerve cells. (S17)

Level 3. Well-organized facts. A rating of 3 was assigned to ideas in which factual information was introduced in a rather well-organized way. These ideas were used to describe different biological and physical phenomena without, however, connecting the description with deeper causal or explanatory relations. Although it was sometimes possible to reconstruct an explanation-seeking question that would be answered by level 3 ideas, no explicit explanation was actually provided, such as,

NI: The apsorptive cell is located around the epithelial cells and small intestines. Its purpose is to eat and/or collect food molecules, salts and water that are in the body. Absorptive cells need to use their entire cell structure to move around. (S17)

Level 4. Partial explanation. A rating of 4 was assigned to ideas that represented some characteristics of explanation but the content of the explanation was
rather limited or only partially articulated. Typical for these ideas was an explicit attempt to answer an explanation-seeking question and produce an explanation. However, certain important aspects of the explanation were left open so that the explanation had apparent weaknesses. However, regardless of limitations of the explanatory sketches provided, these productions can be separated from level 3 ideas, which clearly did not go beyond introducing factual or descriptive information.

I think that the nerves control themselves and that they send messages to the brain so that the brain can control the body. The nerves are just there to tell the brain what is happening because the brain can't be everywhere at once. (S16)

**Level 5. Explanation.** A rating of 5 was assigned to ideas in which a relatively well-elaborated explanation was provided. This rating presupposed neither correctness nor coherence of explanation; it was enough that a student clearly constructed and elaborated his or her own intuitive explanation or introduced a scientific explanation, for instance,

MT: I think that cells reproduce because we couldn't live on the two cells that we start out as. Somehow the cells know that they have to reproduce. I think that how they reproduce is the cells start to split and the parts of the cell also start to split and they go to the new cell. It's kind of like there are two cells stacked on top of each other and then the one cell just moves off the other cell and you have two cells. Now you have two cells and both those cells reproduce giving you four cells and so on. (S5)
Further, in order to examine contents of the explanations generated by the CSILE students more closely, occurrences of explanatory concepts used by them to construct and warrant their explanations were coded both in biology and physics. CSILE students’, however, appeared to use also certain empirical concepts in an explanatory role. In order to examine the nature of CSILE students’ intuitive explanations, these everyday concepts were regarded as explanatory. From each explanation, only one and the most important explanatory concept was coded. Due to the segmentation of the students’ postings, there were usually only one central explanatory concept in each explanation classified.

Further, three widely recognized professors of the philosophy of science from well-known Canadian and Finnish universities were asked to evaluate advancement of inquiry for the CSILE students by assign two cases of CSILE students’ group work in biology. Two of the philosophers of science have extensive background in studying conceptual change in science, including actual investigation of the history of science. The third philosopher had engaged in extensive cultural studies beyond his highly regarded work in the philosophy of science. It was assumed that practicing philosophers of science would be in a position of genuinely appreciating young children’s inquiry process in which the students faced conceptual problems analogous with those of actual scientific discoveries. It is very difficult not to take scientific theories to be self-evidently true after being created; the rationale of asking the philosophers of science was based on an assumption that they would have a lower propensity of trivializing inquiry in this way. The experts were given transcriptions of two cases of CSILE students’ groupwork in biology and two cases in physics. They were asked to estimate whether students’ process of inquiry was progressive in nature.
leading to advancement of their conceptual understanding (progressive nature of inquiry) as well as the cognitive value of their research questions and peer interaction. The instruction stated that “While evaluating the cases, you are asked to take into consideration that the productions represent very young students’ first attempts to intentionally examine the physical and biological phenomena in question.”

Results

Progressive Inquiry in Biology

The task of the students in the Human Biology project was to collaborate in small groups to understand biological processes in the human body. The instruction was to "choose a broad area of interest (for example, the cell, or the circulatory system), then define some problems in your area of interest (for example, how do cells make protein or what happens when a heart attack occurs" (teacher). The students themselves were responsible for finding relevant scientific information about the problems.

The students produced 579 knowledge ideas in biology; 61% (f=355) of them represented intuitive theories and 39% (f=224) scientific theories. The level of explanation scale was used to assess the students’ productions, and indicated that their productions were at a relatively high explanatory level (M=4.1, SD=0.69). In other words, the students did not just produce fragmentary knowledge but aimed at explaining the problems being investigated.
The students’ research questions, which were analyzed separately from their explanations, were explanation oriented in accordance with their explanations. The students produced 252 questions out of which 89.7% (f=226) were explanation seeking and 10.3% (f=26) fact seeking in nature. The questions generated by students consisted in why questions (9.5%, f=24), how questions (38.5%, f=97), what questions (33.5%, f=85), and other (e.g., indirect questions). It is remarkable that the questions generated by the students were so consistently focused on advancement of their inquiry; in many cases young students tend to create only fact-seeking questions (Hakkarainen, et al., 2002).

An analysis of intuitive biological explanations generated by students revealed that they mastered functional explanations, frequently explaining both biological functioning and malfunctioning. Discussion concerning "what happens if your immune system does not work?", initiated by S9, demonstrated how functional explanation was used to explain how a biological system may or may not work properly:

MT: If your immune system is not functioning properly, you could die from almost anything because your immune system is what keeps diseases out of your body and fights the germs. If your immune system is not fighting the germs, then they can do horrid damage to your body. (S12)

I think red blood cells don't have a nucleus because all they have to do is circulate through the body. They don't have much of a job. Of course, they're
blood and without blood we wouldn't be able to live but I don't think that red blood cells need a nucleus. (S18)

Often the students’ intuitive functional explanations, however, diverged from scientific ones; while the latter explain biological processes by functioning of cells, the former often relied on more global observable functions of the human body. The CSILE students' intuitive biological explanations appeared to frequently be intentional in nature; i.e., intentional terms were used to explain biological functions (compare Carey, 1985). Students appeared to attribute psychological decision-making processes to biological objects or at least used a vocabulary of intentionality to conceptualize biological phenomena.

I think that cells reproduce by starting off as small shapes and eventually get bigger and as soon as they think that they're done then they decide to part (split) because they want to make more cells and if they don't reproduce then we would die. (S11, my emphasis)

MT: I think that a nerve cell is a kind of cell that always wants its way so if it wanted to move your right arm than an arm cell would send a message to your brain saying that it would want to move the arm. ... (S11, my emphasis)

An analysis of CSILE students’ intuitive explanations revealed that 46% (n=13) of the students used intentional concepts in some of their biological explanations. In the course of the project practically all students succeeded in overcoming the intentional nature of their biological explanations and arriving at more adequate biological explanations. The analysis indicated that three quarters of
the students succeeded in attaining considerable deepening of explanation, i.e., finding relevant explanatory concepts and scientific biological explanations in the course of their inquiry. Many students transited from describing external functions to explaining biological processes in terms of cellular and subcellular phenomena. Table 2 displayed the frequencies of scientific biological concepts in CSILE students’ explanations.

Insert Table 2 about here

In their process of inquiry, the students adopted advanced scientific conceptions such as cellular explanations of the biological phenomenon being investigated. Adoption of a framework of cell biology appeared, however, to provide considerable conceptual challenges. A problem of explaining biological processes through the students’ own self-regulated inquiry seemed to be a difficulty of understanding cells and their role as a basic unit of living things. A clear conceptual difficulty was to explain and understand biological processes at the level of cells. The following transcriptions illustrate the problem:

I think that cells don't keep you alive entirely but without them you will probably get sick and die. (S2)

I think that the body has smaller and more cells because some parts of the body only have room for small cells. For instance I think that the ear would need small cells because it has no room for large cells. (S17)
Nevertheless, three out of four CSILE students succeeded in finding explanatory scientific information that helped them to understand the functioning of the human body in terms of cells. They were also able to understand and meaningfully use this information in their process of inquiry. Nevertheless, the above analysis focused on examining categories of CSILE students’ inquiry and addressed only frequencies of certain type of productions. In order to provide a deeper picture of CSILE students’ inquiry, the following analysis focus on describing two representative case studies of the students’ inquiry. These case studies indicate how the students were really engaged in an intentional effort to understand biological phenomena but also encountered enormous conceptual problems under the way.

Case Studies of CSILE Students Inquiry in Biology

In order to provide a vivid image of CSILE students’ collaborative inquiry, two cases of CSILE students study projects in biology will be examined as follows (see http://www.helsinki.fi/science/networkedlearning/material/csclmaterial.htm for complete transcriptions of these two cases). The former represented neuroscience and the latter visual perception. The productions were posted to CSILE environment’s database over a period of approximately four weeks while students participated in the Human Biology project. Notice that the students’ postings did not necessarily follow one another immediately.
How Does the Brain Function?

A study group that consisted of three students pursued a question concerning how the brain works. The group advanced from a rather general principal question concerning what kinds of cells there are in the brain to more specific ones. The principal research question of the group was "What kinds of cells are in the brain and how do they differ from other cells?" (S27) The students started from rather vague theories according to which the brain cells are "more developed" (S7) or "bigger" (S26) than other cells of the body. Examination of new scientific information suggested that there are two types of brain cells; neuron cells and glial cells. This piece of information introduced by student 27 was taken as the basis of subsequent activity of the whole group.

New information seemed to make articulation of more specific research questions possible: “How do glial cells hold the brain together?” (S7) and further, "what do neuron cells look like and how do they work?” (S7). The advancement of the present study group’s inquiry appeared to be significantly facilitated by a comment that requested the group to explicate what they meant by being cells being more developed: “When you say that you think brain cells are more developed do you mean that they are cells that are completed in knowledge or are more complicated that most cells?” (S20) Also the teacher’s request of looking at how cells differ in function was likely to push the group to pursue its’ inquiry further: “I think this is a very interesting note. I was wondering if you were going to consider how the cells differ in function? For example, do they have any special structures that enable them to communicate with other cells?”
Analysis of the process of inquiry suggests that articulation of more elaborated research questions and theories is dependent of new relevant information. Information that makes further progression possible contains usually new theoretical or explanatory concepts or principles, which challenge a student's initial assumptions. Factual or purely empirical information is not equally effective, leading in many cases to a dead end. For instance, information about the number of neuron cells in the brain remained completely useless, and the group progressed to another direction. Consideration of scientific theories as new information was an important strategic decision: it implies that those theories should not be adopted as such but constructively used on the basis of one's own background assumptions and research problems (see Scardamalia, 2002).

The present case indicates that interaction between problems, information and theories is extremely important for progression of epistemic inquiry. Hence it may be important to emphasize that explanation as an object of inquiry does not mean that a search of information would not be important. This was noticed by a student who pointed out that one need to do research and look for relevant scientific theories in order to make his or her theories to progress.

**How Does the Eye Function?**

Another group studied how the eye functions; in particular they relied on an analogy between the eye and camera provided by a student from the class. The problem to be explained was why humans see everything right side-up although the “picture” projected on retina is up-side down. Explanations provided by the group
represented two different theories from the very beginning, and the members of the group moved back and forward between these alternatives. A part of the group argued that the brain sees "pictures" and very closely followed the analogy between an eye and a camera in relation to transformation of the picture. Other members of the group argued that the brain sees "waves." The wave theory and the picture theory provided different kinds of explanations for the problem of the up-side down picture on the retina.

Explanation of the fact that the picture of one’s environment is up-side down on one’s retina was quite difficult from the viewpoint of the 'picture' theory, without any knowledge of optics or physiology. This problem was solved by construction of the following theories: “[My theory] Is that an eye sees a picture backwards then a sort of lens turns it right-side up and brings the message to the brain (S28)”. An further “I think that on the way to the brain there is another lens the same as the one on the outside of the eye but upside down so you see the picture right-side up” (S10).

But the hypothesis that there has to be another lens which turns the picture right-side up again was challenged by several comments which asked the students to explain in a detailed way how these lenses would work: “You have written a good theory but you must include more about how the lens turns the picture right side up” (S14).

The students who represented the wave theory of visual perception explained the fact that the picture is up-side down on the retina by arguing that the picture is transformed into "strange waves" which turn the picture right-side up again so that the
brain sees the picture right-side up: “I think that the eye sees objects upside down and while going through the eye it turns the picture right-side up by sending it in strange waves to the brain so that the brain sees it the right way” (S14).

The wave theory was not considered as a very plausible alternative in the beginning. Some students even argued that it does not make sense at all to say that we see only lines and shadows: “In your theory you say that there is a filter behind the eye. … Do you mean that everything we see is little waves of different colors and shades? I don't agree with what you are saying” (S20). Student 14 had a hard time explaining how these "strange waves" function, yet he represented the theory consistently from the beginning to the end. A productive solution involved a change of analogies: from a standard camera to a TV or video camera. The latter instruments transform pictures into electrical pulses.

The perception group’s inquiry is very interesting in many ways. It demonstrates how CSILE students’ progressive inquiry guided them to make theoretical inferences and hypotheses for purposes of explanation. Nothing in our observable environment forced them to postulate internal organs, mechanism and processes which may explain the problem being investigated. Their hypotheses did not appear to be unconstrained or wild guesses, but made perfect sense taking into consideration the nature of the problem and their limited background knowledge.

Social interaction forced the students to further articulate theories that were initially too general, and in this process it soon became evident whether a given theory could be further elaborated or should be abandoned. The theory of two lenses
was a meaningful hypothesis, but the students did not find any support for the theory from scientific literature. Hence they were forced to reject the theory and accept the wave theory instead. Finally the students got new scientific information which explained how humans have learned to function on the basis of an up-side down "picture" on the retina, and that we learn quite quickly to function effectively even when using prism-lenses that turn the visual field upside down.

Mechanism of CSILE Students Conceptual Advancement

Both of these groups appeared to follow the pattern of interrogative activity (see Hakkarainen & Sintonen, 2002). The process included formation of new and more specific research questions, which in turn direct the process. Pursuit of students’ own intuitive explanations and search for explanatory information appeared to make new questions accessible to the students. There appeared to be several lines of inquiry (brain cells, functional organization of the brain, visual perception) that the students pursued through several deepening steps with the help of new scientific information.

Another mechanism of conceptual advancement was a comparisons between intuitive and scientific theories. 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. Often the comparison was mediated by the other students’ comments, a teacher’s request for explication of explanatory relations, or new information found by a student.
My theory was wrong. A chemical synapse is when the message has to go through the axon of one nerve cell and then switches to that of another nerve cell to get to its destination. The is a tiny space between the two cells which is filled with a substance we call the neurotransmitter. ... (S16)

Postings in which the students' commented on each other's research questions formed a clearly identifiable category of distributed regulation of inquiry. In their comments on research questions, CSILE students were requesting each other to select manageable and specific research questions instead of general questions about the topic. Moreover, pointing to an unanswered question was an important way of requesting deepening inquiry that was frequently used by the students:

C: S9 and S12 you are not quite answering your note. Your problem says: Why do you get some diseases once, and some diseases many times, and your theory is just telling information about what happens when you only get it once. (S13)

Comments that were focused on requesting the fellow students to explicate, clarify and further articulate their theories appeared to represented distributed regulation of inquiry. These comments pointed to inadequate presuppositions or other weaknesses in theory. Frequently, these communicative ideas may also contain a request for explicating or clarifying the meaning of complex concepts such as "mitochondria" or "lysosome." Requests for explanation appeared to push the student receiving the comment to do more research and find new information in order to further his or her progress in theoretical understanding. 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):

You said in your note that you thought the cell functions on the air we breathe in. But how? What's the process? (S3)

Expert Evaluation of CSILE Students’ Conceptual Advancement

The experts agreed that the CSILE students were making significant conceptual advancement in their biology studies. According to their evaluation, this advancement relied on the interrogative pattern of their research questions as well as peer interaction that provided analogies and requested the participant to pursue their questions further. The experts noticed that CSILE students did not move randomly from one to another research question; the student-generated research questions formed a pattern, which allowed the students to answer their main research questions by generating a series of more specific questions. As a criterion of conceptual advancement, expert A referred to generation of such subordinate problems:

... a one of way of assessing a cognitive value of questions is say, well, if you have an initial big question, then the small questions, so to speak, are more specific ones, as you are getting more information or a particular purpose. ... I can see a pattern actually here, that is how it works. Because if you have a need for more information, you can always formulate that as a small question. Of course, the main thing, if you look at the process, is to find the questions that are likely to bring you closer to the initial question.
In the context of the visual perception case reported above, expert B evaluated the research questions as very useful:

I presume that this was one of the student-generated questions, where is the eye’s control panel located. I guess this is using some sort of an analogy to a computer, which could be, it is like a robot eye, and it has got to have a control panel. But S14 comes in with a much better question, how does the eye function. And then he gets down to a specific question how the eye sends pictures to the brain. ... And then more specific, yeah, how parts of the eye help sending messages to the brain. So in this case it really does seem that S14 comes in and reroutes the investigation from the potentially problematic question S28 would have started with. So I think that these are very good questions that they are asking. ... The misleading question, the eye’s control panel, is immediately rerouted to more effective. So that looks good.

The experts acknowledged that the students were beginning to propose theoretical explanations concerning the biological problems being investigated. Particularly important for furtherance of inquiry was the provision of analogies that made new conceptual points of view available to the students receiving comment. Expert A stated that “… I think the interaction goes along all right. I mean having comments from somebody else who have 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.” In the context of the Eye case, expert B asserted,
An analogy is useful for understanding, for instance like the Eye and camera, but they do not tend to be enormously unifying, they can lead to unifying pictures, but often they are more narrow. So as long as you are stuck at the analogical level, it tends to make things, not fragmented because you are finding coherence with other things that are better understood, but it is not a general theory … On other hand, they are getting to general optical things so that it is not fragmented. But there is not a general theory of vision emerging, an information-processing view. But I think that they are moving towards an information-processing view that ties things together.

Expert B estimated 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.” Expert B pointed out that CSILE students were providing lots of information to each other through peer-interaction. He stated that although it was difficult to assess how much conceptual change was achieved by the students “here does seem to be [going on] the sort of things in which peer-collaboration is likely to foster conceptual change.”

About the Neuron Cells Case, expert B stated that “What’s nice about this one, it is not just in the beginning, it looks like ‘here is my theory, here is my theory’, but they are not staying at that level, each of them is going away and acquiring information and then feeding it back to the others so ... I think in that case the process looks very useful. ... In this case I am more confident [about conceptual advancement], because of the new concepts they are bringing in that weren’t there in the beginning.” He stated that the students were “really pretty focused” on the
neuron cells case, moving towards more advanced understanding “without wandering around.” According to his evaluation, the students were able to “spontaneously generate the modularity theory of mind.” He concluded the evaluation of the Neuron Cells Case by stating, “This one seems to be stronger in the question of conceptual change, because it looks like a lot of new concepts are introduced by different students as they go along … Not that they have a global theory about how it functions but they are moving toward that direction.”

Expert A concluded that even if it was difficult to estimate whether the students achieved strong restructuring of their conceptions, in the process conceptual enrichment definitely happened. Expert B made a distinction between radical and conservative conceptual change. In the former case, one explicitly rejects some existing beliefs, but in the latter one acquires new concepts. The former kinds of changes “are rare even in the case history of science, and you are not likely to expect them to happen very often in children’s education. So it is more likely that there was conservative conceptual change.“

Expert C’s evaluation was more critical as well as more cursory than the evaluations of the two other experts. He did not consider some of the students’ intuitive theories to be very valuable because those were not true. Further, he pointed out that it is difficult to assess advancement of a group in which some students were making a lot of progress and the others were not. As a whole, however, expert C agreed with the other experts that many of the CSILE students’ intuitive theories were valuable, that the students discussed advanced ideas, and that at least some of them
were making considerable progress in their process of inquiry. He also addressed the question of whether the students went deeper into the topics in question:

to some extent yes, because there was this new information coming that helped to help correct some of them, but on the other hand the discussion went on quite rapidly from one topic to another. So, it would have, I think, been instructive to learn from mistakes in a sense that when you have a wrong theory you would show in detail why it is wrong, why it goes to a wrong direction.

To conclude, the three philosophers of science agreed that CSILE students’ process of inquiry in biology was progressive in nature, even if one of them assessed their conceptual advancement to have been only limited. Even if the students were not doing strong conceptual restructuring, the students’ conceptions were becoming more and more enriched through adoption of explanatory scientific conceptions.

**Discussion**

The analysis revealed that the CSILE students systematically generated their own intuitive theories and searched for explanatory scientific information to answer their research questions. Analysis of CSILE students’ intuitive explanations of biological phenomena indicated that these were frequently intentional in nature. The students were, however, able to move towards scientific explanations that account biological processes in terms of cells. Thus, the results furnished evidence within specific topic areas that children in appropriate conditions are indeed able to go beyond the surface-level phenomena though generating progressively deepening
explanations. There mere existence of these kinds of processes at the elementary level education is a significant achievement. For students to participate in an explanation-driven process of inquiry focused on comprehending very complicated biological phenomenon is a significant cognitive achievement.

Nevertheless, it is somewhat difficult to assess to what extent the students made conceptual progress and really understood scientific conceptions they worked with, as pointed out by one of the philosophers of science. One of the experts was somewhat more skeptical than the others in relation of assessing the students’ conceptual advancement. Notwithstanding methodological problems involved in assessing conceptual understanding by relying on written conceptions, there is a more principal reason for acknowledging that the students’ advancement was only moderate. The meanings of scientific conceptions are dependent on complex systems of other conceptions (Duhem-Quine hypothesis). It is clear that the students achieved at the best only partial understanding of some relevant conceptions without adopting coherent biological frame of explanation. There were a few indications, and this seems understandable, that the students occasionally relied on the verbatim form of scientific texts they were studying while reporting their findings. It is, simultaneously, clear that they were engaged in genuine inquiry guided it by their own questions and need to understand. In other words, there were no indications that the students would have replaced their own inquiry with reproduction of ready-made pieces of scientific knowledge; this is a commonplace phenomenon even in the best schools. In contrast to the results of the present study, there are a large number of other studies indicating how knowledge produced by young children is often very fragmentary in nature (DiSessa, 1988; Hakkarainen et al., 2002; Hakkarainen & Palonen, in press).
The students’ intuitive explanations were based on generalizations of the properties of our perceptual world to explain something outside direct perception. Regardless of apparent limitations, the students’ conceptions were not trivial. CSILE students’ reflected an attempt to reduce an unfamiliar phenomenon to a more familiar one, such as the functional and perceptual environment of human activity. Correspondingly, scientific explanations are based on an attempt to understand a new phenomenon by subsuming it under already familiar phenomena, i.e., well-established scientific theories. 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. Naturally, CSILE students’ intuitive explanations lacked generality, and the range of their explanation was quite limited.

It is a general finding of psychological research on conceptual change that young children tend to attribute intentions to objects, events or processes which are not actually so. The use of intentional explanations in biology projects appeared to represent a transition from psychological to biological explanations, a phenomenon discussed by Carey (1985). In the background of CSILE students’ intuitive explanations seems to be the students' difficulty in selecting an appropriate frame of reference (see Dennett, 1984). The analysis of CSILE students' conceptions suggests that the students frequently had difficulties understanding at what level natural phenomena are explained in science. They had problems understanding how the elementary unit of explanation is a cell in biology. In many cases, the students treated these basic elements of living and non-living kinds as representing a quite high-level
structure of things. For example, it was common for the students to use an individual cell as the unit for explaining problems of seeing, hearing or thinking. The students apparently did not have epistemological knowledge of appropriate level of explanation and of justification of one’s theory.

Cognitive research on educational practice aims at facilitating a research-like process of inquiry in which progressive generation of the students’ own research questions, intuitive theories and search for explanatory scientific knowledge play an important role. However, participation in scientific practices of inquiry in education appears to be constrained by an empiricist epistemology sometimes tacitly assumed by educators. Knowledge processing in elementary level education is frequently fact-seeking in nature and many teachers seldom encourage students to generate their own explanations or theories. The present study underscores the importance of educators encouraging students to engage in explanation-driven process of inquiry, to generate hypotheses and theories, even if initially mistaken. The present analysis indicates that in order to be successful, educational study projects should explicitly be designed to facilitate adoption of explanatory or theoretical knowledge that enables an agent to make sense of the empirical phenomena being investigated. In order to facilitate higher-level practices of inquiry in elementary-level education, a substantial epistemological change in pedagogy and in the wider culture of schooling is needed.

The present investigation encourages science educators to engage young students in their own inquiry guided by their questions and tentative theories of the problems being investigated. While trying the promote these kinds of practices in elementary-level education, it is essential to understand that the results reported here
emerged after several years of deliberately working for developing inquiry culture and creating technological tools for facilitating it. Computer-supported learning environments do not, notwithstanding of their sophistication, do not as such produce an inquiry culture without the teacher’s systematic effort to subsume all classroom activities to inquiry and, thereby, creating supporting social infrastructure for it (Bielaczyc, 2001). It is essential, further, that the teacher is constantly trying to learn from and go beyond his or her earlier achievements, systematically work for social transformations that help all participants of the learning community to focus on and engage in inquiry activities (Paavola, Lipponen, & Hakkarainen, 2002).
References


Progressive Inquiry in Biology …


### Table 1.
Explanatory Level of CSILE Students’ Knowledge Ideas in Biology

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### Table 2.
Explanatory Concepts Used in Biology

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