INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

Bell & Howell Information and Learning
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA

UMI
800-521-0600
EPISTEMOLOGY OF SCIENTIFIC INQUIRY
AND COMPUTER-SUPPORTED COLLABORATIVE LEARNING

by

Kai Pekka Juhani Hakkarainen

A Thesis submitted in conformity with the requirements
for the Degree of Doctor of Philosophy
Department of Human Development and Applied Psychology
University of Toronto

© Copyright by Kai Pekka Juhani Hakkarainen 1998
The author has granted a non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of this thesis in microform, paper or electronic formats.

The author retains ownership of the copyright in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author’s permission.

L’auteur a accordé une licence non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de cette thèse sous la forme de microfiche/film, de reproduction sur papier ou sur format électronique.

L’auteur conserve la propriété du droit d’auteur qui protège cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

0-612-41435-3
ABSTRACT

The problem addressed in the study was whether 10- and 11-year-old children, collaborating within a computer-supported classroom, could learn a process of inquiry that represented certain principal features of scientific inquiry, namely 1) engagement in increasingly deep levels of explanation, 2) progressive generation of subordinate questions, and 3) collaborative effort to advance explanations. Technical infrastructure for the study was provided by the Computer-Supported Intentional Learning Environments, CSILE. The study was entirely based on qualitative content analysis of students' written productions posted to CSILE's database.

Five studies were carried out to analyze CSILE students' process of inquiry. The first two studies aimed at analyzing changes in CSILE students' culture of inquiry in two CSILE classrooms across a three-year period. The results of the studies indicate that the classroom culture changed over three years following the introduction of CSILE. The explanatory level of knowledge produced by the students became increasingly deeper in tracking from the first to third year representing the first principal feature of scientific inquiry. Moreover, between-student communication increasingly focused on facilitating advancement of explanation (the third principal feature). These effects were substantial only in one classroom; the teacher of this class provided strong pedagogical support and epistemological guidance for the students.
Detailed analysis of this classroom's inquiry, carried out in the last three studies, indicated that with teacher's guidance the students were able to produce meaningful intuitive explanations as well as go beyond the functional and empirical nature of their intuitive explanations and appropriate theoretical scientific explanations (the first principal feature). Advancement of the students' inquiry appeared to be closely associated with generation of new subordinate questions (the second principal feature) and peer interaction focused on providing and requesting explanations (the third principal feature). Expert evaluations of three widely recognized philosophers of science confirmed the progressive nature of the students' inquiry as well as the cognitive value of their research questions and peer interaction. Conclusion: it is entirely possible for children, with computer-support for collaborative learning and appropriate teacher guidance, to pursue processes of inquiry that exhibit the principal features of mature scientific inquiry.
ACKNOWLEDGMENTS

Most of the present research was carried out at the Centre for Applied Cognitive Science, Ontario Institution for Studies in Education. I would like to express my warmest thanks to my supervisor Professor Carl Bereiter. Many aspects of my work rely on his theoretical insights; he has a special ability to always approach familiar problems at more complex levels. It has been quite a challenge to follow his thinking over the last six years. For me, he exemplifies the deep and critical thinking so necessary for the progress of cognitive science. I owe a great deal also to the members of my committee. I would like to thank Professor Marlene Scardamalia, whose magnificent lectures and continuous enthusiasm encouraged me to start studying CSILE learning in the first place, and whose comments helped me to restructure the present study. I am also grateful for Keith Oatley, who has introduced me to CACS, continuously encouraged me to go deeper, and been always so supportive, as well as critical in the most constructive way. His comments have been enormously helpful in the development of the current thesis. My other most inspiring teacher was Professor David Olson, who provided intellectually the most exciting partner in philosophical discussion. The time in Canada was crucial in the development of my scientific thinking, and I had a chance to meet many extraordinary people. I am very grateful for the opportunity to work at the CACS and to make contact with a community so appreciative of philosophical and theoretical thinking, as well as the application of cognitive theories aimed at improving cognitive practices in various fields.

At the CACS, I had a privilege to study with many wonderful people. My participation in CACS’s Charles Pierce Study Group, together with Ed Johnson and Hal White, made my studies much more exciting, as well as influencing on the present study in many ways. I am particularly in debt to Hal White, who not only provided a companion of theoretical discussion but helped me to improve my English as well. I wish to thank Elaine Coleman, Wilks Keefer, Jun Oshima and, particularly, Wing Yan Pong for our discussions and friendship. I would like to thank also all members of the CSILE group who in many ways helped me to carry out my study.

I lived over three years in Canada, and I am sure that this period will always be the best part of my life. I would like to thank all my Canadian friends, particularly Darlene and Cecilia with their families without whom our life in Canada would not have been so happy, socially rewarding, and left so many permanent relations of friendship.
Although I started this study in Canada, a main part of the data analysis and completion of the research was carried out at the Department of Psychology, University of Helsinki. I would like to thank my department and particularly the head of the department, Professor Göte Nyman for his support. From the very beginning of my studies, I have been closely collaborating with Dr. Kirsti Lonka who is currently the Director of Development and Research Unit, Learning Centre, Faculty of Medicine, University of Helsinki. Without her example, it would not have even come to my mind that it would be possible to continue my studies at the University of Toronto. Kirsti's encouragement and support has been very important for development of my scientific career; I have a great deal of respect for her insight and depth of thinking. We started our studies together in cognitive psychology with Professor Valde Mikkonen. I have always admired his ability to help me to clarify my research problems and transform theoretical and philosophical ideas into workable empirical research programs. Without his encouragement, I might not have been able to start pursuing a research career. In addition, I am grateful for all the other members of the faculty, such as Dr. Elisabeth Service, Dr. Pentti Laurinen, for many critical discussions over the past years that have pushed me to deeper into problem. Further, I am grateful to Associate Professor Lauri Tarkkonen, who gave me many ideas concerning how to deal with messy data and present results of my statistical analyses. All statistical mistakes are, however, my own. I am also grateful for my former fellow students and current colleagues Olli Louhimo, Sami Mynttinen, Hannu Tiitinen, Pertti Ollinheimo, and Ari Ollinheimo for many challenges of learning that we faced together.

I am currently working on computer-supported collaborative learning in Finland in the context of the Schools of Helsinki 2001 project, coordinated by the Information Technology Center for Schools. I would like to thank my collaborators in CSILE research in Finland, particularly Professor Erno Lehtinen, Dr. Sanna Jarvela, MA Lasse Lipponen, MA Liisa Ilomäki, MA Hanni Muukkonen, and M.Ed. Marjaana Rahikainen. Without their support and patience, this study would not have been finished. I would like particularly to express my gratitude for an opportunity to collaborate with the Helsinki City Department of Education, and thank particularly Chief Advisor Irmeli Halinen, and chairwoman of the pedagogical committee of the Schools of Helsinki 2001 project Tuula Matikainen: their contributions on supporting Finnish research on the CSCL has been very important. An opportunity to test CSILE philosophy in schools and transform my thought into the language of teachers, has been very important for the completion of the present research, and shaped my thoughts in many ways. It has been a privilege to work with so many enthusiastic teachers and principals; without pedagogical development projects I have been involved with this work would not have been finished in its
current form. It has also been instrumental in initiating the European research network for studying collaborative learning networks (CL-NET). In this European collaboration, I have been happy to have an opportunity to work closely with professors Robert-Jan Simmons and Stella Vosniadou as well as Dr. Silvia Caravita, Dr. Beatrice Ligorio and, particularly, Dr. Frank de Jong.

Financially, this work has been made possible by support from the Academy of Finland, Ontario Institute for Studies in Education, Finnish Cultural Foundation, and Kordelin Foundation. I am very grateful for their support.

I would like to express my heartfelt appreciation to thank my mother MA Helena Hakkarainen who has always believed in and encouraged me and provided an expert model of the sort of commitment needed for serious research. Further, I am very grateful for the support of my father Voitto Hakkarainen, as well as my sisters Anna and Tiina and brother Tuomas who have helped me in so many ways. I also appreciate the support of my parent-in-law, Mrs. Irma Seitamaa and sister-in-law, Professor Pirkko Seitamaa-Oravala.

Finally, I am most grateful for my wife Lic.Ed. Pirita Seitamaa-Hakkarainen who has been my closest collaborator in pursuit of various treads of research for so many years. Her merciless although constructive criticism has helped me to transform originally very fuzzy ideas into more clarified ones. Without her support and our mutual understanding, it would not have been possible to pursue our doctoral theses simultaneously. I am particularly grateful to my children Otto and Antti for their patience, while they may have been thinking that this work would never be finished. My youngest child Aino, who asked “why” at 18 months old, help me to believe in the future.

Toronto, June 23, 1998

Kai Hakkarainen
# TABLE OF CONTENTS

1. **INTRODUCTION** ............................................................................................................. 1

2. **THEORETICAL FRAMEWORK** ....................................................................................... 5

2.1 Facilitating Practices of Scientific Inquiry in Education .............................................. 5

2.2 Elements of Knowledge-seeking Inquiry .................................................................. 12

2.3 Research Questions and the Process of Inquiry ......................................................... 16

2.3.1 Inquiry as a Problem-solving Process ........................................................................ 16

2.3.2 Pragmatics of Question-Answer Process ................................................................ 20

2.3.3 Role of Knowledge-seeking Questions in the Process of Inquiry .......................... 22

2.3.4 Text-based and Knowledge-based Questions .......................................................... 26

2.4 Explanatory Scientific Knowledge and the Process of Inquiry ............................... 28

2.4.1 Scientific Explanation as a Vehicle of Understanding ............................................. 28

2.4.2 Functional and Physical Explanations ..................................................................... 32

2.4.3 Empirical and Theoretical Explanations .................................................................. 35

2.5 Intuitive Explanation and the Process of Inquiry ....................................................... 37

2.5.1 The Role of Theories and Conjectures in Learning Science ................................. 38

2.5.2 Abduction and Conceptual Advancement ................................................................. 42

2.5.3 Nature of Intuitive and Scientific Explanations ....................................................... 47

2.6 Distributed Cognition and Process of Inquiry ............................................................. 52

2.6.1 Socially Distributed Nature of Inquiry ..................................................................... 52

2.6.2 Writing and Visualization as Cognitive Tools of Inquiry ...................................... 53

2.6.3 Social Interaction and Advancement of Inquiry ...................................................... 56

2.6.4 Cultures of Adaptive Expertise and the Process of Inquiry .................................... 60

2.7 Advancement of Knowledge-seeking Inquiry ............................................................... 65

2.7.1 Knowledge Advancement ......................................................................................... 65

2.7.2 Dynamic Change in Concept Meaning ..................................................................... 67

2.7.3 Metacognitive and Epistemological Change ............................................................. 70

2.8 Research Aims ................................................................................................................. 74

2.8.1 The First Principal Feature of Scientific Inquiry: Engagement in Deepening Levels of Explanation .................................................. 75

2.8.2 The Second Principal Feature of Scientific Inquiry: Progressive Generation of Subordinate Questions .................................................. 76

2.8.3 The Third Principal Feature of Scientific Inquiry: Collaborative Effort to Advance Explanation .................................................. 77
3. METHOD ....................................................................................................................... 81
3.1 An Overview of Method .......................................................................................... 81
3.2 Participants: Classrooms A and B ........................................................................ 86
3.3 Study Material: The CSILE Database ..................................................................... 91
3.4 Qualitative Analysis of Content: Classification of CSILE Students' Ideas .......... 96
   3.4.1 General Description of Content Analysis ......................................................... 96
   3.4.2 Classification of Knowledge Produced by CSILE Students .......................... 101
   3.4.3 Classification of CSILE Students' Comments ................................................ 110
   3.4.4 Proportional Analysis: Nature of CSILE Students' Inquiry ........................... 116
4. RESULTS ...................................................................................................................... 119
4.1 Study I: Emergence of Deepening Levels of Explanation in CSILE Students' Culture of Inquiry ................................................................. 119
   4.1.1 Analysis 1: Change in Explanatory Level of Knowledge Processed by Two CSILE Classes Across a Three-Year Period ................................. 121
   4.1.2 Analysis 2: Change in Explanatory Level of Knowledge Processed in Biology and Physics ................................................................. 129
   4.1.3 Analysis 3: Effects of CSILE Experience on Level of Explanation .............. 138
   4.1.4 Discussion ......................................................................................................... 143
4.2 Study II: Emergence of Explanation-oriented Culture of Interaction in Two CSILE Classes ................................................................................. 147
   4.2.1 Method ............................................................................................................. 147
   4.2.2 Analysis 1: Change in Practices of Peer Interaction in Two CSILE Classes Across a Three-Year Period .......................................................... 149
   4.2.3 Analysis 2: Patterns of Interaction in Two CSILE Classes .............................. 162
   4.2.4 Discussion ....................................................................................................... 168
4.3 Study III: The Nature of Intuitive Explanation and Conceptual Advancement in Physics and Biology ................................................................. 171
   4.3.1 Method ............................................................................................................. 171
   4.3.2 Nature of Intuitive Explanation in Physics ....................................................... 187
   4.3.3 Functional Explanations .................................................................................. 189
   4.3.4 Empirical-physical Explanations .................................................................. 191
   4.3.5 Theoretical-physical Explanations ................................................................. 193
   4.3.6 Conceptual Advancement in Physics .............................................................. 198
   4.3.7 Intuitive Explanation and Conceptual Advancement in Biology ................... 202
   4.3.8 The Nature of Intuitive Explanation in Biology ............................................. 206
   4.3.9 Expert Evaluation of CSILE Students' Conceptual Advancement ............... 209
   4.3.10 Discussion ..................................................................................................... 214
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.4</td>
<td>Study IV: Influence of Progressive Generation of Subordinate Questions on Conceptual Advancement</td>
<td>218</td>
</tr>
<tr>
<td>4.4.1</td>
<td>Method</td>
<td>218</td>
</tr>
<tr>
<td>4.4.2</td>
<td>Question Transformation and Advancement of Inquiry</td>
<td>223</td>
</tr>
<tr>
<td>4.4.3</td>
<td>Practices of Question Transformation and Strategy Inquiry</td>
<td>229</td>
</tr>
<tr>
<td>4.4.4</td>
<td>Expert Evaluation of the Cognitive Value of CSILE Students' Research Questions</td>
<td>233</td>
</tr>
<tr>
<td>4.4.5</td>
<td>Discussion</td>
<td>236</td>
</tr>
<tr>
<td>4.5</td>
<td>Study V: Influence of Explanation-oriented Peer Interaction on Conceptual Advancement</td>
<td>239</td>
</tr>
<tr>
<td>4.5.1</td>
<td>Method</td>
<td>239</td>
</tr>
<tr>
<td>4.5.2</td>
<td>Categories of CSILE Students' Communication</td>
<td>243</td>
</tr>
<tr>
<td>4.5.3</td>
<td>Providing Explanation as Division of Cognitive Labor</td>
<td>245</td>
</tr>
<tr>
<td>4.5.4</td>
<td>Distributed Regulation of Inquiry</td>
<td>248</td>
</tr>
<tr>
<td>4.5.5</td>
<td>Comparison Between Intuitive and Scientific Theory</td>
<td>255</td>
</tr>
<tr>
<td>4.5.6</td>
<td>CSILE's Database as a Source of Knowledge</td>
<td>256</td>
</tr>
<tr>
<td>4.5.7</td>
<td>The Cognitive Value of Peer Interaction</td>
<td>257</td>
</tr>
<tr>
<td>4.5.8</td>
<td>Expert Evaluation of the Cognitive Value of Peer Interaction</td>
<td>260</td>
</tr>
<tr>
<td>4.5.9</td>
<td>Discussion</td>
<td>262</td>
</tr>
<tr>
<td>5.</td>
<td>GENERAL DISCUSSION</td>
<td>265</td>
</tr>
<tr>
<td>5.1</td>
<td>Methodological Limitations of the Study</td>
<td>265</td>
</tr>
<tr>
<td>5.2</td>
<td>Epistemology of Inquiry and the Nature of Learning Tasks</td>
<td>268</td>
</tr>
<tr>
<td>5.3</td>
<td>Teacher Support for Advancement of Inquiry</td>
<td>273</td>
</tr>
<tr>
<td>5.4</td>
<td>The Nature of CSILE Students' Intuitive Explanations</td>
<td>278</td>
</tr>
<tr>
<td>5.5</td>
<td>Engagement in Deepening Levels of Explanation in CSILE Student's Inquiry</td>
<td>283</td>
</tr>
<tr>
<td>5.6</td>
<td>Collaborative Effort to Advance Explanations</td>
<td>287</td>
</tr>
<tr>
<td>5.7</td>
<td>The Metacognitive Nature of CSILE Students' Peer Interaction</td>
<td>291</td>
</tr>
<tr>
<td>5.8</td>
<td>Implications</td>
<td>296</td>
</tr>
</tbody>
</table>
LIST OF TABLES

TABLE 3-1. AN OVERVIEW OF THE FIVE STUDIES CARRIED OUT TO ANALYZE THE EPISTEMOLOGICAL NATURE OF CSILE STUDENTS' INQUIRY

TABLE 3-2. CSILE STUDENTS WORKING IN CLASSROOMS A AND B

TABLE 3-3 GROUPS OF CSILE STUDENTS WORKING FOR TWO YEARS IN CLASSROOMS A OR B

TABLE 3-4. CSILE STUDENTS' GENDER, AND STUDY GROUP

TABLE 3-5. FREQUENCIES OF CLASSROOMS A AND B STUDENTS' PRODUCTIONS SELECTED FOR ANALYSIS

TABLE 3-6. THE LEVEL OF EXPLANATION SCALE

TABLE 3-7. AGREEMENT COEFFICIENTS IN CLASSIFYING CSILE STUDENTS' RESEARCH QUESTIONS AND KNOWLEDGE IDEAS

TABLE 3-8. AGREEMENT COEFFICIENTS IN CLASSIFYING CSILE STUDENTS' COMMUNICATIVE IDEAS

TABLE 4-1. RESULTS OF DISCRIMINANT FUNCTION ANALYSIS OF KNOWLEDGE PROCESSING BY STUDENTS IN CLASSROOMS A AND B ACROSS THE PERIOD ANALYZED

TABLE 4-2. CELL MEANS AND STANDARD DEVIATIONS FOR MEAN LEVEL OF EXPLANATION OF KNOWLEDGE PROCESSED BY STUDENTS FROM CLASSROOMS A AND B

TABLE 4-3. CELL MEANS AND STANDARD DEVIATIONS FOR THE MEAN PROPORTION OF STUDENT-GENERATED EXPLANATION-SEEKING RESEARCH QUESTIONS

TABLE 4-4. CELL MEANS AND STANDARD DEVIATIONS FOR THE MEAN PROPORTION OF PERSONALIZED EPISTEMOLOGY

TABLE 4-5. POOLED WITHIN GROUP CORRELATIONS AMONG THE KNOWLEDGE-PROCESSING VARIABLES

TABLE 4-6. CELL MEANS AND STANDARD DEVIATIONS FOR THE MEAN PROPORTION OF STUDENT-GENERATED EXPLANATION-SEEKING RESEARCH QUESTIONS AND MEAN LEVEL OF EXPLANATION

TABLE 4-7. CELL MEANS AND STANDARD DEVIATIONS FOR THE MEAN PROPORTION OF INTUITIVE EXPLANATIONS AND MEAN PROPORTION OF PERSONALIZED EPISTEMOLOGY

TABLE 4-8. CELL MEANS AND STANDARD DEVIATIONS FOR MEAN LEVEL OF EXPLANATION AND CSILE EXPERIENCE

TABLE 4-9. MEAN NUMBER OF COMMENTS ACROSS THE PERIOD ANALYZED

TABLE 4-10. BASIC TYPES OF THE OBJECT OF CSILE STUDENTS' INQUIRY

TABLE 4-11. FREQUENCY DISTRIBUTION OF THE OBJECT OF COMMUNICATIVE IDEAS-produced by students from classrooms A and B

TABLE 4-12. THE MEAN PROPORTION OF INQUIRY-RELATED COMMENTS ACROSS THE PERIOD ANALYZED
TABLE 4-13. CELL MEANS AND STANDARD DEVIATIONS FOR THE MEAN PROPORTION OF EXPLANATION-RELATED COMMENTS 156

TABLE 4-14. EXAMPLES OF UNEXPLICATED REFERENTIAL RELATIONS IN CSILE STUDENTS' PRODUCTIONS 159

TABLE 4-15. CELL MEANS AND STANDARD DEVIATIONS FOR THE MEAN PROPORTION OF EXPLICATED COMMENT IN FOR STUDENTS IN CLASSROOMS A AND B 160

TABLE 4-16. RESULTS OF DISCRIMINANT FUNCTION ANALYSIS OF COMMUNICATION VARIABLES 165

TABLE 4-17. POOLED WITHIN-GROUP CORRELATIONS AMONG PREDICTORS OF COMMUNICATION 166

TABLE 4-18. SUMMARY OF MEASURES USED TO ASSESS CHANGE IN THE FRAME OF EXPLANATION 178

TABLE 4-19 EXPLANATORY SCIENTIFIC CONCEPTS USED BY CSILE STUDENTS' IN THE FORCE PROJECT 194

TABLE 4-20. EXPLANATORY SCIENTIFIC CONCEPTS USED BY CSILE STUDENTS IN THE COSMOLOGY PROJECT 196

TABLE 4-21. EXPLANATORY SCIENTIFIC CONCEPTS USED BY CSILE STUDENTS' IN THE ELECTRICITY PROJECT 197

TABLE 4-22. NUMBER OF STUDENTS REPRESENTING DIFFERENT DEGREES OF DEEPENING OF EXPLANATION IN PHYSICAL STUDY PROJECTS 201

TABLE 4-23. EXPLANATORY CONCEPTS USED IN BIOLOGY 204

TABLE 4-24. AN EXAMPLE OF GENERATION OF SUBORDINATE QUESTIONS IN THE CONTEXT OF NEURAL BIOLOGY 224

TABLE 4-25. AN EXAMPLE OF GENERATION OF SUBORDINATE QUESTIONS IN THE VISUAL PERCEPTION CASE 226

TABLE 4-26. FREQUENCY DISTRIBUTION CONCERNING CATEGORIES OF CLASSROOM A STUDENTS' COMMENTS 244

TABLE 4-27. CELL MEANS AND STANDARD DEVIATIONS FOR MEAN PROPORTION OF PROVIDING EXPLANATION 247

TABLE 4-28. COMPARISONS OF INTUITIVE WITH SCIENTIFIC THEORY 258
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure Number</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-1</td>
<td>Elements of Knowledge-Seeking Inquiry</td>
<td>13</td>
</tr>
<tr>
<td>2-2</td>
<td>Question Transformation and Knowledge-Seeking Inquiry</td>
<td>19</td>
</tr>
<tr>
<td>3-1</td>
<td>Categories of CSILE Students’ Productions Analyzed in the Study</td>
<td>92</td>
</tr>
<tr>
<td>3-2</td>
<td>CSILE Students’ Biological and Physical Study Projects Analyzed Qualitatively</td>
<td>95</td>
</tr>
<tr>
<td>3-3</td>
<td>Coding Categories of CSILE Students’ Knowledge Production</td>
<td>102</td>
</tr>
<tr>
<td>3-4</td>
<td>Coding Categories of CSILE Students’ Communicative Ideas</td>
<td>111</td>
</tr>
<tr>
<td>4-1</td>
<td>Plots of Six Group Centroids on Two Discriminant Functions Derived from Three Knowledge-Processing Variables</td>
<td>123</td>
</tr>
<tr>
<td>4-2</td>
<td>Mean Proportion of Explanation-Seeking Research Questions in Biological and Physical Study Projects</td>
<td>132</td>
</tr>
<tr>
<td>4-3</td>
<td>Mean Level of Explanation in Biological and Physical Study Projects</td>
<td>133</td>
</tr>
<tr>
<td>4-4</td>
<td>The Mean Proportion of Intuitive Theories in Biological and Physical Study Projects</td>
<td>136</td>
</tr>
<tr>
<td>4-5</td>
<td>The Mean Proportion of Personalized Epistemology in Biological and Physical Study Projects</td>
<td>137</td>
</tr>
<tr>
<td>4-6</td>
<td>Mean Level of Explanation and CSILE Experience</td>
<td>141</td>
</tr>
<tr>
<td>4-7</td>
<td>The 95% Confidence Intervals for Mean Level of Explanation in CSILE Groups Year 1 and Year 2</td>
<td>142</td>
</tr>
<tr>
<td>4-8</td>
<td>The Mean Proportion of Explanation-Related Comments for Students in Classrooms A and B</td>
<td>158</td>
</tr>
<tr>
<td>4-9</td>
<td>Plots of Four Group Centroids on Two Discriminant Functions Derived from Four Communicational Variables</td>
<td>164</td>
</tr>
<tr>
<td>4-10</td>
<td>Levels of Analysis of CSILE Students’ Intuitive and Scientific Explanations</td>
<td>174</td>
</tr>
<tr>
<td>4-11</td>
<td>The Nature of Explanation in CSILE Students’ Intuitive and Scientific Conceptions in Physics</td>
<td>188</td>
</tr>
<tr>
<td>4-12</td>
<td>The 95% Confidence Intervals for Male and Female Students’ Change in Frame of Explanation</td>
<td>200</td>
</tr>
<tr>
<td>4-13</td>
<td>Mean Number of Subordinate Questions for Individual Students Displayed in a Scatterplot Against Mean Scores of Deepening of Explanation</td>
<td>227</td>
</tr>
<tr>
<td>4-14</td>
<td>Strategy of Inquiry and 95% Confidence Intervals for Mean Scores of Deepening of Explanation in the Electricity Project</td>
<td>232</td>
</tr>
<tr>
<td>4-15</td>
<td>Mean Cognitive Value of Received Comments for Individual Students Displayed in a Scatterplot Against Mean Scores of Deepening of Explanation</td>
<td>256</td>
</tr>
</tbody>
</table>
LIST OF APPENDIXES

Appendix A1: Coding Categories of Inquiry-Structure Graphs 325
Appendix A2: An Example of Truncated Inquiry 326
Appendix A3: An Example of Extensive Inquiry 327
Appendix A4: An Example of Intensive Inquiry 328
Appendix B1: Scales for Expert Evaluation of CSILE Students’ Process of Inquiry 329
Appendix B2: Instructions for Expert Evaluation of CSILE Students’ Process of Inquiry 330
Appendix C1: Transcription of Neuron Cells Case Used in the Expert Evaluation 332
Appendix C2: Transcription of Eye Cells Case Used in the Expert Evaluation 336
Appendix C3: Transcription of Cosmology Case Used in the Expert Evaluation 339
Appendix C4: Transcription of Gravity Case Used in the Expert Evaluation 343
Appendix D1: A Complete Transcription of Expert C’s Evaluation 345
1. INTRODUCTION

The purpose of the study is to analyze elementary school students' process of knowledge-seeking inquiry in computer-supported collaborative learning from the viewpoint of the philosophy of science and cognitive theory. The main problem addressed in the study was whether 10- and 11-year-old children are capable of showing any or all of the following three principal features of scientific thinking, namely: 1) increasingly deep levels of explanation, 2) progressive generation of subordinate questions, and 3) collaborative effort to advance explanations. In other words, the problem is whether the students are able to participate in the process of knowledge-seeking in anything like the way scientists do. When analyzing elementary school students' process of inquiry from the viewpoint of scientific inquiry, a generous allowance should, naturally, be made for the students' knowledge limitations as well as their limited access to experimental inquiry. However, there is little published evidence in the educational-literature database which addresses the question of whether elementary school students are able to participate in higher-level practices of inquiry analogous to scientific research at all, yet it is clearly a worthwhile problem to investigate.

Technical infrastructure for the study was provided by the Computer-supported Intentional Learning Environments, CSILE (Scardamalia, Bereiter, McLean, Swallow, & Woodruff, 1989). CSILE is a networked learning environment for fostering higher-
level processes of inquiry in elementary education. The design of CSILE is based on an ingenious application of recent research on expertise, literacy, collaborative cognition and complex problem solving. Although several cognitive researchers (e.g., de Corte, 1993; Salomon, in press a; Salomon & Perkins, in press) have pointed out that many applications of educational technology support only lower-level processing of knowledge, computer-supported learning environments designed by following cognitive principles over technological considerations provide a noticeable exception. There is evidence that CSILE, in fact, facilitates higher-order cognitive processes and collaborative knowledge-building (see Lamon, Secules, Petrosino, Hackett, Bransford, & Goldman, 1996).

CSILE is an environment for building, articulating, exploring, and structuring knowledge (Scardamalia & Bereiter, 1989, 1990, 1993; Bereiter & Scardamalia, 1991). The system contains tools for text and chart processing, and a central part of the system is a communal database for producing, searching, classifying, and linking knowledge. In order to facilitate in-depth processing of knowledge, the students themselves are responsible for producing all knowledge in the database. The system facilitates sharing of cognitive achievements by providing each student an access to all textnotes, comments and charts produced by their fellow students. CSILE is designed to foster collaborative learning through its advanced facilities for searching out and commenting on 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. CSILE is
designed to provide facilitating structure and tools, i.e., procedural facilitation, that enable students to use their own thinking and knowledge (Scardamalia et al., 1989).

The present study analyzes whether CSILE students' processes of inquiry share essential characteristics with scientific inquiry. By relying on conceptual tools provided by the philosophy of science and cognitive theory, I developed methods for analyzing the epistemological nature of the students' inquiry. In particular, the study was focused on analyzing their practices of question generation, theory formation, knowledge production, and between-student communication. 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. However, CSILE's database provided unique information concerning the students' practices of inquiry, development of their conceptions, and their discourse interactions. 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.

Five studies were carried out to analyze the epistemology of CSILE students' inquiry. The first two studies analyzed how CSILE students' culture of inquiry changed in two CSILE classrooms (A and B) across a three-year period following introduction of CSILE. These studies focused on analyzing the level of explanation of knowledge produced by the students (the first principal feature of scientific inquiry) and whether between-student interaction mediated by the CSILE network facilitated
advancement of their explanations (the second principal feature). Because results of the first two studies indicated that only classroom A systematically participated in a research-like collaborative process of inquiry, studies 1-3 focused on analyzing, in a detailed way, processes of inquiry only in this classroom. The third study focused on deepening the analysis of CSILE students’ level of explanation through examining the nature of their intuitive explanations with respect to scientific explanations they proposed as well as the advancement of their conceptual understanding during their inquiry (the first principal feature). In the fourth study, I examined the extent to which CSILE students were able to generate new subordinate questions for answering their principal question and analyzed relations between this process of question transformation and the advancement of the students’ explanations (relations between the second and first principal features). The fifth study analyzed more closely CSILE-mediated interaction between the students in order to determine whether comments providing or requesting explanation facilitated the students’ conceptual advancement (relations between the third and first principal features). In the last three studies, expert evaluations by three internationally-known philosophers of science were used to assess whether CSILE students’ inquiry shared certain, essential characteristics of scientific inquiry.
2. THEORETICAL FRAMEWORK

2.1 Facilitating Practices of Scientific Inquiry in Education

An analogy between the history of science and the development of scientific thinking in childhood as well as between scientific thinking and children's thinking has been a very important foundation of cognitive research on educational practices. Several philosophers or historians of science (Kitcher, 1988; Nersessian, 1989; 1992; Thagard, 1992) as well as cognitive researchers (e.g., Burbules & Linn, 1991; Carey, 1986; Cobb, Wood, & Yackel, 1991; Duschl & Gitomer, 1991; Duschl, Hamilton, & Grandy, 1992; Hawkins & Pea, 1987; Piaget, 1977; Piaget & Garcia, 1989; Scar-damalia & Bereiter, 1994; Posner, Strike, Hewson, & Gertzog, 1982; Strike & Posner, 1985; 1992) have argued that there is a close relationship between the process of scientific thinking and learning science as well as between the philosophy of science and science education. It seems that without considering the epistemological and philosophical foundations of scientific inquiry, it is possible neither to explain and understand complex processes of learning scientific knowledge and scientific thinking nor to make successful "design experiments" (Brown, 1992; see also Salomon, in press b) for facilitating higher-level practices of inquiry in education.

The proposal that practices of school learning should more closely correspond with processes of inquiry characteristic of scientific research or academic disciplines has been argued for by several cognitive researchers (e.g., Bruner, 1960). The traditional, most common, approaches to facilitating scientific thinking in education fo-
ocused on examining how individual students' abilities and dispositions enabled them to engage in the processes of scientific inquiry (see Scardamalia & Bereiter, 1994). In the traditional view, scientific thinking has been seen as a logical process which is free from the limitations of everyday thought. Yet there is a considerable amount of evidence which shows that people do not think in accordance with scientific principles in everyday life but show many kinds of biases and rely more on crude heuristics than abstract, formal procedures (Kahneman, Slovic, & Tversky, 1982; Nisbett & Ross, 1980). There is much evidence that even scientists are not able to think "scientifically", demonstrating, for instance, the very same confirmation bias (see Wason & Johnson-Laird, 1972) as ordinary subjects (see Mahoney & DeMonbreun, 1981; Mynatt, Doherty, & Tweney, 1977; Tweney, Doherty, Worner, Pliske, & Mynatt, 1980). Moreover, laboratory studies of scientific reasoning in practice have indicated that scientific inquiry is not so logical a process as traditional philosophy of science has assumed (Latour & Woolgar, 1979). These empirical findings have created a growing interest in the nature of human rationality (Cherniak, 1986; Harman, 1986; Stich, 1990) and encouraged pragmatically oriented and empirically grounded research on scientific practices (e.g., Giere, 1988; Nersessian, 1984, 1986; Thagard, 1988, 1990, 1992).

In accordance with these findings, several studies have indicated that knowledge constructed by students in the course of school learning diverges from generally accepted scientific knowledge (Champagne, Klopfer, Desena, & Squires, 1981; Champagne, Gunstone, & Klopfer, 1985; DiSessa, 1982; McClelland, 1984;
McCloskey, 1983a, 1983b; Pines & West, 1986; Posner et al., 1982; Strike & Posner, 1985). There is a growing body of evidence that students come to the classroom with many intuitive conceptions that are resistant to change. They do not change their conceptions when exposed to observations, experiments, and arguments which provide counter-evidence for their conceptions. In many cases counter-evidence is assimilated by compartmentalizing knowledge and making only minor local changes when necessary (see Hewson, 1985; Hewson & Hewson, 1984; Holland, Holyoak, Nisbett, & Thagard, 1986). In fairness, it must be pointed out that scientists, similarly, have sometimes sequestered their findings from counter-evidence (see Thagard, 1992).

Further, cognitive studies indicated that school children’s processes of reasoning do not correspond to metaconceptual or epistemological norms, such as a commitment to systematicity (DiSessa, 1983, 1988), consistency (Champagne, Gunstone, & Kloppfer, 1985; Dunbar & Klahr, 1988), parsimony and generalizability (Hewson & Hewson, 1984; Hewson, 1985), coherence (Reif & Larkin, 1991; Perkins & Simmons, 1988), logical consistency (Reif & Larkin, 1991) or theory-evidence differentiation (Kuhn, 1989, 1992, Kuhn, Damsel, & O’Loughlin, 1988), that are assumed to characterize scientific thinking. Yet many of the above mentioned studies of scientific thinking in educational contexts have underestimated the pragmatic limitations of human information processing; it is questionable, for instance, whether “global coherence” or “long deductive inference chains” (Reif & Larkin, 1991) are really attainable epistemic
virtues for inexperienced cognitive agents with limited cognitive resources (see Cherniak, 1986; Harman, 1986; Stich, 1990).

The above presented short review indicates that many past efforts to bring scientific inquiry into schools have suffered from promoting an idealistic model of scientific inquiry that does not correspond to actual practice of scientific inquiry (Scardamalia & Bereiter, 1994). Rather than trying to pursue abstract forms of scientific thinking in education, it would be profitable to start with certain practices of working productively with knowledge that characterize scientific inquiry and rely on extended cognitive resources embedded in a community of inquirers.

A promising new approach to facilitating scientific thinking in education is based on an idea that scientific inquiry represents a special kind of cultural practice. Several researchers have proposed that in order to facilitate higher-level processes of inquiry in education, cultures of schooling should more closely correspond to cultures of scientific inquiry (Brown et al., 1989; Cobb et al., 1991; Collins, Brown, & Newman, 1989; Hawkins & Pea, 1987). It has been argued that a major constraint that prevents conceptual change and development of scientific thinking is that educational practices do not correspond to the practices of authentic, scientific inquiry (Carey, Evans, Honda, Jay, & Unger, 1989; Cognition and Technology Group in Vanderbilt, 1993; Duschl & Gitomer, 1990; Hashweh, 1986; Linn & Songer, 1991; Perez & Carrascosa, 1985). In order to get an idea how scientific inquiry is actually pursued, the students should systematically participate in processes in which they have to apply scientific methodology, such as generating research questions, solving complex problems,
constructing hypotheses, building theories, and designing experiments. Experiences of the actual "doing" of science would help students to make conceptual change and learn scientific thinking, not just assimilate scientific knowledge as a finished product of the process (Cognition and Technology Group in Vanderbilt, 1993).

Scardamalia and Bereiter (1991, 1992, 1994; see also Cobb, et al., 1991; Hawkins and Pea, 1987) have argued that traditional approaches to facilitating scientific thinking in education assumed that scientific thinking is an individual accomplishment and failed to acknowledge the significance of the social structures and dynamics of scientific, research communities for progressive inquiry. They proposed (1994) that scientific thinking could be facilitated in school by organizing a classroom to function like a scientific research community and guiding students to participate in practices of progressive scientific discourse. Thus, schools should be restructured as knowledge-building communities through facilitating the same types of social processes, such as public construction of knowledge, that characterize progressive research teams and laboratories. From a cognitive viewpoint, science is concerned with the generation of knowledge; a fundamental task of science is to produce new knowledge and understanding (Giere, 1988). Characteristically scientific communities work to produce knowledge, take the ideas constructed as an object of inquiry, and collectively pursue advancement of the knowledge constructed.

Scardamalia and Bereiter (1994) have argued that there are no compelling reasons why school education should not have the dynamic character of scientific inquiry. The analogy between school learning and scientific inquiry is based on a close
connection between processes of learning and discovery. Inquiry pursued for producing new knowledge and inquiry carried out by learners working for understanding new knowledge are based on the same kinds of cognitive processes. Learning, analogously with scientific discovery and theory formation, is a process of working toward more thorough and complete understanding. Although students are learning already existing knowledge, they may be engaged in the same kind of extended processes of question-driven inquiry as scientists and scholars. Nersessian (1989, 1992) also proposed that there is a close relation between the processes of scientific discovery and learning scientific knowledge. In order to make conceptual change in science, for instance, scientists themselves have to engage in a learning process. Both the process of conceptual restructuring and the reasoning processes involved in the construction of scientific explanations are similar for scientists and learners of science. The argument was that it is essential to cultivate reasoned “processes of invention” that characterize scientific inquiry, to involve students with same kind of extended process of problem solving through which scientists articulate new knowledge (Nersessian, 1992).

In the present study, the sustained processes of advancing and building of knowledge characteristic of scientific inquiry are called knowledge-seeking inquiry. Several, concurrent, cognitive research projects share a common goal of fostering such research-like processes of inquiry in education (Brown & Campione, 1996; Carey & Smith, 1995; Lamon et al, 1996; Lampert, 1995; Perkins, Crismond, Simmons, & Unger, 1995; Scardamalia & Bereiter, 1994; Xiadong, Bransford, Hmelo,
Kantor, Hickey, Secules, Petrosino, Goldman, & The Cognition and Technology Group at Vanderbilt, 1996). Knowledge-seeking inquiry entails that knowledge is not simply assimilated but constructed through solving problems of understanding. Characteristic of this kind of inquiry, instead of direct assimilation, is that the seeker treats new information as something problematic that needs to be explained (Bereiter & Scardamalia, 1993; Chan, Burtis, & Bereiter, 1997). By imitating practices of scientific research communities, children can be guided to participate in extended processes of question- and explanation-driven inquiry. An essential aspect of this kind of inquiry is to engage collaboratively in improving of shared knowledge objects, i.e., hypotheses, theories or explanations (Scardamalia & Bereiter, 1996). Through intensive collaboration and peer interaction, resources of the whole learning community may be used to facilitate advancement of inquiry.

The present study, as stated, assumes that by relying on cognitive practices characteristic of scientific inquiry, educational practices can be restructured in a way that facilitates higher-level cognitive achievements. Even if there certainly is more in scientific thinking than the present framework captures, such as systematic experimental research, it appears to represent good practices for working with knowledge that characterizes scientific inquiry. Moreover, there is a reason to believe that these practices of knowledge production are procedures of which people are actually capable, both in science and everyday life (cf., Thagard, 1988), unlike many traditional models of scientific thinking.
2.2 Elements of Knowledge-seeking Inquiry

By synthesizing results of the philosophy of science and cognitive research a framework can be constructed for analyzing essential aspects of progressive knowledge-seeking inquiry that characterize scientific research (Figure 2-1). In the following, an overview will be provided of the conceptual framework by presenting elements that appear to be important aspects of knowledge-seeking inquiry as applied in educational contexts. In subsequent sections each of these elements will be elaborated by relying on conceptual tools and empirical research results provided by the philosophy of science and cognitive research.

The process of knowledge-seeking inquiry starts from an agent's cognitive or epistemic goals that arise out of his or her dissatisfaction with the state of present knowledge (Hintikka, 1985). Cognitive goals guide and regulate the process of inquiry. Knowledge-seeking inquiry is facilitated by learning that is focused on working toward more coherent and deeper understanding through recognizing weaknesses and limitations of one's own knowledge, i.e., puzzling, unclear or incoherent aspects of one's knowledge (Scardamalia & Bereiter, 1993, 1996). Advancement of inquiry can be assessed by comparing the emerging situation with the goal as the process goes on. Simultaneously there emerge new goals as more information is obtained and new questions become accessible. An important condition for dynamic advancement of inquiry is that the agent has committed him- or herself to the goals of understanding characteristic of knowledge building, also labeled "intentional learning" (Bereiter & Scardamalia, 1989). Through restructuring educational practices accord-
ing to knowledge-seeking inquiry, understanding becomes the focus of schooling (Perkins et al., 1995).

**Figure 2-1**
Elements of knowledge-seeking inquiry.

From a cognitive point of view, inquiry can be characterized as a question-driven process of understanding. Without a research question there cannot be a genuine process of inquiry although information is frequently produced at school without any guiding questions. A research question activates an agent's background knowledge by facilitating in-depth search of memory and focusing memory search in a specific direction; simultaneously, it facilitates making inferences from one's knowledge through parallel activation of different beliefs; it guides one continuously to relate
what he or she already knows to new information (Hintikka, 1986; Sintonen, 1990b; Scardamalia & Bereiter, 1992).

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. Further, large bodies of information cannot be managed without questions that guide and constrain the knowledge-seeking process and help to structure information obtained (Bereiter, 1992). Indeed, all scientific information does not have equal cognitive value; explanatory or theoretical knowledge has a key role in conceptual understanding, and, thus, a special status in the cognitive process of inquiry.

Another important aspect of inquiry is generation of one's own explanations, hypotheses or conjectures (Carey & Smith, 1995; Lampert, 1995; Perkins et al., 1995; Scardamalia & Bereiter, 1989, 1993). In order to foster dynamic change of conceptions and integration of knowledge structures, an agent has to engage in an intentional process of generating his or her own explanations and theories. If the process of inquiry is carried out as a strong, systematic cognitive effort and relevant new information is obtained, the agent often succeeds in creating more and more sophisticated explanations. Knowledge emerges through his or her intentional attempts to explain and understand problems being investigated; it is usually connected with the learner's other knowledge in a rich web of meaning connections.
Facilitation of higher-level practices of inquiry at school requires a change in the division of cognitive labor between the teacher and the students. Traditionally, the teacher takes care of a major part of all higher cognitive functions at school, such as planning, questioning, explaining and evaluating, while the students are required to understand, restore and reproduce transmitted information. Based on cognitive studies of expertise, Bereiter and Scardamalia (1987a, 1987b; Scardamalia & Bereiter, 1991) have proposed that an important prerequisite for development of higher-level cognitive competencies is that students themselves take on a responsibility for all cognitive (e.g., questioning, explaining) and metacognitive (e.g., goal-setting, monitoring, and evaluating) aspects of inquiry.

Further, the progressive process of inquiry is not an individual accomplishment but a *socially distributed process* both in science and in learning (see Hutchins, 1991, Oatley, 1991; Salomon, 1993; Kitcher, 1993). Limitations of human information processing can be overcome by relying on socio-culturally developed cognitive tools, artifacts, and good cognitive practices. All aspects of inquiry, such as generation of research questions, search for explanatory scientific information or construction of one's own theory, can be shared with other inquirers. Cognitive research indicates that 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.

By restructuring educational practices according to cognitive theory of inquiry, schools can be transformed into a community in which collaborative knowledge build-
ing is a primary goal of both students and teachers (Scardamalia & Bereiter, 1994).
Knowledge building is a process of increasing understanding by intentionally con-
structing, articulating, elaborating, generating and producing knowledge. The aim is
to support expert-like processing of knowledge by guiding students to work collabora-
tively to improve shared knowledge objects (Scardamalia, Bereiter, & Lamon, 1994;
Bereiter & Scardamalia, 1997). Through collaborative building of knowledge, the pro-
cess of knowledge-seeking inquiry aims at dynamic changes in an inquirer’s epistemic
state as well as growing metacognitive and epistemological awareness concerning the
ongoing process of inquiry. In the following, each of these elements of knowledge-
seeking inquiry is examined in detail.

2.3 Research Questions and the Process of Inquiry

2.3.1 Inquiry as a Problem-solving Process

Recent approaches to the philosophy of science have strongly emphasized the
role of problems or questions in scientific inquiry. Laudan (1977), Hintikka (1981,
1985, 1988), and Sintonen (1985, 1990a) argued that problems, not theories, consti-
tute the fundamental unit of the philosophy of science. Laudan (1977; see also Kuhn,
1962; Lakatos, 1978) as well Simon (1977) argued that scientific inquiry in general
and scientific discovery in particular is a problem-solving process. Scientific theories
can be seen as solutions to problems; good theories provide adequate solutions to
important problems. Selection of theories with more problem-solving efficacy is the
basis of scientific progress. Problems can be seen as “umbrellas under which facts
and theories are gathered” (Sintonen, 1985, p. 41).
Jaakko Hintikka's (1981, 1985, 1988) interrogative model of scientific inquiry takes knowledge-seeking activity in general and scientific inquiry in particular as a dynamic question-answer process. From the viewpoint of the interrogative approach, inquiry is a process of solving problems through questioning. Accordingly, to solve a problem is to answer a question. A solution to a problem or a piece of information can be regarded as an answer to an underlying question. Questions and cognitive goals are closely connected; a starting point of inquiry is a problem that arises when a cognitive goal cannot be achieved by knowledge immediately available to the agent.

The interrogative approach on inquiry has a long history. For example, Socratic dialogues were based on an assumption that questioning is the source of knowledge (Meno, 85d, quoted by Macmillan & Garrison, 1988, p. 147). In the background of the interrogative theory of inquiry is erotetic logic, i.e., the logic of questions and answers (see Hintikka, 1988). Erotetic logic is concerned with conceptualizing how epistemic states change in the process of inquiry. However, the logical basis of the interrogative model is not relevant for purposes of the present study. Although the interrogative process can be formalized, it does not entail an assumption that the actual cognitive process of inquiry would be logical in nature. The model can rather be seen as a conceptual tool for analyzing question-driven process of inquiry; it has been productively been applied to analyze actual history of science, such as Darwin's theory of evolution (see Sintonen, 1990b, 1991).

The interrogative model of inquiry conceptualizes a dynamic process of inquiry through which new knowledge and understanding emerge by separating two types of
questions (Hintikka, 1985; Hintikka & Bachman, 1991; Sintonen, in press). On one hand, there is an initial principal or big question which is determined by the cognitive goals of inquiry. On the other hand, there are small subordinate questions to which answers are needed in order to approach answering the principal question. Principal questions are often explanation-seeking in nature and arise when an agent tries to fit new phenomena to his or her already existing knowledge. However, the principal question cannot be answered in a single move, but through a series of interrogative steps. Small questions form the basis of each interrogative step, guide the search of knowledge, and provide a part of the information needed to answer the principal question.

The two levels of questions differentiated by the model are a dynamic feature that fosters acquisition of new information during the process of inquiry. The agent tries to solve the big question through using his or her existing knowledge and new information that provide answers to a series of subordinate questions. Advancement of inquiry can be captured by examining a chain of questions generated. By finding answers to subordinate questions, an agent approaches step by step toward answering the big initial question, and thus changes his or her epistemic situation. 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, 1991, 1992; Simon, 1977; Schank, 1986).
In the interrogative framework, scientific inquiry can be seen as a process of putting questions to Nature (Hintikka, 1985; Sintonen, 1990a, 1991, in press). In this view, knowledge-seeking inquiry is a game against Nature in which the agent pursues his or her cognitive goal by interrogating Nature. However, the questions-put-to-Nature metaphor is only one possibility for conceptualizing the interrogative process (Sintonen, 1985), and it mostly characterizes experimental research. Inquiry may also be seen as a process of seeking answers to questions put to some other information source such as an expert, scientific literature, a teacher, or a peer. The question-answering process can also be carried out through a search of the agent’s own memory, his or her thought experiment, or observation. In educational contexts, it might be useful to interpret the interlocutor to be the body of scientific knowledge representing
Popper's (1972) world₃ instead of world₁ due to the limited access to and resources for experimental research.

2.3.2 Pragmatics of Question-Answer Process

The interrogative model is aimed at capturing the dynamics of the process of inquiry, not just "the argument of a finished research report" (Hanson, 1958, p. 71). In order to productively guide practices of inquiry, the model is grounded in a pragmatic conception of 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 a "theory to work with" (Sintonen, 1991, p. 170). 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 an agent focuses on improving his or her theory by generating more specific questions and searching for new information. In the interrogative process initially very general, unspecified and "fuzzy" questions are transformed to a series of more specific questions. The dynamic nature of inquiry is, further, based on the fact that new questions emerge in the process of inquiry that "cannot be foreseen when the principal question is raised" (Sintonen, 1990b, p. 481). Generation of intuitive explanations and obtaining of new scientific information make new research questions accessible to the agent that would otherwise be completely beyond his or her epistemic horizon.
Further, questions provide heuristic guidance for the process of inquiry by constraining and directing the search for information. The interrogative approach encourages agents to solve a problem from what they already know and whatever new information they have searched for and acquired during the process of inquiry. By setting up questions to help answer his or her problem, the agent facilitates activation of his or her relevant background knowledge (Hintikka, 1982; Macmillan & Garrison, 1988; Sintonen, 1990b). Thereby, question-driven inquiry appears to elicit an in-depth search of memory and active interrogation of one's knowledge base for finding relevant information. This, in turn, supports integration of knowledge structures (see Perkins et al., 1995). Questioning also guides an agent in deriving new inferences from his or her knowledge and explicating consequences of what he or she already knows.

Bereiter (1992) has argued that through a question-driven process of inquiry problem-centered knowledge emerges, such knowledge having a very important role in experts' complex problem-solving skills. Domain knowledge is taught at school as a referent-centered knowledge, i.e., as definitions and factual statements to be memorized. However, this kind of referent-centered knowledge cannot be applied for solving problems in a flexible way. Problem-centered knowledge, by contrast, refers to higher-level conceptual knowledge emerging through solving problems of understanding and explanation. The distinction is not the same as that between declarative and procedural knowledge (see Anderson, 1983). Bereiter (1992; see also Bereiter & Scardamalia, 1993) argued that, through a question-driven process of inquiry, one constructs problem-centered knowledge that provides not only a significant condition
for conceptual understanding but facilitates conceptual reorganization as well. Through solving problems of understanding, formal knowledge is transformed into informal knowledge, and new structures of knowledge emerge organized around problems. It follows that in educational contexts, problems of explanation and, correspondingly, explanation-seeking research questions are of critical importance.

The interrogative process is related to changes in an agent’s epistemic state and situation (Sintonen, 1985). Answering a question changes an agent’s epistemic situation by requiring activation of relevant background knowledge and drawing inferences from that knowledge. Further, finding new scientific information changes the agent’s epistemic situation by challenging concurrently held beliefs. As a consequence, each episode of inquiry gives rise to new questions that direct the subsequent process of inquiry.

2.3.3 Role of Knowledge-seeking Questions in the Process of Inquiry

The interrogative model was applied to conceptualize teacher-student interaction by Hintikka (1982). Macmillan and Garrison (1988) further explicated implications of the model for education by developing a theory of teaching based on an erotetic conception of inquiry. From the viewpoint of the interrogative model, teaching can be seen as a question-answering process. The goal of teaching is to “answer questions that students ought to ask concerning the subject matter with which the teacher and the students are engaged” (Macmillan & Garrison, 1988, p. 16).
Macmillan and Garrison (1988) emphasized questions teachers ought to be asking of students. Bereiter and Scardamalia (1987b, 1989; Scardamalia & Bereiter, 1991), in contrast, argued that advancement of conceptual understanding in question-driven process of inquiry is critically dependent of questions generated by students themselves. An important condition of facilitating higher-level inquiry at school is encouragement for students asking themselves the questions that are usually asked by teachers or textbooks. Questions that the students ask themselves and each other facilitate the process of intentional learning (Bereiter & Scardamalia, 1989) focused on understanding as well as the emergence of new cognitive commitments. Through generation of questions to be jointly pursued, students themselves can take responsibility for extending their knowledge and going beyond their current level of understanding (Scardamalia & Bereiter, 1991). It is common, however, that only a small percentage of questions asked in a classroom are generated by students themselves; students are usually answering questions provided by the teacher or reproducing information without any guiding questions (see Geisler, 1994).

Current educational practices seldom correspond to epistemic ideals in the dialogue teaching that Macmillan and Garrison (1988) emphasized, i.e., engagement in thoughtful learning and deepening inquiry. According to Mehan (1979, quoted by Geisler, 1994), the standard interaction pattern of classroom lessons is organized around the exchange of factual information. Very common is a sequence in which the teacher elicits information by asking a question, the students give responses, and then the teacher provides feedback about these replies. However, the expected re-
response usually represents textbook information and is factual in nature. For the students and teachers investigated by Mehan (1979, quoted by Geisler, 1994, p. 29), fact elicitations were three times more frequent than any other kind of teacher elicitation. Moreover, the students are generally expected to rely on information provided by textbooks even in situations in which their own ideas or hypotheses would be equally appropriate. Major questions that could be answered through the interrogative process frequently do not even arise.

According to Hintikka's (1982) analysis, interrogative movements carried out by a student alone are more demanding than teacher-controlled movements. It is much more difficult for the student successfully to carry out the knowledge-seeking process alone than with the teacher's support. As a consequence, it is not advisable to rely on the students' unguided creativity, but to provide a significant amount of guidance (see Lampert, 1995; Brown & Campione, 1996). It is important, however, that the teacher does not carry out the cognitive work on the behalf of the student. A student should him- or herself take responsibility for the goals of inquiry, generation of research questions, regulation of the process of inquiry and other higher-level functions (Bereiter and Scardamalia, 1987b). In each pedagogical situation a productive balance should be found between teacher-controlled and student-controlled aspects of inquiry, and the two approaches are not necessarily fundamentally different. Macmillan and Garrison (1988) stated that in knowledge-seeking inquiry the roles of the teacher and students could reverse or become indistinguishable. This, indeed, appears to be the
case in the most advanced applications of computer-supported collaborative learning designed for facilitating research-like process of inquiry.

A genuine process of inquiry appears to presuppose authentic knowledge-seeking questions in addition to teacher’s diagnostic questions. A diagnostic question differs semantically from an ordinary question because the teacher, in the latter case, already knows the answers to the question she is asking. Geisler (1994, p. 2) stated that “if someone asks us a question to which she already knows the answer and then evaluates our response for its correspondence with this predetermined answer, we know we are being treated like students – no matter what our age or physical surroundings.” Characteristic of diagnostic questions is that they are not asked for extending knowledge or solving an authentic problem, but for the purpose of finding out what a student knows. As a consequence of the ordinary questioning approach, problems are usually not pursued in depth through articulating more specific problems; but students move to another problem if the former one is immediately answered (Scardamalia & Bereiter, 1993, 1996). Diagnostic questions, however, have an important role in the learning-instruction process. In order to facilitate engagement with authentic inquiry and encourage students to consider themselves as inquirers, the teacher should implement an expert model of knowledge-seeking inquiry by setting up authentic, real questions that no one in the learning community can answer beforehand (Scardamalia & Bereiter, 1991).
2.3.4 Text-based and Knowledge-based Questions

Miyake and Norman (1979) argued that in order to ask valuable questions, students ought to have a minimum amount of domain-specific knowledge. Yet there are convincing reports that even when students do not know a topic very well they are able to ask cognitively valuable questions. In one series of investigations, questions were analyzed from elementary school children working with the CSILE environment (Scardamalia & Bereiter, 1991, 1992b). Two types of students' questions were separated; i.e., text-based and knowledge-based questions. Text-based questions arise while studying a text. These are often focused on content-related problems or linguistic and grammatical considerations emerging from reading the text. Knowledge-based questions, in contrast, arise from children's epistemic goals and their need to understand and make sense of the world. The distinction between text-based and knowledge-based questions is closely related to the distinction between a text base and situation model (see van Dijk & Kintsch, 1983). Within the CSILE environment, and with respect to knowledge-based questions, wonderment questions were further separated from basic level question. Basic level questions only oriented the students to the subject matter being investigated, but wonderment questions reflected students' epistemic curiosity, their puzzlement or critical assessment of information available. It appears that wonderment questions represent conceptual problems (see Laudan, 1977) arising through the process of inquiry. Further, although there was substantial variability between the students, they were frequently also able to identify conceptually advanced questions (Scardamalia & Bereiter, 1991).
There is evidence, from the studies just reviewed, that students are able to generate cognitively valuable questions on the condition that they are not required to be able to provide answers to their questions. If students are, on the contrary, so required, it is likely that in order to avoid failure and save cognitive effort they would adopt a strategy of asking questions to which they already know an answer or have information very easily available. Hatano and Inagaki (1992) observed, correspondingly, that performance orientation and a need for correct answers is counterproductive from the viewpoint of comprehension activity. Scardamalia and Bereiter's (1991, 1992b) study indicated, further, that if students were asked to generate questions before introducing a new topic, they were likely to ask knowledge-based questions, i.e., questions derived from their need to understand and focused on things they were genuinely interested in and wondered about.

Cognitive research has revealed that computer-supported collaborative learning can be used to facilitate deepening inquiry through questioning. Scardamalia and Bereiter (1991, 1992b) reported that a significant proportion of questions generated by students were regarded by experts as representing significant additions to knowledge or an advance in conceptual understanding if successfully answered. Answering those questions was estimated to require a rather complex search. An important prerequisite for question-driven inquiry seemed to be having one's own understanding as a conscious goal of learning (Scardamalia and Bereiter, 1989). Further, there is evidence that participation in an extended process of inquiry fosters children's ability to ask complex questions (Brown & Campione, 1994).
Generation of knowledge-based questions has an essential role in CSILE students' inquiry. An important aim of the CSILE project has been to foster question generation by the students. CSILE provides means for the entire learning community to work together for solving shared questions. In the CSILE environment, a question-driven process of inquiry is fostered by using specific thinking types for three levels of question, i.e., Problem (P), I Need to Understand (INTU) and Higher-level Question. These levels of question facilitate a dynamic process of question transformation that constitutes the core of the interrogative process. Problem represents the initial principal question, INTU represents small questions articulated for answering the big question, and Higher-level questions are, roughly speaking, metaconceptual questions arising from the problem area in question. Bereiter and Scardamalia (1992b) observed that I-Need-To-Understand questions appeared to facilitate particularly valuable knowledge-based questions.

2.4 Explanatory Scientific Knowledge and the Process of Inquiry

2.4.1 Scientific Explanation as a Vehicle of Understanding

The cognitive goal of knowledge-seeking inquiry is to obtain new understanding through question generation. Search for new scientific information is an important condition for conceptual advancement of knowledge-seeking inquiry. However, not all knowledge is equally valuable from the viewpoint of conceptual understanding. Salmon (1989) distinguished between three types of scientific knowledge, i.e., empirical facts revealed by observations, empirical generalizations across observables and theories that make reference to unobservable entities. Although each category of
knowledge is important for a successful process of inquiry, conceptual understanding is critically dependent on explanatory knowledge, and, therefore, the search for explanation has a fundamental role in the process of inquiry.

Cognitive psychologists have extensively discussed two types of knowledge, knowing that and knowing how, referred to respectively as declarative and procedural knowledge (e.g., Anderson, 1983, see also Ryle, 1949). However, one can distinguish a third type of knowledge that has not been considered as intensively as the two categories mentioned above. Salmon (1989) distinguished knowing why from knowing that, arguing that knowledge of the latter category is descriptive and knowledge of the former type is explanatory. He argued that science can give us not only descriptive knowledge but also explanatory knowledge that provides scientific understanding of the world. Through explanation understanding is reached about how things work in the world.

The theory of question-answer process outlined above and the theory of explanations are closely connected. Sintonen (1991) argued that the search for explanations can be modeled as a search for answers to explanation-seeking questions. Explanations are intimately related with explanation-seeking why and how questions (Braithwaite, 1953; Salmon, 1989; Sintonen, 1989; van Fraassen, 1980). Many indirect questions can be transformed to why questions. A need for explanation arises when an agent has a particular why question, but not an adequate answer. The process of explanation increases understanding by pushing an agent to explicate conse-
quences of his or her view; it provides new information needed for answering an agent's why question and achieving his or her cognitive goals. In order to be an explanation, an answer to a why question should provide new relevant information, produce intellectual satisfaction, and facilitate epistemic change (Salmon, 1989, p. 11). Explanation elicits epistemic change not only through obtaining new information but also by generating new accessible questions (Sintonen, 1985, 1989). Thus, explanation may be primarily seen as a dynamic process rather than as a finished product (see Achinstein, 1977, 1983).

According to Salmon (1989, p. 6), a general view of scientific explanation consists of showing how some unfamiliar phenomena can be reduced to others that are already familiar. It appears to be characteristic of the human mind to try to comprehend a new phenomenon by relying on what one already knows. In some cases, however, less known phenomena (e.g., particles) are used to explain phenomena which are apparently more familiar to us (Salmon, 1984, p. 12-15). Nevertheless, from a cognitive point of view it is necessary to use existing knowledge structures as a starting point for explanation although theoretical entities constructed for explaining unknown phenomena may go beyond familiar knowledge. It appears always to be necessary to try to understand a new phenomenon by using existing knowledge as a 'bridge'.

One can distinguish good explanations that make sense from correct explanations that are true (Salmon, 1989). A correct explanation is not a good explanation if it is does not correspond to the agent's level of expertise or cognitive goals. Railton
(1981) distinguished between an ideal explanatory text and explanatory information. The ideal text would explicate all the causal and nomic connections that explain a given phenomenon, and, as a consequence, it would be extremely large and complicated. In practice, what aspect of this ideal text is considered depends upon the cognitive goals and the background knowledge of the agent seeking explanation as well as other relevant epistemic and pragmatic factors. The particular explanation-seeking question that has arisen determines what kind of explanatory information is sought in order to reach understanding of a part of the ideal explanatory text.

Friedman (1974) and Kitcher (1981, 1989) argued that science explains various phenomena through unification. The very essence of scientific explanation is to increase human understanding by "reducing the total number of independent phenomena that we have to accept as ultimate or given" (Friedman, 1974, p. 15). According to the unification thesis, explanations organize and systematize our knowledge in a very efficient way. Through explanation an agent's knowledge is organized in a way that enables him or her to understand what is known by using a smaller number of assumptions than previously. Scientific understanding emerges through subsuming individual pieces of knowledge within general laws and fundamental principles. Understanding involves having a coherent and intelligible model of the world and seeing how various aspects of the world and our experience fit into that model (see Rescher, 1979).
2.4.2 Functional and Physical Explanations

Salmon (1989, see also von Wright, 1974) distinguished causal and teleological explanations. *Causal explanations* refer to causal laws under which the event being explained can be subsumed. Accordingly, an event is explained by determining its cause or revealing a causal connection. From the viewpoint of *teleological explanations*, in turn, an event is explained by referring to human intentions, goals or purposes. Mackor's (1995, undated) distinction between *physical* and *functional explanations* is parallel to the distinction between causal and teleological explanations. Following Millikan (1984, 1986), she characterized social, psychological and biological sciences as functional. These sciences have in common that they deal with functional phenomena, i.e., intentions, goals or purposes of cultural, psychological or biological systems. Functional explanations categorize things according to their actual or potential functions. Functional explanations are legitimately used in biology, and adaptation in biological evolution is a model example of functional explanation. Further, institutions, customs, and rituals can be explained by referring to their functional role in society. Mackor argued that functional explanations contain a reference to normal conditions, i.e., whether an object is working properly, fulfilling its function. As a consequence, for functional items one can judge whether, in fact, they do or do not work properly, that is, fulfill their function. The human body is an example of the kind of system that does not necessarily always work properly.

Physical explanations, in contrast, do not attribute any purposes or goals to physical systems. Physical explanations are descriptions about what physical sys-
tems do or have a disposition to do. For example, a description of a system's microstructure is a kind of physical explanation. About a physical system, one cannot say that it is or is not working properly; physical systems just exist and are determined by causal laws or regularities. Physical explanations characterize a physical system's dispositions and microstructure. According to Millikan (1986), the phenomena accounted for by functional and physical explanations represent different ontological categories.

The distinction between functional and physical explanation appears to be a valuable conceptualization for analyzing the nature of explanation in educational contexts. Functional explanations referring to intentions, goals and purposes are contrasted with physical explanations which do not contain any reference to these processes. Further, while functional explanations may contain reference to correct functioning or malfunctioning, physical explanations do not. Presumably, an important aspect of conceptual development is a transition from functional to physical explanations in childhood: At early ages children's explanations seem to be functional in nature regardless of what domain of knowledge is examined. This developmental transition can be contrasted with two parallel transitions, i.e., a shift from psychological to biological explanations (Carey, 1985) and conceptual change across ontological categories (Chi, 1992).

Carey (1985) distinguished between psychological and biological explanations. In cognitive development, children's explanations change from explanation by using intentional, psychological terms to explanation on the basis of biological functions.
Young children do not have an autonomous domain of biology and tend to embed biological phenomena in social and psychological explanatory structures such as an assumption that individual motivation and social conventions determine animal behavior. Although functioning of internal organs is explained in terms of biological considerations in the 10-year-old's conceptual system, these are typically explained in terms of psychological considerations in the 4-year-old's conceptual system. Carey (1985) argued that a new ontologically basic category of living thing and a corresponding explanatory structure emerge in childhood, providing a ground for conceptual change. Analysis of functional and physical explanations implies, however, that beyond this transition from psychological to biological explanations, there is a further step in the process of conceptual change in which functional explanations (whether biological, psychological or social) gradually yield space for physical explanations. This change, in fact, concerns particularly the domain of physical phenomena. Changes described by Carey (1985) take place within functional explanation, but, presumably, there is a further step in which functional explanations are replaced by physical ones which refer only to the causal structure of the world.

Chi (1992) argued that it is important to distinguish conceptual change within and between ontological categories. She defined radical conceptual change as a change across ontological categories. According to Chi's (1992) analysis, matter (substance), events and abstractions should be distinguished psychologically as basic, physically distinct, ontological categories. Different physical laws govern the behavior of each ontological category, and it is not possible to transform an object from
one to another ontological category. Chi's (1992) contention is that different mechanisms are needed for conceptual change within an ontological category and between ontological categories. The former can be conceptualized as development of concept meaning, and the latter as acquisition of completely new concepts. Learning physics is difficult because it requires conceptual change across ontological categories: "the scientific meaning of physical science concepts belongs to a different ontological category than naive intuitive meaning" (p. 136). Learning physics requires a radical conceptual change from perceiving physical entities as substances to perceiving them as "constraint-based events." The distinction between functional and physical explanations resembles Chi's distinction, but is not identical with the latter. If functional and physical explanations are seen as ontologically different explanations, there is a reason to believe that Chi's cognitive change across ontological categories is preceded by a corresponding change in the childhood.

**2.4.3 Empirical and Theoretical Explanations**

Scientific change happens by articulating theoretical knowledge of hidden mechanisms of the world (Salmon, 1984, 1989). The role of theoretical concepts which refer to unobservable theoretical entities is crucial in this process. Scientific concepts occur in hierarchical explanatory relations to one another, forming scientific theories. Theoretical concepts constitute the core of theories; theoretical concepts explain relations between observation concepts by postulating underlying entities, processes and mechanisms (Tuomela, 1985). *Theoretical explanations* refer to non-observable entities that allow the explanation of a wide variety of complex events, and
make these events more understandable. The fundamental epistemic value of theoretical concepts relies on the explanatory unification provided by them (Salmon, 1984; see also Kitcher, 1981; Thagard, 1988). Finding causal relations and causal explanations often take investigators beyond observable phenomena, and such explanations often contain reference to microstructures of objects being explained. Scientific explanation relies on explanatory knowledge about the underlying mechanisms or common causes that produce the phenomena to be explained (Salmon, 1989, p. 134). In other words, scientific explanation provides:

explanatory knowledge of the hidden mechanisms by which nature works. It goes beyond phenomenal descriptive knowledge into knowledge of things that are not open to immediate inspection. Explanatory knowledge opens up the black boxes of nature to reveal their inner workings. It exhibits the ways in which the things we want to explain come about. (Salmon, 1989, p. 182)

Theoretical explanations can be contrasted with empirical explanations based on empirical generalizations across observables. According to Sellars (1963, see also Tuomela, 1985), empirical or everyday concepts refer to the manifest image whereas scientific concepts refer to the scientific image. The manifest image represents our phenomenal everyday world which primarily consists of perceptual middle-size objects which serve our practical purposes. The scientific image, in contrast, refers to ontologically different microphysical processes (Tuomela, 1985). Empirical explanations are based on the manifest image and refer to empirical facts and our everyday perceptual physical objects. Theoretical concepts appear to have a special status in advancement of the process of inquiry. A transition from explaining a given phenomenon on the basis of empirical concepts to explaining it theoretically is a crucial step in advancement of conceptual understanding. Often it is not possible to identify and un-
understand a phenomenon without appropriate theoretical concepts such as "field" (Nersessian, 1984; Thagard, 1988).

The above review has given reasons why explanatory scientific knowledge is cognitively more valuable than factual scientific knowledge. Adoption of theoretical concepts and theoretical explanations has a special cognitive significance due to increased explanatory unification. In an educational context, the idea concerning the cognitive value of theoretical explanations is not new. There have been many corresponding analyses such as Bruner's (1960) "explanatory principles" or Ausubel's (1963) "anchoring ideas." Brown and Campione (1996) emphasized the importance of connecting collaborative learning with domain-specific "big ideas", "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 a very significant influence on advancement of one's conceptual understanding only if it is adopted in a process of knowledge-seeking inquiry and provides an understandable answer to an agent's own research question.

2.5 Intuitive Explanation and the Process of Inquiry

Generation of an agent's own intuitive explanations, hypotheses and conjectures is a substantial aspect of the process of inquiry. The cognitive significance of explanation is based on the close connection between explanation and understand-
According to Thagard (1988, p. 44), explanation can be seen as a cognitive process of providing or achieving understanding. Craik (1943) and Perkins et al. (1995; also Schank, 1982; 1986) argued that understanding is intimately linked with explanation: people demonstrate their understanding by offering explanations. Explanation in everyday life and in science have a corresponding epistemic role, and in this sense, good everyday explanations resemble scientific explanations (compare Sintonen, 1989, p. 254). From the intimate link between explanation and understanding, it follows that explanation should have a far more essential role in learning-instruction process than is currently the case.

2.5.1 The Role of Theories and Conjectures in Learning Science

An important aspect of inquiry and a critical condition of developing conceptual understanding is generation of explanations and theories for the phenomena being investigated (Bruner, 1960, 1996; Brown & Palincsar, 1989; Carey & Smith, 1995; Dunbar & Klahr, 1988; Lampert, 1995; Nersessian, 1992; Perkins et al., 1995; Scardamalia & Bereiter, 1989, 1993; J. L. Schwartz, 1995). Yet students' own explanations, hypotheses or conjectures do not have a significant role in current practices of science education. Through explanation-driven learning both intuitive and scientific ideas and thoughts can be made the focus of inquiry (Scardamalia & Bereiter, 1989). This, in turn, may facilitate a shift from naive realism to scientific conceptual frameworks; i.e., a move from thinking directly about the world to thinking of it in terms of an abstract representation (Olson, 1994; Olson & Bruner, 1996). By engaging students with construction of their own explanations, they may be guided to see themselves as
contributors to knowledge, as prospective scientists (Scardamalia & Bereiter, 1993; Cognition and Technology Group at Vanderbilt, 1993; Xiadong et al., 1995). Construction of students' own hypothesis and conjectures guides students to systematically use their background knowledge and make inferences to extend their understanding.

Current practices of science education are, however, mainly based on an inductivist or empiricist view of science (Carey et al., 1989; Carey & Smith, 1993, 1995; Järvelä, Hakkarainen, Lipponen, Niemivirta, & Lehtinen, 1997; Nersessian, 1989; J. L. Schwartz, 1995). Accordingly, it is assumed that unbiased observation of the world is the source of scientific knowledge, that conceptual understanding should somehow directly emerge from observational data. Accordingly, school science typically focuses on process skills of science based on careful observations of natural phenomena and some principles of experimental research (Carey & Smith, 1993; Scardamalia et al., 1994; see also Järvelä et al., 1997). As a consequence of empiricist practices, however, science education does not acknowledge the role of theories in understanding empirical phenomena. Thus students often, without reflections, adopt explanatory concepts and theories only as new facts or mechanical procedures. However, theories have a fundamental role in scientific practice guiding design of experiments. Therefore, science education should be focused 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.
Klahr and Dunbar (1988; Kulkarni & Simon, 1988, 1990) have argued that a successful process of inquiry is carried out through two problem spaces, i.e., the hypothesis space and testing space. While solving problems, experts are simultaneously functioning in both the hypothesis space and testing space while novices are only functioning in the testing space. The hypothesis space corresponds to abductive construction of hypotheses and the latter to empirical testing of selected hypotheses. While experts generate hypotheses to be experimentally tested, the novices test different ideas in a non-systematic way (Klahr & Dunbar, 1988). Successful problem solving requires an interaction between these spaces. However, current educational practices focus almost entirely on the testing space in the form of laboratory experiments, data collection and so on. Although experimental testing and factual knowledge have a very important role in scientific inquiry constraining possible hypotheses, it is necessary to emphasize the cognitive value of hypothesis generation and theory formation without which conceptual growth can hardly be achieved.

From empiricist practices of science education it follows that students are mostly working with empirical problems that concern simple facts and represent experimental testing of theory. Yet conceptual problems are critical in scientific inquiry (Laudan, 1977). These are problems about the world arising from some unexpected phenomena. Conceptual problems are based on ontological, epistemological and methodological problems created by scientific explanations constructed for answering empirical problems. Laudan (1977) pointed out that conceptual problems are primarily problems of understanding, and arise if there are several theories explaining a
given phenomenon or when there is a conflict between scientific and common-sense beliefs.

Chi, Bassok, Lewis, Reiman and Glaser (1989, see also VanLehn, Jones, & Chi, 1992) studied effects of self-explanation in physics learning. They found out that students who explained examples to themselves achieved better learning results than other students having identical declarative knowledge (measured separately). Through articulating new meaning connections and deriving consequences of examples, students obtained a superior capacity to deal with new problem-solving tasks. Moreover, a prerequisite for the effect to occur was that the students articulated explanations independently; adoption of ready-made explanations did not provide the same result. Therefore, it appears that an agent is able to genuinely understand scientific explanations studied only by participating him- or herself in the process of explanation.

The process of explanation elicits new ways of integrating and elaborating knowledge (Brown & Palincsar, 1989, p. 395). Construction of explanations engages students in extended working with knowledge that Perkins et al. (1995) characterizes as a process of understanding by “working through.” It facilitates elaborative processing of knowledge, i.e., reflecting on, extending, and testing of ideas. Through generating one’s own conceptions, one is engaged in elaborative processing that establishes connecting cognitive linkages between new knowledge and an agent’s concurrent knowledge, and thereby produces increased coherence and systematicity of knowledge structures. Rescher (1979) argued that the process of explanation en-
ables cognitive systematization, i.e., creates new connections of meaning and relevance that make things more intelligible to us. As far as a piece of knowledge is not a part of an explanation, it remains a useless and disconnected part of one's conceptions.

Generation of intuitive explanation before obtaining scientific information makes differences between one's own conceptions and scientific conceptions salient and accessible to the agent. If scientific conceptions are assimilated without explicating one's own view, it is likely that potential differences or gaps of knowledge are not at all identified. As a consequence, the agent is likely to assimilate scientific knowledge without any conceptual restructuring and reproduce misconceptions or wrong theories later on in the process of inquiry.

2.5.2 Abduction and Conceptual Advancement

Cognitive theory of inquiry emphasizes the significance of an agent's own explanations and hypotheses in the process of inquiry. Explanation is a critical aspect of inquiry; it elicits elaborative processing and productive working on knowledge. In addition, explanation is closely connected with generation of new understanding and knowledge. The process of generating new hypotheses and theories is conceptualized by C. S. Peirce's (1955, 1957; see also Fann, 1970; Hanson, 1958; Rescher, 1976) theory of abduction. The theory of abduction is the only well-articulated conceptualization of reasoning which applies to advancement of understanding and creation of new knowledge. The importance of abductive inference in human reasoning
practices is based on the observation that humans are always functioning on the ba-
sis of imperfect and partial information (see Hautamäki, 1986; McDermott, 1990; Re-
scher, 1976; Shoham, 1990). Instead of logical inferences, assessment concerning
plausibility of different hypotheses is needed for dealing with this kind of epistemic
situation that is a rule, not an exception, in human lives. Modeling of abductive rea-
soning is a central problem for artificial intelligence (Falkenhainer, 1990; McDermott,
1990; O'Rorke, Morris, & Schulenburg, 1990) and cognitive science (Thagard, 1978,
1988).

According to Pierce (1955, 5.590), abduction covers all operations by which
theories and conceptions are engendered. Abduction is a process of generating ex-
planatory theories: from a surprising or unexpected phenomenon we construct a hy-
pothesis which would be a plausible explanation for that phenomenon. Pierce (1901,
7.202) emphasized that "an explanation is needed when facts contrary to what we
should expect emerge." There is a reason to believe in the hypothesis constructed if
it makes the surprising phenomenon understandable and expectable. Abduction is
based on intelligent guesses or conjectures on the basis of theoretical and practical
background knowledge.

Because there is no guarantee that an abductive inference is correct, it is im-
portant to derive logical consequences from these hypotheses and experimentally test
them so as to make a decision on the best explanation. Accordingly, within abductive
reasoning, one can distinguish two stages: mere abduction, which involves only the
initial formation of the hypothesis, and an inference to the best explanation, which in-
volves the evaluation of alternative generated hypotheses (Fann, 1970; Thagard, 1978, 1988, 1992). Harman (1965, 1986) argued that inference to the best explanation rather than (enumerative) induction, is the basis of reasoning in everyday life and science. In Harman’s (1965) framework, inference to the best explanation means inference from the fact that a certain hypothesis would explain the evidence to the truth of that hypothesis. Inference to the best explanation is based on accepting a hypothesis on the ground that it provides a better explanation of the evidence than is provided by alternative hypotheses. The best explanation, in Harman’s view, is one that is more plausible, explains more, is less ad hoc and maximizes explanatory coherence and minimize epistemic change. Inference to the best explanation is relative to a cognitive agent’s background knowledge and explanations available to him. Further, how carefully and systematically the alternatives are considered depends on the context and goals of inquiry. In an everyday context, a decision of the best explanation is usually based on plausibility considerations rather than experimentation (see Rescher, 1976). Moreover, abduction and inference to the best explanation are processes which people actually do, both in science and in everyday life (Thagard, 1988). It has been further asserted that plausible reasoning with incomplete knowledge, based on an abductive process, is an important aspect of an expert’s complex problem solving (e.g., Brown & Campione, 1996, p. 300).

Hatano and Inagaki (1992) argued that abduction plays an important role in comprehensive activity that focuses on construction of conceptual understanding: Abduction is the principal process of constructing mental models for explaining and un-
derstanding new phenomena in the biological domain. A central aspect of the abductive process is use of existing knowledge and models to make analogical inferences about a new puzzling phenomenon. They argued that the process of making abductive inferences is focused on answering explanation-seeking why questions and understanding the objects being investigated. When confronted with an unexpected phenomenon, young children are motivated to understand why their expectation has failed and how to integrate the new data with existing knowledge. However, an important condition for the abductive process to occur is that students encounter, often enough, a phenomenon that is against their expectations and recognize the difference between their own view and new information. Dialogical interaction with other inquirers may facilitate making of abductive inferences as far as it facilitates expression of one’s implicit assumptions, explication of cognitive commitments and explanation of one’s view to the others.

Several cognitive researchers (e.g., Cherniak, 1986; Craik, 1943; Harman, 1975, 1986; Rescher, 1979, 1987; Thagard, 1988, 1989, 1992) have argued that the most fundamental property of the human cognitive system is that it tends to construct a coherent internal representation of the natural and social environment. Explanatory coherence entails that explanatory relations between a subject’s beliefs are coherent (Harman, 1986; Thagard, 1988, 1989, 1992). Explanatory coherence can be seen as a process by which a subject makes sense of reality by creating spontaneous or implicit theories (Harman, 1986; Murphy & Medin, 1985). By an implicit theory, a cognitive agent is able to explain why or how something is the case, i.e., the theory pro-
vides a vehicle for increasing connections of intelligibility within one's belief system. The cognitive value of explanation is based on a process of facilitating integration of one's intuitive conceptions. One problem is that human knowledge structures are compartmentalized in nature (see Cherniak, 1986, p. 70); humans deal with the vast amount of information by organizing knowledge in memory into independent subsets. Due to our limited processing capacity, it is very difficult to recognize inconsistencies between these subsets of knowledge. However, by means of explanation, compartmentalized knowledge may be transformed into a more connected and systematic unity. By engaging in a process of articulating his or her conceptions, an agent is forced to carry out a profound search of memory, and, thereby, change a larger associated knowledge structure. Major changes emerge only gradually in a compartmentalized knowledge base, because old conceptions may hide within inactivated knowledge structures and surface only in special situations (see Rescher, 1979).

The process of explanation seems to facilitate epistemic change in the agent by furnishing special reasons for changing his or her view. Cognitive agents tend to be methodological conservatives: i.e., they try to manage as far as possible by using their existing conceptual systems, making only local corrections when necessary (Thagard, 1988, p. 154; see also Harman, 1986; Rescher, 1979). By engaging with an intentional process of explanation, one creates an epistemic need for constructing a more coherent and systematic conception. Through the process of explanation new knowledge structures emerge abductively which may provide a basis for advanced conceptual understanding. Further, elaborative processing seems to facilitate an
agent's ability to revise and extend his or her explanations, and apply these to new, but conceptually related, cases. This generative character of explanations is a very important aspect of conceptual understanding (Perkins et al., 1995).

2.5.3 Nature of Intuitive and Scientific Explanations

Several conceptual-change researchers have argued that people construct, on the basis of everyday experience, rather well-articulated theories (Carey, 1985; McCloskey, 1983a, 1983b). However, DiSessa (1983, 1988) has proposed, instead, that there are in ordinary persons no well-articulated intuitive theories, just disconnected fragments of knowledge or "knowledge in pieces." His analysis suggests that these knowledge-fragments are based on phenomenological primitives, i.e., simple abstractions from common experiences which are taken not to need any explanation. DiSessa's theory implies that children are sensitive only to phenomenal primitives, not underlying causal or theoretical connections. According to DiSessa (1988), "theory theories" attempt to produce a theory change by exposing and confronting the intuitive theory with evidence and arguments in order to facilitate theory change. The problem is that these theories are not so organized or coherent that they could be refuted by counter-evidence. DiSessa's contention is that deeper scientific understanding can be grounded only on a new and deeper systematicity.

Chi (1992) has pointed out that empirical studies support both the thesis that students' knowledge forms theory-like structures as well as the thesis that their knowledge is fundamentally fragmented. Chi (1992) and Keil (1989) asked, in order to
evaluate DiSessa's (1988) claims, whether it is possible that phenomenological primitives have theory-like properties. Keil's (1989, 1994) analysis provided extensive evidence of conceptual development in childhood by analyzing how young children learn to understand natural kinds and artifacts. His analysis concerning relationships between surface features and deep connections in children's conceptions supports 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 (Keil, 1989, 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. Moreover, Keil (1989, p. 249; see also Gopnik & Meltzoff, 1997) presented evidence that even pre-schoolers make inductions that go beyond mere appearance on the basis of their conceptual background knowledge. Karmiloff-Smith (1988, see also Karmiloff-Smith & Inhelder, 1977) came to a similar conclusion from analysis of children's activity in her well-known block-balancing task. Although elementary theories constructed by younger children were phenomenally oriented, older children's observations were mediated by theory. She argued that the latter were building a unifying and coherent theory to explain the problem in question.

Conceptual-change studies have found evidence for the existence of inconsistent beliefs; it has been argued that people are not able to tell the difference between theory and evidence (D. Kuhn, 1991, 1992; D. Kuhn, Damsel, & O'Loughlin, 1988). Yet some recent investigations have shown that even 7-10 year-old school children are able to select between two alternative explanations using metaconceptual criteria.
like empirical consistency, logical consistency and range of explanation (Samarapungavan, 1992; Sodian, Zaitchik, & Carey, 1991). These studies suggest that a great majority (70-90%) of children is able to do these kinds of inferences, although they are not always able to articulate the metaconceptual criteria used. Range of explanation, however, is the weak point of intuitive conceptions: such conceptions are often based on many ad hoc assumptions, and a new explanation frequently has to be constructed in order to deal with a new phenomenon.

Cognitive research on young children's explanations has revealed that they frequently produce analogical explanations while dealing with new problems (Hatano & Inagaki, 1992, 1995; Brown & Campione, 1994; 1995; Nersessian, 1992). According to an analysis of Holyoak and Thagard (1995), analogies may rely on mapping of properties, relations or systems. Young children rely frequently on the property analogies, i.e., use a property of a better known phenomenon to make sense of a new phenomenon: Hatano and Inagaki (1992, 1995), for instance, found evidence that young children's analogical explanations are frequently based on such analogies. Children tend to use their knowledge concerning human biological functioning for making inferences about biological kinds. The quality as well as quantity of these analogies appear to be dependent of the children's conceptual knowledge about one or another animal. Children with an extensive experience from taking care of goldfish, used their knowledge about human beings as well as goldfishes, to make inferences about a new kind of animal. Thus, conceptual knowledge mediated by practical experience of taking care of animals facilitated transition from similarity- to category-based
attribution (Inagaki, 1989). In their analogical or personifying inferences young children selectively attribute some human properties to the target object. These analogical explanations are often functional or empirical in nature.

It seems that many intuitive theories can be seen as ingenious abductive inferences, i.e., attempts to make sense and to achieve explanatory coherence in a situation in which scientific conceptions are not intelligible. Vosniadou (1991; Vosniadou & Brewer, 1992) analyzed children's conceptions of the earth. She showed that elementary school children construct ingenious mental models of the earth in order to understand counter-intuitive physical ideas such as the form of the Earth. Many of the models were based on a synthesis between intuitive and scientific conceptions. These models can be seen as unifying explanations which provide explanatory coherence, and correspondingly Vosniadou (1991, p. 225) argued that students' knowledge is not so fragmented as suggested by DiSessa (1988). Vosniadou and Brewer (1992) pointed out that "the argument in favor of the position that children are self-contradictory and inconsistent often does not take into consideration that what may appear as contradictory and inconsistent from the adult or expert point of view may not be contradictory from the point of view of the child" (p. 580).

A propensity to seek explanatory coherence is a fundamental principle of the human cognitive system (Cherniak, 1986; Craik, 1943; Rescher, 1979; Harman, 1986; Thagard, 1988). However, this explanatory coherence can be achieved in many ways; and a system which seems to be inconsistent and hopelessly fragmented, if considered from outside, may be seen as completely coherent from an agent's own
viewpoint. Consideration of rationality constraints on human cognition shows that coherence is always relative: due to the compartmentalization of human cognitive systems only locally coherent systems are possible to achieve (Cherniak, 1986). Just as research questions with false presuppositions can be useful (see Macmillan & Garrison, 1988), intuitive explanations can be productive even if they are not correct – as far as they function as “theories to work with” (Sintonen, 1991, p. 170), and provide a starting point of deepening inquiry. Absolutely true conceptions are not attainable; inquiry has to start with imperfect knowledge and with inconsistent premises. The main point is to ensure that one’s conceptions are progressing in the course of inquiry. Towards this end, it is very important that an agent acquire confidence that the world makes sense, although there are many things that are very difficult to understand, and continuously try to go beyond his or her current level of understanding and reach explanatory coherence at a higher level.

Human attempts to achieve a coherent model of reality are based on a process of explanation, not only on simple observation or empirical generalization. Both everyday and scientific thinking are based on processes of making theoretical inferences which go beyond immediately observed phenomena to underlying mechanisms and processes. These abductive inferences allow one to make sense of the reality by finding meaningful and relevant connections among observed phenomena. On the basis of plausibility considerations, an agent is able to make inferences to the best explanation. Change in view is a laborious process because concepts are not represented individually in the human mind but as conceptual systems (Thagard, 1990;
Harman, 1987). By engaging oneself with articulation of one's intuitive conceptions in a question-driven process, an agent is forming functional roles and conceptual systems that are likely to increase his or her problem-solving efficacy and facilitate conceptual advancement.

2.6 Distributed Cognition and Process of Inquiry

2.6.1 Socially Distributed Nature of Inquiry

Traditionally, cognitive theories have examined inquiry as an individual and mental process. As a consequence, cognitive theories have focused on analyzing how an individual agent processes mental representations (e.g., Fodor, 1981). Scientific thinking has traditionally been seen as a characteristic of an individual mind. However, in explaining human intelligent activity, both cognitive theory and current philosophy of science increasingly emphasize the socially distributed (or shared) nature of cognition (cf., Hutchins, 1991, 1995; Oatley, 1991; Pea, 1993; Perkins, 1993; Resnick, 1991; Salomon, 1993; see also Kitcher, 1990, 1993). Distributed cognition refers to a process in which cognitive resources are shared socially in order to extend individual cognitive resources or to accomplish something that an individual agent could not achieve alone. Human cognitive achievements are based on a process in which an agent's cognitive processes and the objects and constraints of the world reciprocally affect each other. Cognitive processes can be distributed between humans and machines (physically distributed cognition, Norman, 1993; Perkins, 1993) or between cognitive agents (socially distributed cognition). Salomon (1993, p. 112) has
pointed out that distributed cognitions form systems that consist of an individual agent, his or her peers, teachers, and socio-culturally formed cognitive tools.

2.6.2 Writing and Visualization as Cognitive Tools of Inquiry

The cognitive significance of distributed cognition is based on a fact that human beings have only limited cognitive resources such as time, memory, or computational power (Cherniak, 1986; Harman, 1986). Norman (1993, p. 43) argued that human cognitive resources are highly overestimated; without external aids humans have only a limited memory and reasoning capacity. Higher cognitive accomplishments presuppose that an agent uses the external world and his or her fellow inquirers as sources of knowledge, organizers of activity, and in general as extensions of his or her cognition. A critical condition for successful process of inquiry is adoption of socio-culturally developed cognitive tools or artifacts. By using cognitive tools, multiple forms of representation, and other artifacts inquirers are able to reduce the cognitive processing load and take on more complicated problems to solve than would otherwise be possible (Pea, 1993; Salomon, Perkins, & Globerson, 1991). Scientific thinking does not happen only in the mental plane, but requires different kinds of vehicles of externalization, as anthropological studies in scientific laboratories have revealed (e.g., Latour, 1988; Latour & Woolgar, 1979).

Both historically and cognitively most important has been development of tools for externalizing one's psychological processes and representations which have made epistemic achievements possible that were otherwise completely unattainable
Externalization is a process of transferring knowledge from Popper's (1972) world$_2$ (subjective knowledge) to world$_3$ (objective, cultural knowledge). The most important tools of externalization are writing and visualization. Writing forces an agent to derive certain conclusions from his or her beliefs and theories and thereby articulate them more thoroughly (Goody, 1977, 1987; Olson, 1991). Through externalization of conceptions, otherwise implicit meanings can be explicated and information represented in a more abstract and decontextualized form (Goody, 1977, 1987; Olson, 1988, 1991). Further, externalization requires an agent to explicate connections between his or her conceptions, and thereby connect together information from different points of view (cf. Minsky, 1975). This makes inconsistencies and illogicalities readily available to an agent, and establishes a cognitive need to construct more advanced conceptions. Through writing down questions and findings weaknesses of one's conceptions may become more salient. Written text can also be repeatedly scanned for eliminating inconsistencies (Goody, 1977). Explication of conceptions by writing and visualization is needed to overcome the compartmentalization of knowledge as well as to activate relevant background knowledge. Further, writing enables one to represent conceptual information visually, thereby facilitating explication concerning the inner relations of the phenomenon being explained (compare Pea, 1993). Through scientific visualization, advantages of the powerful human visual system can be used to facilitate conceptual understanding (Edelson, Pea, & Gomez, 1996; Latour, 1988; Latour & Woolgar, 1979).
Practices of reading and writing determine, to a great extent, how effectively cognitive resources provided by externalization are used in education. Writing can be seen as the most important tool of thinking, and it has a crucial significance in explanation and articulation of one's conceptions (Bereiter & Scardamalia, 1987a, 1987b, 1991a). However, according to Geisler's (1994) analysis of recent studies on school writing, students are not usually required to write extensively at school. The audience of writing is almost always the teacher, and the function of writing is most often to demonstrate that students have understood texts in question and acquired desired knowledge. Students are not encouraged to use writing for articulating their ideas in an extended way. Extensive thinking is not facilitated through writing assignments; such assignments do not usually require production of more than one or two paragraphs. Presumably as a consequence of practices of writing at school, students are generally not able to use knowledge in a transformative way in texts they produce. A comparison between expert and novices writers, carried out by Bereiter and Scardamalia (1987a, 1991), indicated that novice writers usually do not extensively develop their preceding ideas in the process of writing. Students tend to follow a knowledge-telling strategy, i.e., write down their ideas in the same form and order as those ideas come to mind without extending their knowledge or considering their text from the viewpoint of the audience. Several cognitive researchers have emphasized the importance of integrating writing and inquiry (Bereiter & Scardamalia, 1991; Brown & Campione, 1996). In order to facilitate extensive thinking, writing should be focused on constructing, articulating, and communicating knowledge. For such focus, com-
puter-supported collaborative learning environments, such as CSILE, designed to facilitate the use of writing as a tool of inquiry, provide strong support.

2.6.3 Social Interaction and Advancement of Inquiry

In the background of theories concerning socially distributed cognition are observations according to which many cognitive problems, which cannot be solved individually, can be addressed by combining limited knowledge and skills of several agents (Forman & Cazden, 1985; Hatano & Inagaki, 1991, 1992; Hutchins, 1995; Miyake, 1986; Norman, 1993; Oatley, 1991; Roschelle, 1992; Scardamalia & Bereiter, 1989). A fundamental source of advancement of inquiry is social communication and, in the context of science, scientific argumentation. Mead (1977) and Vygotsky (1978) argued that the basic mechanism of cognitive growth is communicative in nature; it is based on the 'resultant' of a communicative act in the case of Mead and on the Zone of Proximal Development in Vygotsky's (1978) framework. Through social interaction, contradictions, inconsistencies and limitations of an agent's explanations become available because it forces an agent to perceive his or her conceptualizations from different points of view. Limited cognitive resources can be overcome by distributing the cognitive load to several agents, each of whom is equipped with restricted powers of cognition. Externalization is an important prerequisite for socially distributed cognitive achievements: as a part of objective knowledge, externalized conceptions can be compared with the conceptions of the others; this opens a way to an agent's Zone of Proximal Development (Vygotsky, 1978).
Cognitive research on peer interaction indicates that sociocognitive conflicts emerging in interaction situations facilitate cognitive performances superior to those of the individual (Mugny & Doise, 1978; Piaget, 1980, 1985). Pairs of subjects tend to perform better than subjects working alone. Moreover, collaboration fosters the learning process of both less and more advanced students. Mugny and Doise (1978) argued that the learning process is more progressive when children with different cognitive strategies work together and engage in conflictual interaction. Although it is generally acknowledged that collaboration is a very important cognitive and motivational force required for fostering conceptual advancement (see, for example, Miyake, 1986; Forman & Cazden, 1985; Roschelle, 1992), there is a controversy concerning whether the interaction needs to be conflictual. Hewson and Hewson (1984) argued that emergence of a cognitive conflict does not guarantee conceptual advancement because it may be taken as a paradox and resolved by ignoring one of the conflicting elements. A study carried out by Chan, Burtis and Bereiter (1997) indicated that a cognitive conflict facilitated conceptual advancement on the condition that it was connected with active processing of knowledge. Characteristic of knowledge building activity was taking conflicting information as problematic, something that needs to be explained (Bereiter & Scardamalia, 1993). In addition, it may be plausible to assume that mere epistemic curiosity or puzzlement might fuel a need for epistemic change.

Miyake (1986) and Hutchins (1995) have argued that social interaction provides new cognitive resources for human cognitive accomplishment. According to Miyake's analysis, understanding is iterative in nature, i.e., it emerges through a series
of attempts to explain and understand processes and mechanisms being investigated. In a shared problem-solving process, agents who have partial but different information about the problem in question appear both to improve their understanding through social interaction (see also Oatley, 1991; Brown & Palincsar, 1989). Miyake (1986) and Hutchins (1995) argued that the cognitive value of social interaction appears to be based on the fact that human beings cannot keep more than one complex hypothesis activated at a time. Although an agent does not have an easily accessible cognitive mechanism for testing his or her hypothesis, this testing process occurs naturally with pairs of agents working together. Similarly, research on self-explanation effects, mentioned above, has revealed that explaining problems to oneself fosters cognitive achievements. Hatano and Inakagi (1992) as well as Brown and Palincsar (1989; Brown, 1988; Bielaczyc & Brown, 1994) argued, further, that deep conceptual understanding is also fostered through explaining a problem to other inquirers. In order to explain one's view to his or her peers, an individual student has to commit his or herself cognitively to some ideas, explicate his or her beliefs, as well as organize and reorganize one's knowledge (Hatano & Inakagi, 1992). Through this kind of process, inadequacies of one's understanding tend to become more salient. Moreover, social interaction fosters emergence of a more abstract conception than individual working (D. L. Schwartz, 1995). Therefore, distribution of a task among several agents has fundamental cognitive significance.

The cognitive value of externalization and social interaction is based on a process of making internal processes of thought visible (Brown, Collins, & Duquid, 1989;
Scardamalia & Bereiter, 1989). From a cognitive point of view, it is particularly important to transform internal and hidden processes of inquiry into a public form in which those can be examined and imitated. Advancement of one's inquiry can be fostered by making metacognitive processes (e.g., comprehension monitoring), which cannot normally be observed, "overt, explicit, and concrete" (Brown & Palincsar, 1989, p. 417; Brown & Campione, 1996). Hence it is plausible to assume that imitation of good cognitive practices and appropriation of more advanced processes of inquiry can be elicited by creating learning environments that mediate all stages of the process of inquiry, not just the end result. This, in turn, would allow students to become aware of their conceptual advancement as well as changes in their practices of inquiry.

Pea (1994) argued that computer-supported collaborative learning can foster transformative communication that facilitates new ways of thinking and inquiring in education. It seems that for the purposes of transformative communication, written communication, combined with face-to-face communication, is more effective than face-to-face alone because it requires more extensive thinking processes (Cohen, 1994; Lamon, 1992; Woodruff & Brett, 1993). CSILE facilitates transformative communication by providing sophisticated tools for written communication between students.
2.6.4 Cultures of Adaptive Expertise and the Process of Inquiry

Theories of distributed cognition imply that the subject of cognitive growth is a community of inquirers or a socio-cultural system rather than an individual agent. Reciprocal relationships between the nature of environment and the cognitive characteristics of an agent seem, to a great extent, to determine the nature of one's inquiry. The cognition of humans is adaptive in nature (see Anderson, 1990; Hutchins, 1995; Perkins, 1992; Scardamalia & Bereiter, 1996): Cognitive agents have a propensity to adapt to their environments, and, therefore, many characteristics of cognitive activity can be explained by analyzing the structure and functions of the environment rather than the mental capacities of individual agents involved. The nature of the environment of cognitive activity and corresponding cultural practices structure and shape cognitive activity.

From the pragmatic constraints on human cognition it follows that an agent attempts to adapt to his or her environment with limited cognitive resources. The goals of an agent and the context of cognitive activity determine how these resources are allocated between different cognitive tasks. All cognitive acts have their costs, and engagement with complex and reflective cognition especially requires a great deal of cognitive effort (Perkins, 1992). Therefore, it is not rational to use more than a "sufficient" amount of cognitive effort to carry out one's cognitive tasks. Examination of this "economy of inquiry" had a central role in C. S. Peirce's (1955, 1957; see also DeLanney, 1993; Misak, 1991; Rescher, 1978) pragmatic theory of inquiry.
Adaptive cognition provides an economical explanation for the generality of cognitive strategies that are non-optimal from a cognitive viewpoint, but appear to represent purposeful and useful adaptation to local conditions of the environment (Bereiter & Scardamalia, 1996; Perkins, 1992). Current educational practices do not usually make deepening conceptual understanding an “epistemologically desirable” (Cherniak, 1986) alternative. Traditional learning environments allow a student to manage and even succeed without engaging in an extensive process of thought. Participation in higher-level processes of inquiry tends to require, in traditional learning environments, cognitive efforts very much above what is needed for doing well at school (see Scardamalia & Bereiter, 1996). As a consequence, adaptation in current learning environments usually does not tend to elicit reflective thinking, complex cognition or higher-level inquiry (see Norman, 1993; Perkins, 1992; Scardamalia & Bereiter, 1996).

Yet there is evidence that certain environments facilitate adaptation through developing new cognitive competencies and higher-level expertise (Bereiter & Scardamalia, 1993). One may distinguish between first- and second-order environments. *First-order environments* are static in nature, and adaptation in these environments is oriented toward meeting a fixed set of conditions. In the *second-order environments*, by contrast, conditions to which an agent has to adapt change dynamically as a function of other people's progress in the environment (Bereiter & Scardamalia, 1993). Scientific research communities represent this kind of second-order environment that sets up progressively changing requirements. A community that sets up gradually
tightening requirements for an agent as well as provides support for higher-level accomplishments when needed, facilitates dynamic development of one's expertise. A very important condition for development of expertise is to go beyond the current level of accomplishment by continuously taking on more challenging problems to solve as accumulation of experience decreases cognitive processing load (Bereiter & Scardamalia, 1993). A social community could provide strong support for progressive problem solving, i.e., facilitates agents' working continuously at the edge of their competence, a practice critical for development of adaptive expertise.

There is a growing body of evidence that cognitive diversity and distribution of expertise promote knowledge advancement and cognitive growth. Kitcher (1989, 1993; Dunbar, 1995) showed that cognitive division of labor is an important prerequisite for advancement of science. Distribution of cognitive efforts allows the community to be more flexible and achieve better results than otherwise would be possible. Moreover, studies of Hutchins (1991, 1995) and Dunbar (1995) revealed that groups which consist of members having different but partially overlapping expertise were more effective and innovative than groups with homogeneous expertise. New pedagogical models as well as technology-based learning environments are emerging that are grounded on distributed expertise and which utilize cognitive diversity. The Fostering Communities of Learning approach, developed by Brown and Campione (1994, 1996), is a pedagogical model that is designed to take advantage of distributed expertise and cognitive diversity characteristic of communities of scientific practice. The approach is focused on adopting the goals, values, beliefs, and forms of discourse
characteristic of scientific practice. Conceptual advancement is facilitated by cultivating each student's own expertise. Students engage in a self-regulated and collaborative inquiry being, as a group, responsible for the task. They are guided themselves to monitor progress of their distributed inquiry. Social support for deepening inquiry could provide overlapping zones of proximal development (Vygotsky, 1978) in which students can operate at the edge of their competence (Brown & Campione, 1996). By collaborating with their peers and relying on powerful cognitive artifacts participants are able to go beyond their current level of cognitive accomplishment.

Theories of distributed cognition imply that socio-cultural cognitive systems have cognitive and epistemic characteristics different from those of individual agents (Hutchins, 1995). In order to facilitate development of higher-level processes of inquiry characteristic of scientific research, classroom practices should be restructured by imitating practices of scientific research communities rather than teaching scientific thinking skills as such (Bereiter & Scardamalia, 1989, 1994; Brown & Campione, 1996; Carey & Smith, 1995). All components of knowledge-seeking inquiry, such as setting up goals, research questions, explanations or search for scientific information, can be shared or distributed between inquirers. A technologically sophisticated collaborative learning environment designed by following cognitive principles could provide an advanced support for this kind of distributed process of inquiry, facilitate advancement of a learning community's knowledge as well as transformation of the participants' epistemic states through a socially distributed process of inquiry. A collaborative process of inquiry in the new learning environments seems to have the potential
to elicit some characteristics of the second-order environments, particularly to encourage students to work at the edge of their competence rather than rely on routine problem solving, and, thereby, create new conditions of cognitive adaptation at school.

The analysis, thus far, has revealed that human cognition is a socially distributed process in nature. However, a cognitive theory focused on explaining dynamic changes in human cognitive activity cannot manage without referring to changed individual cognitions. According to a dynamic interaction view, individual and distributed cognitions are in interaction and reciprocally affect each other (Salomon, 1993; Salomon et al., 1991). Salomon et al. (1991) have argued that distributed cognitive processes produce "cognitive residues" by enhancing an agent’s cognitive competencies which affect subsequent distributed activities.

Perkins (1993) has emphasized the importance of individual cognition in distributed cognitive processes because epistemological or higher-order knowledge is nowhere represented in a distributed cognitive system. He argued that epistemological knowledge, such as knowledge concerning strategies of inquiry, patterns of explanation, and forms of justification cannot become distributed because it is continuously needed for executing complex processes of inquiry. Perkins (1993) has proposed that in order to overcome cognitive processing load and participate in purposeful inquiry, epistemological knowledge should be in the person rather than physically downloaded; represented, for instance, in the structure and functioning of artifacts. Many weaker students, however, have inadequate higher-order knowledge needed for
regulating their process of inquiry in different domains of knowledge (Perkins, 1993; Perkins & Simmons, 1988). An optimal solution would be having the epistemological knowledge both in the person and physically downloaded. An important part of epistemological knowledge can be implemented in the design of a technology-supported learning environment and corresponding cognitive practices. For example, CSILE’s thinking types represent epistemological knowledge concerning critical aspects of inquiry that structure students’ cognitive activities without presupposing that the students themselves have epistemological awareness of the underlying principles.

2.7 Advancement of Knowledge-seeking Inquiry

2.7.1 Knowledge Advancement

The purpose of knowledge-seeking inquiry is to produce new knowledge and understanding that helps a community of learners to achieve their cognitive goals. From a cognitive viewpoint, success in knowledge-seeking inquiry can be assessed by evaluating advancement of the group’s knowledge as well as dynamic changes in the individual learner’s conceptions. These changes are reciprocally dependent from each other; optimally through working for advancing their communal knowledge, individual agents engage in activities that tend to facilitate dynamic changes in the meaning of their conceptions.

Bereiter and Scardamalia (1997) have analyzed practices of working with knowledge in school and in science. He pointed out that knowledge is produced at school mainly as a means for carrying out learning tasks and assessing results of
learning. These kinds of activities are focused only on making changes in an agent's mental state, i.e., oriented towards Popper's (1972) world$_2$ of subjective knowledge. However, knowledge production has a substantially different role in scientific research communities. It is characteristic of research laboratories to produce knowledge objects, such as a theory or a design, that have a permanent value and occupy Popper's world$_3$. Externalized knowledge can be shared and articulated, and extended by relying on the cognitive resources of the whole community. Scientific research produces new knowledge and understanding through criticizing, extending, elaborating, and transforming knowledge objects.

Practices of working transformatively with knowledge are facilitated by CSILE through providing students with an environment for working together with knowledge objects (Scardamalia et al., 1994). CSILE students are guided to create world$_3$ objects by constructing their own intuitive theories. CSILE's public database creates a sort of plane of objective knowledge, Popper's world$_3$ is, for a classroom, a plane in which students can jointly work toward advancing their communal knowledge. Students are engaged in productive working with knowledge objects in the same way as the scientific community is engaged with theory improvement. Scardamalia et al. (1994) argued that a very effective way of learning to understand and explain a knowledge object is to generate another object (e.g., hypothesis, theory) based on it. Even though inquiry cannot be grounded on any absolute presuppositions or truths (Rescher, 1979; Harman, 1986), one can evaluate how a revised theory is improved in comparison with its predecessors.
2.7.2 Dynamic Change in Concept Meaning

According to Austin (1962; see also Searle, 1969), asking and answering questions as well as requesting and providing explanations are illocutionary acts. By engaging students in a process of knowledge-seeking inquiry acts with illocutionary force can be elicited that foster epistemic change in the participants. By asking questions from themselves and along with fellow inquirers, the students can push each other to go beyond their current levels of understanding. In the process of articulating explanations for hypothetically answering his or her research questions, an agent is engaging in a process of explicating the meaning of his or her concepts. This opens a way for creating new connections of meaning and intelligibility within one's knowledge structure and, thereby, facilitates dynamic changes of one's concepts. A corresponding process in scientific inquiry is emphasized by Laudan (1977). He examined how conceptual advancement in science happens through careful clarifications and specifications of meaning. The cognitive value of students' generating their own explanations and hypotheses is grounded on the fact that the meaning of one's concepts is growing in the process of inquiry. The dynamic change of concepts' meaning is emphasized by a new pragmatic theory of meaning, according to which the meaning of a concept emerges and grows from the use of that concept (cf. Thagard, 1988; Nersessian, 1984, 1989, 1992a).

Dynamic change of the meaning of a concept was theorized in C. S. Peirce's (1955; 1991) semiotics and especially his ideas regarding interpretants (for analyses of Peirce's theory of meaning see Greenlee, 1980; Johansen, 1993; Litzka, 1990; Sa-
van, 1976; Shapiro, 1973). Peirce's semiotics implies that a concept's meaning is not merely its sense and referent in a given piece of time (compare Frege, 1970; Wittgenstein, 1981); it is determined by a concept's relation to previous and following ones. Peirce argued that the meaning of a sign is not a two-placed relation between sign and object but presupposes a genuine triadic relation between sign, object and interpretant: "A sign is only a sign in actuality by virtue of its receiving an interpretant, that is, by virtue of its determining another sign of the same object" (Peirce, 1955, pp. 99-100). An interpretant of a sign is itself a member of an infinite series of signs, a process in which each interpretant is a sign (representing an object) for a further interpretant. Thinking and action are interwoven in the process of meaning change; a sign is translated into a more determinated and articulated sign through the process of using signs. The interpretant's function is to continuously transform a sign, a process which makes that sign more specific and places it in a context of other signs, and thereby articulates its meaning more thoroughly. The process of meaning-change is based on the fact that a sign does not represent its object in all respects but only some particular point of view (compare Hautamäki, 1986). A meaning is never completely determinate but can always be further articulated. Thus, a concept's meaning is virtual, i.e., it does not only represent what is actually thought, but also new meanings emerging from a connection with subsequent thoughts (Rosenthal, 1990, p. 205).

The dynamic theory of meaning indicates that participation in a process of question-driven inquiry, aimed at the construction of new connections of meaning and relevance, is an important condition for advancement of conceptual understanding.
Peirce's analysis corresponds very closely to recent cognitive models of human thought that emphasize a close connection between thinking and action (see, for example, Minsky, 1975; Thagard, 1988). The meaning of scientific explanations cannot be directly assimilated without participating in solving of problems and finding answers upon which these explanations are constructed. Students cannot be expected to learn to understand the meaning of scientific concepts without themselves engaging in research-like activity focused on explaining the problems being investigated. New concepts emerge only when corresponding conceptual systems and functional roles are formed (see Harman, 1987; Thagard, 1988).

From the dynamic theory of meaning it follows that the meaning of an agent's concepts is continuously growing. In the educational context, conceptual change can be seen as a process in which the meaning of an agent's spontaneous concepts change to correspond to well-defined and articulated scientific concepts. Simultaneously, hierarchical relations between a student's concepts change while the intuitive organization of concepts is reorganizing to correspond to more articulated relations between scientific concepts (Carey, 1985; Vygotsky, 1962). This allows new ways of problem solving as well as the solution of new problems with a familiar structure. Weak conceptual change refers to gradual meaning change on the basis of existing conceptual structures. In the process, conceptual enrichment may happen as an agent adopts new concepts to structure his or her view. Moreover, an agent may go beyond weak conceptual change by adopting new abstract concepts and schemata. Radical or strong conceptual change entails that new core concepts and explanatory
systems emerge to restructure concept-concept relations in a domain (Carey 1985; 1986; see also Vosniadou & Brewer, 1987, 1992; Vosniadou, 1991; Thagard, 1990). An important aspect of radical conceptual change is not only to adopt new ones but replace old cognitive commitments as well. It seems plausible to assume that adoption of new theoretical concepts and explanations has an important role in radical conceptual change. Radical conceptual change thereby affects ontological commitments, as has been suggested by Carey (1985, 1986) and Chi (1992).

2.7.3 Metacognitive and Epistemological Change

Knowledge-seeking inquiry facilitates development of students' metacognitive skills by encouraging students to take responsibility for planning, regulation and evaluation of the process of inquiry (Scardamalia & Bereiter 1987a, 1987b, 1991). Further, a question-driven process of inquiry facilitates activation of tacit knowledge and provides metaknowledge about an agent's own knowledge (Macmillan & Garrison, 1988). Extensive participation in and reflecting on in-depth inquiry fosters development of an agent's metacognitive skills. By examining one's problem or intuitive theory with the help of new information, the agent may become aware of his or her inadequate presuppositions or background assumptions. A comparison between one's own intuitive and well-established scientific theories tends to make weaknesses and limitations of one's conceptions salient to the agent. Monitoring progress of one's conceptual understanding facilitates metacognitive awareness of knowledge-seeking inquiry.
Further, socially distributed process of inquiry provides strong support for development of the participants' metacognitive skills. Social interaction between participants forces them to consider their conceptions from the viewpoint of the others, and this facilitates a growing awareness of one's own knowledge and beliefs. Collaborative learning in which thought processes are externalized in the form of public discourse provides an agent access to other participants’ processes of thought, supporting development of the agent’s metacognitive skills. A metacognitive environment provides structures and activities that foster monitoring of one's own and the other students' comprehension and reflect advancement of inquiry (Brown & Campione, 1996). Further, computer-supported collaborative learning appears to engage students to participate in in-depth inquiry over substantial periods of time and to provide socially distributed cognitive resources for comprehension monitoring and other metacognitive activities. Active participation in comprehensive activity may not only support advanced conceptual understanding, but also emergence of new metacognitive beliefs about knowing and particularly about the importance of understanding (Hatano & Inagaki, 1992).

Further, it may be argued that intensive participation in knowledge-seeking inquiry also facilitates epistemological change. Following Snir, Smith and Grosslight (1995), three levels of approaching natural phenomena can be distinguished. At the empirical level students study directly observable facts about natural phenomena and form empirical generalizations based on these facts. This empirical level dominates current elementary-level education. However, it does not help students to understand
the fundamental role that problems, hypotheses and hypothesis testing play in knowledge advancement. At the theoretical level, however, students inquire into the current scientific theories by which the observed facts can be conceptualized and explained. The theoretical level is concerned with relations between theories used to conceptualize empirical phenomena. At the third, metaconceptual level students learn to conceptualize methods and processes needed in scientific inquiry, and especially the metaconceptual principles that can be used to evaluate explanations. They reflect about the epistemological basis of the theoretical level. Carey and Smith (1995) have argued that metaconceptual knowledge about science can be learned only through actively constructing scientific understanding and reflecting on this process. Deep conceptual understanding of science can be achieved only through approaching all the three levels of scientific knowledge.

Epistemological or metaconceptual knowledge has a crucial role in educational inquiry (Carey & Smith, 1995; Perkins et al., 1995; Snir et al., 1995). It is plausible to assume that the process of knowledge-seeking inquiry leads not only to development of one's metacognitive skills but also to a growing epistemological awareness of the process of inquiry. Presumably, students' epistemological knowledge and beliefs, such as their knowledge concerning the norms of explanation and justification, significantly affect the nature of the process of inquiry. It is likely that through participation in a process of knowledge-seeking inquiry, students are learning epistemological or metaconceptual knowledge concerning the nature of scientific inquiry.
As mentioned before, several conceptual-change investigators have emphasized the importance of epistemological or metaconceptual knowledge (see DiSessa, 1988; Hewson, 1985; Hewson & Hewson, 1984; Posner, Strike, Hewson, & Gertzog, 1982; Strike & Posner, 1985). They have argued that conceptual change is unlikely to happen without epistemological commitment to systematicity in general and to internal consistency, generalizability, and parsimony in particular. However, epistemological commitments cannot be adopted simply by being told about them. A crucial prerequisite for the emergence of new epistemic commitments appears to be intensive participation in the process of question-driven inquiry in which one's epistemological awareness and more sophisticated epistemological commitments have a chance to emerge. A process of articulating explanations for answering one's research question, comparing different explanations and constructing of a more unified conception for dealing with the problem-area under investigation presumably facilitates development of new epistemological commitments. If only one explanation is provided, there may not be any reflection on the possible range of explanation or the relation to empirical evidence. Through making inferences to the best explanation, a higher-level cognitive system can be created for conceptualizing the process of inquiry, becoming aware and gradually changing one's epistemological commitments. However, new epistemological commitments cannot be formed without participating in corresponding processes of higher-level inquiry. Therefore, conceptual change should be seen as a multi-level process presupposing changes at the epistemological, ontological and methodological levels. None of the levels alone is sufficient.
Morrison and Collins (1996) referred to epistemological change as *epistemic fluency*, the ability to recognize different epistemic games and corresponding concepts. Further, it entails an ability to practice a culture’s epistemic games and corresponding epistemic forms, goals, rules, and strategies. The authors argued that technology-based learning environments, designed by following constructivist principles, facilitate emergence of learning communities that have access to particular epistemic games. Epistemic fluency develops through social interaction with other members of a community of practice. They pointed out, further, that learning environments such as CSILE or CoVis (see Edelson et al., 1996) are specifically designed to support certain productive ways of working with knowledge, and thereby function as simulation environments to play epistemic games. There is evidence, for example, that CSILE’s thinking types *Problem, My Theory, New Learning, Plan, Higher Level Question, and Comment* structure cognitive activity in a way that corresponds to moves in the knowledge-seeking or interrogative process.

### 2.8 Research Aims

The present investigation is intended to analyze 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. Young children cannot, naturally, be expected to participate in very sophisticated forms of scientific inquiry. However, regardless of the apparent limitations of young children’s cognitive resources, it seems worthwhile to investigate whether their inquiry may have characteristics that even remotely correspond to the cognitive prac-
ties of scientific inquiry. The main problem investigated was whether 10- and 11-year-old children are capable of showing any or all of the following three principal features of scientific thinking, namely: 1) engagement in deepening levels of explanation, 2) progressive generation of subordinate questions, and 3) collaborative effort to advance explanation. On the basis of the research review presented above, these principal features of scientific inquiry appear to be both essential aspects of pursuing scientific research and within the pragmatic limits of school children's cognitive resources. In the following each of these principal feature will be shortly described.

2.8.1 The First Principal Feature of Scientific Inquiry: Engagement in Deepening Levels of Explanation.

Scientific inquiry aims at explaining complex phenomena by constructing unifying explanations that rely on a minimal set of independent assumptions (Friedman, 1974; Kitcher, 1989). Unexpected or puzzling empirical phenomena are explained in science by generating hypotheses and theories. In many cases, observable phenomena are explained by constructing theoretical concepts that refer to unobservable theoretical entities (Salmon, 1989). Thus, characteristic of the epistemology of scientific inquiry is reliance on theoretical or abstract models of the world instead of generalizations made directly across observables. It seems worthwhile to investigate whether young children are able to participate, even in an elementary form, in the same sort of theory-driven or explanation-oriented process of inquiry that characterizes scientific research. Evidence of this kind of epistemology in the context of school children's inquiry would be participation in a process of generating hypotheses and explanations, and processing of explanatory instead of purely factual or descriptive
information. Such activities would reflect a movement from common sense epistemology or naive realism towards a more sophisticated scientific epistemology in which theories and models play an important role.

Further, scientific inquiry is progressive in the sense that it is focused on continuously going beyond existing explanations and producing new understanding. Conceptual advancement or conceptual change provides evidence of progress both in science and in the learning process. An important criterion for assessing elementary school students’ process of inquiry is to evaluate whether it leads students to seek the progressive advancement of explanation characteristic of scientific inquiry. Although elementary school students’ intuitive theories would not have, in thorough fashion, essential qualities of scientific explanations, such as empirical and logical coherence, it seems important to investigate whether such students are able to commit themselves to progressive improvement of their theories and prefer explanatory scientific information over their intuitive knowledge.

2.8.2 The Second Principal Feature of Scientific Inquiry: Progressive Generation of Subordinate Questions.

Pursuit of problem and question-driven inquiry has a fundamental role in scientific research (Bereiter, 1992; Hintikka, 1985; Laudan, 1977). Characteristic of scientific inquiry is participation in an interrogative process of question transformation, progressive generation of new specific questions out of principal ones, and working with these emergent problems arising in the course of inquiry (Hintikka, 1981, 1985; Sintonen, 1990a). The principal question cannot usually be immediately answered except
through obtaining answers to a series of small subordinate questions. Small questions form the basis of each interrogative step, guide the search of knowledge, and provide a part of the information needed to answer the principal question. Generation of new questions for answering one's principal question encourages one to make a cognitive commitment to solve one's problem, elicits activation of what one already knows, and provides heuristic guidance in the search for new information. The cognitive value of transforming one's initial question into a series of more specific questions is emphasized by several philosophers of science (Hintikka, 1991; Sintonen, 1990a) as well as cognitive researchers (Ram, 1991; Scardamalia & Bereiter, 1991, 1992; Schank, 1986; Simon, 1977). Therefore, I analyzed the nature of research questions generated by elementary school students and examined whether they are able to engage in an extended process of generating subordinate questions for answering their principal research questions.

2.8.3 The Third Principal Feature of Scientific Inquiry: Collaborative Effort to Advance Explanation.

Scientific inquiry is not an individual enterprise, but a socially distributed process that builds on cultural-historically created knowledge and relies on cognitive resources embedded in community of researchers and division of cognitive labor (e.g., Bereiter, 1994; Kitcher, 1990, 1992; Oatley, 1990). In scientific communities, advancement is made through scientific argumentation and processes of peer review and publication. A collaborative effort to work toward more complete and coherent understanding is characteristic of progressive scientific discourse. In science, investigators are not good at stepping outside their own theories, so conceptual change of-
ten comes when other people request clarifications, make suggestions or offer alternative interpretations of an investigator’s theory or data. The CSILE environment is designed to provide support for organizing a classroom to function according to a collaborative scientific community. In order to assess whether school children’s peer interactions shared characteristics of progressive scientific discourse, it is important to analyze whether between-student communication is focused on advancing explanations and other cognitive goals of inquiry instead of merely social purposes. Further, the extent to which each student is able to facilitate advancement of his or her fellow students’ conceptual understanding as well as take the other students’ suggestions or requests of clarification into consideration in further articulation of their own explanations provides evidence of progressive discourse characteristic of scientific inquiry.

It is generally believed that children are not capable of participating in these kinds of advanced scientific processes of inquiry, and, therefore, conventional pedagogical practices are not aimed at encouraging them. However, new computer-supported learning environments emerging from cognitive research promise to facilitate participation in these higher-level processes of inquiry in education. Several important aspects of knowledge-seeking inquiry characteristic of scientific research outlined above are implemented in the structure of the Computer-supported Intentional Learning Environment, CSILE, and corresponding cognitive practices. CSILE is designed to engage students with an extensive process of setting up research questions, generating and improving their own intuitive explanations and searching for scientific information. Participation in all aspects of the process of knowledge-seeking
inquiry is facilitated by use of CSILE's Thinking Types. Moreover, a special kind of Thinking Type (INTU) facilitates articulation of new specific research questions and promotes the agent's engagement in deepening inquiry. Further, CSILE fosters socially distributed inquiry by providing tools for sharing of cognitive achievements. The systems database facilitates objectification of knowledge, i.e., collaborative working for developing shared knowledge objects. CSILE students' learning community is jointly responsible of their knowledge advancement. The system provides the users with advanced tools for communicating with the other members of the learning community. Thus, on the evidence reviewed above, it appears that the CSILE environment has a potential to facilitate participation in higher-level practices of inquiry as well as create new conditions of adaptation at school.

The study focused on analyzing grade 5 and 6 students' process of knowledge-seeking inquiry in the CSILE environment. Because CSILE students' written productions provided the data, one did not obtain direct information about the actual psychological processes involved. Educational effects of CSILE were not directly examined; such an examination would have required a comparison between effects of conventional educational practices and practices of working with CSILE that was not possible to carry out in the context of the present study. Numerous studies, however, have provided evidence that CSILE learning approach produced higher-level school achievements and gave a considerable advantage over conventional approaches (Lamon et al., 1996; Scardamalia & Bereiter, 1994, 1996; Scardamalia, Bereiter, Brett, Burtis, Calhoun, & Smith, 1992; Scardamalia, Bereiter, & Lamon, 1994). In or-
der to examine how CSILE can be used to facilitate higher-level research-like processes of inquiry at school, it seems important to compare the combined effect of the CSILE environment and practices of knowledge-seeking inquiry with the use of the CSILE environment without any profound pedagogical changes. This kind of comparison appears to be more plausible than a direct comparison with conventional educational practices. A problem of the latter kind of comparison is that students in CSILE classes and normal classes are engaged with very different kinds of activities. Further, it is important to notice that CSILE provides only a technical infrastructure for knowledge-seeking inquiry; hence it can be used also as a new means towards traditional ends (see Salomon, 1997). In order to have significant pedagogical advantages, CSILE use should be intentionally grounded on practices of knowledge-seeking inquiry. Thus, an important aim of the study was to examine how different practices of doing computer-supported collaborative learning influenced the epistemological nature of the students’ inquiry.
3. METHOD

3.1 An Overview of Method

The purpose of the study was to analyze whether and to what extent CSILE students' process of knowledge-seeking inquiry exhibited the principal features of scientific inquiry. Table 3-1 presents a summary of the five studies carried out and the principal features of scientific inquiry analyzed in each study. The analysis focused on CSILE students' research questions, intuitive theories, scientific information sought by them, and between-student interaction mediated by CSILE's database. Measures derived from the philosophy of science were used to examine the epistemological nature of CSILE students' inquiry. Although the main problem of the study was determined at the point of design of the study, the more specific aspects of inquiry examined in the five studies emerged only after the analyses were completed.

In the first two studies, I examined how CSILE students' culture of inquiry changed in two CSILE classrooms (A and B) across a three-year period. The rationale of the analysis was that advanced practices of CSILE use may not be completely understood without examining how the recent culture of inquiry emerged. CSILE appears to be a developing culture in which higher forms of inquiry emerge gradually through a process of continuously exploring, testing and evaluating different ways of using CSILE to facilitate higher-level practices of inquiry.
Table 3-1.
An Overview of the Five Studies Carried out to Analyze the Epistemological Nature of CSILE Students’ Inquiry

<table>
<thead>
<tr>
<th>STUDY</th>
<th>DESCRIPTION</th>
<th>PURPOSE OF THE STUDY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>An analysis of change in CSILE students' culture of inquiry in classrooms A and B over a three-year period</td>
<td>The purpose of the study was to examine changes in the epistemological nature of knowledge produced by CSILE students over a three-year period. The problem addressed was whether CSILE students were capable of engaging in processing of knowledge at a deep level of explanation instead of being bound to surface-level phenomena (the first principal feature of scientific inquiry).</td>
</tr>
<tr>
<td>2</td>
<td>An analysis of change in CSILE students' discourse interaction in classrooms A and B over a three-year period</td>
<td>The purpose of the study was to analyze how the object of CSILE students' discourse interaction changed over a three-year period. The problem addressed in the study was whether elementary school students are capable of engaging in explanation-oriented discourse interaction that facilitates improvement of their explanations (the third principal feature of scientific inquiry).</td>
</tr>
<tr>
<td>3</td>
<td>An analysis of the nature of explanation and conceptual advancement for the students in classroom A</td>
<td>The purpose of the study was to arrive at a deeper analysis of CSILE students' explanation-oriented process of inquiry by examining in the context of physics and biology how the level of explanation changed from the beginning to the end of a project (the first principal feature of scientific inquiry). The study focused on examining change in the frame of CSILE students' intuitive explanations (functional, physical, empirical, and theoretical) and assessing each student’s conceptual advancement in physics and biology.</td>
</tr>
<tr>
<td>4</td>
<td>An analysis of how generation of subordinate questions influenced on conceptual advancement for the students in classroom A</td>
<td>The problem addressed in the study was whether elementary school students are capable of engaging in progressive generation of subordinate questions for answering their principal questions (the second principal feature of scientific inquiry). The study was, further, focused on analyzing relations between the students’ level of explanation and their process of question transformation (relations between the second and first principal features of scientific inquiry).</td>
</tr>
<tr>
<td>5</td>
<td>An analysis of how peer interaction influenced on conceptual advancement for the students in classroom A</td>
<td>The problem addressed in the study was to deepen the analysis of peer interaction within classroom A and examine whether and how categories of between-student interaction facilitated deepening levels of explanation (relations between the third and first principal features of scientific inquiry).</td>
</tr>
</tbody>
</table>

The comparison between classrooms A and B was intended to permit examination of how different practices of computer-supported collaborative learning affected
the epistemological nature of the students' inquiry. The analysis focused on examining how CSILE students' culture of inquiry—and, correspondingly, contents of their productions—changed from one year to the next in classrooms A and B. Only a few students, however, used CSILE more than one year, so that the analysis did not reveal information about change in individual students’ inquiry. Rather, the analysis provided information concerning change in CSILE students' culture of inquiry as a whole. However, a small group of students were in these groups for over two years, allowing an analysis of how individual students’ inquiry developed in relation to changes at the level of classroom culture; this was one of the foci of the first study.

The first study focused on analyzing how the epistemological nature of knowledge processed by CSILE students within classrooms A and B changed over a three-year period. A problem addressed in the study was whether CSILE students were capable of engaging in deepening levels of explanation characteristic of scientific inquiry (the first principal feature of scientific thinking). By using a five-step scale for assessing explanatory level of knowledge produced by students, I examined whether the students were generating and using factual and descriptive, or explanatory knowledge. Further, an engagement with problems of explanation and understanding was regarded as an important indication of engagement with explanation-oriented process of inquiry. As mentioned above, explanation-seeking research questions are ultimately connected with conceptual understanding, and the extent to which an agent is engaged with generating such questions is regarded as strongly determining his or her epistemology of inquiry.
The second study focused on how the epistemological nature of network-mediated peer interaction within classrooms A and B changed across the three-year period studied. The problem addressed in the study was whether the CSILE students' written communication mediated by the CSILE network facilitated advancement of their explanations (the third principal feature of scientific inquiry). Accordingly, I examined whether the object of the students' communication was linguistic form, factual information, explanatory knowledge or methods of inquiry. The quality of communication between the students was assessed by examining explication of referential relations of their comments, i.e., whether they explicated reasons for their agreement or disagreement in a way analogous to scientific discourse.

The last three studies focused on analyzing in detail processes of inquiry for students in classroom A during the last year investigated. The third study aimed to deepen the analysis of CSILE students' explanations through a detailed analysis of the nature of classroom A students' intuitive explanations and scientific information sought by them in the context of physical and biological study projects. The purpose of the third study was to assess whether students from classroom A were able to overcome their, in many cases, inadequate intuitive theories, and prefer more scientific physical and theoretical explanations, i.e., made conceptual advancement (the first principal feature of scientific inquiry). Conceptual advancement was assessed by using scales constructed for evaluation of a student's productions as a whole. Conceptual advancement entails that a more scientific frame of explaining the problems being investigated is adopted and new explanatory concepts introduced in the course
of inquiry. Conceptual advancement is an indication of possible conceptual change, i.e., change in the students’ conceptual structures. Strong restructuring of knowledge structures or conceptual change, however, cannot be assessed on the basis of students’ written productions. Nevertheless, a series of explanations posted into CSILE’s database over several weeks during a given project provides evidence of conceptual advancement, i.e., indicates whether later conceptions were more articulated than the earlier ones. Expert evaluations of three internationally known philosophers of science were used to assess CSILE students’ conceptual advancement. The analysis focused only in classroom A because the results of the first two studies indicated that students from classroom B did not systematically produce explanations.

The purpose of the fourth study was to analyze the relationships between CSILE students’ conceptual advancement (the first principal feature of scientific inquiry) and the progressive generation of subordinate questions (the second principal feature of scientific inquiry). In other words, the study assessed how the students transformed their principal research questions to new, more specific ones and how students’ commitment to an extended and in-depth interrogative process of inquiry affected their conceptual advancement. Further, the cognitive value of CSILE students’ research questions was assessed by the three philosophers of science.

The CSILE environment enables the students to communicate in parallel with each other and provides them access to each other’s productions. The purpose of the fifth study was to examine whether between-student communication mediated by the CSILE environment fostered the students’ conceptual advancement and provided
socially distributed resources for organizing one's inquiry (relations between the third and first principal feature of scientific inquiry). The analysis focused on identifying categories of communication that appeared to facilitate advancement of the students' inquiry, such as comments requesting explanation or clarification and comments providing explanation. Further, the cognitive value of CSILE students' peer interaction was assessed by three highly respected philosophers of science.

3.2 Participants: Classrooms A and B

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 two parallel grade 5 and 6 classes over a period of three years (1989-1992) at an inner-city public school in Toronto, Canada. In the school studied a larger than normal proportion of children came from middle-class and upper middle-class homes. However, the student population was ethnically heterogeneous, and included a number of students from educationally disadvantaged homes (see Scardamalia et. al., 1992).

From a methodological viewpoint it was problematic that although the experimental classrooms consisted of both grade 5 and grade 6 students, most individuals spent only a single year in a CSILE class. A few students stayed in the classes for both grades. However, this design of the CSILE experiment was an intentional deci-
sion intended to facilitate enculturation of new students into practices of CSILE use (see Hewitt, 1996). In classroom A, the teacher attempted to guide the group to go beyond its earlier achievement by teaching the best practices, thus far developed, to a new student group in the beginning of each academic year:

Each year, the goal was to improve on the previous year’s attempt to foster a Knowledge-Building Community. In the spring, the performance of the class was evaluated, and comparisons were made to the performances of previous classes. This process helped the teacher assess the success or failure of his interventions, and also suggested possible areas for further experimentation. In summary, the annual turnover of the student population and the subsequent efforts at re-establishing a collaborative, knowledge-building culture, resulted in an iterative research approach in which each ‘iteration’ was a year in length. (Hewitt, 1996, p. 21).

Progressive changes in classroom A’s inquiry were captured by analyzing how their culture of inquiry changed from one year to another. The CSILE experiment was carried out in a normal (Canadian) school environment in which a teacher usually works with same grade level from one year to another. Within these conditions the iterative approach of working repeatedly with the same grade level appeared to facilitate progressive changes in pedagogical practices. As a consequence, different students studied with CSILE in different years, and only a few students remained in the classes across a two-year period. Apparently, “design experiments” (Brown, 1992) carried out in real-world contexts do not correspond very well to common methodological norms.

The subjects were all the students in two CSILE classes. During the three-year period analyzed, 145 students in total worked with CSILE in one of the groups. However, 112 of these 145 students worked only one academic year with CSILE and 33
students used CSILE over a two-year period (thus, there appeared to be altogether 178 students in statistical analyses). Thus, the research material allowed a detailed examination of the students' inquiry within one year but only restricted analysis concerning long-standing effects of CSILE use. In order to deal with these limitations, the CSILE groups were compared at two levels. The first was based on a descriptive analysis of the evolution of culture of inquiry in the groups across the period studied. This analysis provided information only about change in a group's culture of inquiry because different students used the system each year. Table 3-2 presents a summary of 178 students who worked with CSILE for one or two years, and whose data were used in the descriptive analysis.

<table>
<thead>
<tr>
<th>GROUP</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>%</td>
<td>N</td>
<td>%</td>
</tr>
<tr>
<td>Classroom A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One year</td>
<td>20</td>
<td>32.8</td>
<td>19</td>
<td>31.1</td>
</tr>
<tr>
<td>Two years</td>
<td>11</td>
<td>18.0</td>
<td>13</td>
<td>21.3</td>
</tr>
<tr>
<td>Classroom B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One year</td>
<td>16</td>
<td>26.2</td>
<td>9</td>
<td>14.8</td>
</tr>
<tr>
<td>Two years</td>
<td>14</td>
<td>23.0</td>
<td>20</td>
<td>32.8</td>
</tr>
<tr>
<td>TOTAL</td>
<td>61</td>
<td>100.0</td>
<td>61</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Note. The frequencies of the Table do not represent the number of different students working with CSILE because 33 students worked in the groups for two years, and appear twice in the statistics. During the period analyzed 145 different students worked in the groups, 112 for one year and 33 for two years. Further, some of the students who appeared in statistics only once had started their CSILE studies already before the beginning of the period investigated so that they were studying with CSILE for their second year.
The second level of analysis concerned a small group of students – 33 students, as earlier stated – who worked with CSILE across a two-year period allowing examination concerning the effects of CSILE experience from one or another study group. As shown in Table 3-3 some of the students worked in classrooms A or B for the two-year period, and some of them switched study groups after one year of CSILE study. Through an analysis of these students’ inquiry, I examined how the CSILE experience and particularly change of a study group affected these students’ inquiry. The results of this analysis were related to changes in the classroom culture as a whole.

Table 3-3.
Groups of CSILE Students Working for Two Years in Classrooms A or B

<table>
<thead>
<tr>
<th>GROUP</th>
<th>n</th>
<th>Year 1</th>
<th>Year 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-to-A</td>
<td>8</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>B-to-B</td>
<td>10</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>A-to-B</td>
<td>9</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>B-to-A</td>
<td>6</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>TOTAL</td>
<td>33</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CSILE students’ processes of inquiry were related to their ability level and gender. Ability level represents the students’ school achievements assessed by the Canadian Test of Basic Skills (the CTBS), which did not vary in a statistically significant way between classrooms A and B. However, due to the nonexperimental context of carrying out the CSILE experiment, the students were selected for classrooms A and B as a part of normal school administration. Although assigning the students to these
two classes was reported by teachers and principal to be random (Scardamalia et al., 1992), the gender distribution of the students in the classroom was outside of what might be expected with randomized sampling (see Table 3-4). The relative proportion of female students was larger in classroom A than in classroom B during year 3 ($\chi^2=7.1, df=1, p<.008$); during the two earlier years there were not corresponding statistically significant differences in the gender distribution of the groups. Because comparison between the classes was an important aspect of the study, also those students who studied with CSILE over a two-year period are included into Table 3-4 so that the number of cases (n=178) does not correspond to the number of students (n=145) that worked in the groups.

Table 3-4.
CSILE Students' Gender, and Study Group

<table>
<thead>
<tr>
<th></th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td><strong>GROUP</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Classroom A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>17</td>
<td>54.8</td>
<td>19</td>
<td>59.4</td>
</tr>
<tr>
<td>Male</td>
<td>14</td>
<td>45.2</td>
<td>13</td>
<td>40.6</td>
</tr>
<tr>
<td>TOTAL</td>
<td>31</td>
<td>100.0</td>
<td>32</td>
<td>100.0</td>
</tr>
<tr>
<td>Classroom B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>16</td>
<td>37.5</td>
<td>14</td>
<td>55.6</td>
</tr>
<tr>
<td>Male</td>
<td>14</td>
<td>62.5</td>
<td>15</td>
<td>44.4</td>
</tr>
<tr>
<td>TOTAL</td>
<td>30</td>
<td>100.0</td>
<td>29</td>
<td>100.0</td>
</tr>
</tbody>
</table>

*Note.* The frequencies of the Table do not represent the number of different students working with CSILE because 33 students worked in the groups for two years, and appear twice in the statistics. During the period analyzed 145 different students worked in the groups, 112 for one year and 33 for two years.
Information about the time used in working with CSILE by the groups was available only from year 2. On average, the students worked with CSILE 74hr ($SD = 59hr$) during year 2. This represents only the actual time spent working with CSILE, writing and doing charts; the study projects carried out by the students also required that they use at least the same time for individual or small group work searching out and analyzing information. The mean time used for working with CSILE did not significantly vary between classroom A ($M = 77hr$, $SD = 56hr$) and classroom B ($M = 71hr$, $SD = 63hr$). An assumption that the groups used approximately the same amount of time for working with CSILE during each year analyzed was supported by the fact that the groups every year produced approximately the same number of CSILE notes (each year approximately 2000-2500 notes per class).

3.3 Study Material: The CSILE Database

The study was based on qualitative analysis of CSILE students' written productions posted to the system's database during three academic years. In working with CSILE, the students produced daily, or at least several times a week, computer entries called "notes" in the context of their study projects. Textnotes, comments and charts formed the three main categories of notes. Each production (or "posting" to the database) contained identification information including the number of the note, the (student) author's student number, the date of creating the note as well as topic and student-generated keywords. The notes provided content-rich information about the students' inquiry. Further, the notes were in time-order providing information about development of each student's conceptions from the beginning to the end of a study
project. The analysis was focused on the students' research questions and intuitive explanations and scientific information that together represented approximately 90% of the contexts of textnotes (see Figure 3-1). The textnotes included, in addition, plans, references and other kinds of unstructured material (e.g., the students' narratives); these classes of material, that were neither systematically produced by each student nor homogeneous across years, were left unanalyzed.

**Figure 3-1.**

**Categories of CSILE students' productions analyzed in the study.**

Brown (1992, p. 173) argued that in cognitive research on educational practices there is a tendency to "rest claims of success on a few engaging anecdotes or particularly exciting transcripts." In order to avoid this kind of weakness, a major part of CSILE students' productions was selected for the analysis instead of taking a smaller sample of students and their productions. However, the CSILE students produced yearly about 1000-1500 pages of text per class that was in the form of a hypermedia database having a very complex internal link-structure. Regardless of the unmeasurable amount of work involved, this approach seemed to be justifiable because it provided generalizable information about CSILE students' inquiry, taking the students as a whole; the approach enabled me to determine whether the processes
analyzed concerned just a few students or represented a general phenomena in the database.

The methodological choice to focus analysis on CSILE students' written productions was based on an assumption that writing mediated by a computer-supported learning environment requires explication and articulation of one's conceptions and facilitates reflective communication between students. However, analysis of students' written productions brings up certain other methodological problems. A general problem of analyzing verbal records of problem-solving processes is that some subjects do not verbalize all steps of their inquiry (see Chi, 1997). The incompleteness problem of verbal analysis is even more serious when analyzing written productions. There were considerable individual differences concerning productivity of the CSILE students, particularly in classroom B. Some students produced only a small number of notes that did not provide sufficiently detailed information about their process of inquiry. A further problem was that conclusive inferences concerning cognitive changes involved cannot be made on the basis of written notes. Given that the focus of the study was on CSILE students' written productions, it should be understood that conclusions about cognitive processes and changes in the background of phenomena studied should be taken as tentative and inferential; such conclusions require confirmation from further, authentic classroom studies. However, taking pragmatic limitations of the study into consideration, it would have been very hard to find any other means of carrying out the study. CSILE's database represented a huge amount of unique and content-rich material concerning elementary school students' sustained processes of
knowledge-seeking inquiry in an authentic school environment. In fact, there is “a trade-off between experimental control and richness and reality” in cognitive research on educational practice (Brown, 1996, p. 400).

For groups of CSILE students the topics of inquiry were changing from one year to the next, but only biology was studied during each year analyzed (see Figure 3-2). The course of classroom A was as follows: They studied human biology during each year analyzed as well as conducted projects in evolution theory and natural history. Further, they studied physics yearly (physics had only a minor role in classroom B’s CSILE work during the first two years period examined). During the first year students from classroom A studied kinetic-molecular theory with the goal of explaining what happens inside metal when it is heated; in the next year they started to study electricity, explaining during year 2 how circuits work, and during year 3 what happens inside a wire when electric current flows through. Gravity and cosmology had a minor role during year 1, but they were in a central position during year 3. The material analyzed represented about 70% of the entire production in classroom A during year 1 and year 2 and about 90% of their production in year 3.

The students in classroom B were often working on individual projects, and, therefore, their topics were more heterogeneous than those of classroom A. Biology was the main focus of classroom B, and the most important projects carried out were Endangered Species (year 1), Animal Wildlife, Geographical Areas (year 2), and Protozoa (year 3). The Geographical Areas project examined different kind of habi-
tats, so that it was closely connected with animal biology. In addition, the group used CSILE in working with mathematics, which was not a focus of classroom A; such work was excluded from the analysis. Only in biology did the productions of classroom B provide comparable material across years of CSILE use. However, during the last year classroom B did carry out projects in electricity, levers (Mammoth) and continental drift that represented physics. The material analyzed represented approximately 70% of classroom B's production across each year analyzed.

![Diagram of biology and physics projects]

**Figure 3-2.** CSILE students' biological and physical study projects analyzed qualitatively.

For qualitative analysis of students' productions, I selected research questions and intuitive explanations generated and scientific knowledge searched for in biology (each years) and physics (last year) as well as all comments regardless of domain of knowledge. These categories of content represent essential aspects of the students' inquiry as well as provide a relatively homogeneous material from both of the groups and across years of CSILE work. Although research questions and knowledge pro-
duced by CSILE students varied from one to another domain of knowledge, comments were relatively homogeneous across domains of knowledge. Therefore, all comments, regardless of the domain of knowledge, were analyzed in order to obtain a detailed picture of the students' peer interaction.

3.4 Qualitative Analysis of Content: Classification of CSILE Students’ Ideas

3.4.1 General Description of Content Analysis

CSILE students’ written productions from CSILE’s database were analyzed through qualitative content analysis (see, for example, Chi, 1997, Krippendorf, 1980; Weber, 1985). The analysis was based on measures derived from the philosophy of science and cognitive theory, and was carried out at multiple levels, using multiple units of analysis in order to improve validity of the study (compare Chi, 1997). Accordingly, CSILE students’ productions were 1) analyzed conceptually by reading them through, 2) segmented or partitioned into constituent parts (ideas) representing elements of CSILE students’ inquiry, and 3) analyzed qualitatively. Further, CSILE students’ productions were, in the context of classroom A, 4) examined to identify occurrence of certain explanatory concepts, and 5) assessed as a whole in the context of an individual student in order to evaluate his or her conceptual advancement in different projects. Methods used in analyzing the first three studies will be elaborated below; the specific methods used in assessment of conceptual advancement will be reported in the context of corresponding studies.
Coding categories used in the qualitative content analysis were derived from the theoretical review concerning knowledge-seeking inquiry in order to increase the content validity of the study (see Andren, 1981; Chi, 1997). The analysis was semantic in nature and focused on the basic categories of CSILE students' knowledge-seeking inquiry, i.e., research problems, intuitive explanations, scientific information sought by students, and comments. As mentioned before, these elements corresponded to CSILE's thinking types. However, in cases when a student did not use the label, these elements were identified on the basis of the contents of students' productions by the present author. Students from classroom A subdivided their textnotes into these elements during year 3, and partitioning of material from the preceding years was made by following this practice. Classroom A started to use what were labeled “discussion notes” in year 3, representing this small group's intensive inquiry. The content of groupnotes corresponded to that of individual notes although there were structural differences. A groupnote consisted of contributions of a small group of students. Members of a group were providing intuitive theories, scientific information or comments to support the student who was responsible for the note. However, each student's contribution was identifiable in a discussion note. Through qualitative analysis of the productions, classification schemata were created to analyze frequencies of qualitative types of contents.

For qualitative classification, in order to make a reliable classification of the material possible, CSILE students' notes were first partitioned into ideas (regarding segmentation of data for content analysis, see Chi, 1997; Krippendorf, 1980; Weber,
1985). An idea as the unit of analysis corresponded to the basic elements of CSILE students' inquiry, e.g., their research questions, intuitive explanations, pieces of scientific information or explanation sought by them, or comments between the students.

CSILE students' productions were organized as notes, and a note would have been a natural recording unit of content analysis. A pilot study suggested, however, that partitioning of notes into ideas (i.e., elements of inquiry) was a necessary prerequisite for reliable classification of the data because some students presented many ideas (e.g., several research questions) in a single note although others presented their ideas in many different notes. Partitioning of CSILE students' notes into ideas also allowed analysis of the discussion notes, notes that were different in structure but not in content from individual textnotes produced in earlier years. Therefore, it was necessary to segment notes into smaller constituent parts representing elements of inquiry and to use an idea as the unit of analysis in the qualitative content analysis.

Reliability of partitioning was assessed by asking two independent coders (the present author and a senior educational researcher from the University of Helsinki) to segment 200 notes into ideas. These notes represented both of the groups, and first and last year were analyzed. The Pearson correlation between number of ideas identified by the two coders was \( r(200) = .94 \). Research questions and comments were partitioned quite straightforwardly. Partitioning of CSILE students' content ideas was
more complex. The coders were guided to consider each thought as an answer to an underlying fact- or explanation-seeking question. Inter-coder reliability of classification, reported below, was measured by using this presegmented material.

On average, CSILE students produced 3.9 \((SD = 4.0)\) research questions per note. The mean number of distinguishable ideas representing intuitive theories or factual or explanatory scientific information was 3.6 \((SD = 3.1)\) per note. Comments which obviously contained more than one communicative idea were also partitioned. Examination of the comments revealed that there were 1.6 \((SD = 0.9)\) ideas per comment. For practical reasons, communicative ideas and content ideas will be referred to simply by talking about comments and knowledge produced. Frequencies of CSILE students' ideas, analyzed qualitatively, are presented in Table 3-5 (page 100).

During the period analyzed, the CSILE students produced thousands of research questions, notes presenting their intuitive and scientific knowledge, as well as written comments. From Table 3-5 it can be inferred that there were considerable differences in the productivity of classrooms A and B as well as differences between the years of using CSILE. It is particularly evident that the students from classroom B did not produce as many communicative ideas as the students from classroom A did during the first two years analyzed. An examination of the notes produced by class-

\[1\] The same coders were used in all of the reliability analyses to be reported in the following sections.
room B indicated that the students worked individually, and between-student communication was left to the students' own initiatives during the first two years analyzed.

Table 3-5.
Frequencies of Classrooms A and B Students' Productions Selected for Analysis

<table>
<thead>
<tr>
<th>PERIOD</th>
<th>Classroom A</th>
<th></th>
<th></th>
<th></th>
<th>Classroom B</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Year 1</td>
<td>Year 2</td>
<td>Year 3</td>
<td>TOTAL</td>
<td>Year 1</td>
<td>Year 2</td>
<td>Year 3</td>
</tr>
<tr>
<td>Category of Production</td>
<td>f</td>
<td>%</td>
<td>f</td>
<td>%</td>
<td>f</td>
<td>%</td>
<td>f</td>
<td>%</td>
</tr>
<tr>
<td>Research questions</td>
<td>535</td>
<td>25.6</td>
<td>938</td>
<td>46.9</td>
<td>983</td>
<td>30.3</td>
<td>2456</td>
<td>33.5</td>
</tr>
<tr>
<td>Content ideas</td>
<td>926</td>
<td>44.3</td>
<td>649</td>
<td>32.4</td>
<td>1727</td>
<td>53.2</td>
<td>3302</td>
<td>45.0</td>
</tr>
<tr>
<td>Communicative ideas</td>
<td>631</td>
<td>30.1</td>
<td>414</td>
<td>20.7</td>
<td>537</td>
<td>16.5</td>
<td>1582</td>
<td>21.5</td>
</tr>
<tr>
<td>TOTAL</td>
<td>2092</td>
<td>100.0</td>
<td>2001</td>
<td>100.0</td>
<td>3247</td>
<td>100.0</td>
<td>7340</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Note. The numbers presented in the Table represent frequencies of ideas corresponding to basic elements of CSILE students' inquiry instead of numbers of actual CSILE notes. "Content ideas" refers to intuitive theories constructed or pieces of factual or explanatory scientific information searched for answering research questions. "Communicative ideas" refers to written comments between the students.

The content analysis primarily aimed to obtain a comprehensive picture concerning the contents of CSILE students' notes and comments. In order to provide an adequate characterization of the wide variety of contents of CSILE students' productions, "the Method of Excerpt" (see Chi, 1997) was used in reporting the results. In other words, the contents of CSILE students' productions were illustrated by transcriptions from their notes. Further, the analysis not only aimed to examine the most
general contents of the notes, but also to identify and analyze specific and unique phenomena. This was regarded as important in order to identify particularly advanced processes of inquiry that may be systematically facilitated in CSILE students' practice of inquiry, in the future.

In the following, the classification methods used in the first three studies are described. Specific methods developed to analyze the process of inquiry for students in classroom A in a detailed way, such as their conceptual advancement, will be described in the context of corresponding studies.

3.4.2 Classification of Knowledge Produced by CSILE Students

This section contains a description of the coding categories used for qualitative classification of knowledge produced by CSILE students (see Figure 3-3). The main categories of CSILE students' knowledge were their research questions and content ideas. Research questions were separated from the students' textnotes by following explicit labeling such as "Problem", "I Need to Understand" or "Higher-level Question." In cases where the students did not explicitly label their research questions, these were separated from contents of their textnotes. Content ideas, i.e., intuitive knowledge and scientific information generated by the students, represented the main body of their textnotes. Research questions and content ideas were classified independently from each other; i.e., before classification these categories of inquiry were separated from each other.
A basic assumption of the study was that knowledge-seeking inquiry is a question-driven process. The general nature of research questions appeared to determine the epistemic nature of the knowledge-seeking process and what kinds of cognitive operations were available for a student during inquiry. 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 are the reasons for gravity?" or "what is inside of a battery?" In the present study a few research questions that
were focused on evidential relations (e.g. "why do scientists believe in the Big Bang theory") were regarded as explanation-seeking questions. Also, questions representing a sort of practical reasoning (e.g., “What could we do for protecting environment from pollution?”) often represented explanation-seeking questions. Who, where, when, how many, and some what questions represented fact-seeking questions that can be answered by providing factual information concerning, for example, persons, things, places, times or numbers.

Further, the origin of research question was analyzed. A student-generated research question was created by a student him- or herself whereas a given question was provided by the teacher. Further, given questions were common to a whole project and usually stated by the teacher at the beginning of the project in question. The CSILE students were often both working on given questions and generating their own questions. Some projects, however, were exclusively based on student-generated questions. Given questions were identified by analyzing project instructions and questions common to all students in the context of each project.

In answering their research questions, CSILE students searched for different kinds of scientific information and generated their own intuitive explanations and theories. Each content 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. The criterion for identifying type of knowledge was the origin of information; i.e., whether it represented different forms of scientific or school knowl-
edge or was generated by the students themselves. "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 view or an explicit theory about the phenomenon in question. These basic types of CSILE students' ideas were rather easily distinguishable. Usually, the students introduced new scientific information by explicitly labeling it as "new information" and referred to the information source used. Intuitive explanations were referred to by talking about "my theories." In the case of classroom B, however, which did not systematically use thinking types, contents of their ideas were used to make inferences concerning the type of knowledge produced.

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 content 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 (see Table 3-6).

Level 1. Separated pieces of facts. A rating of 1 was assigned to CSILE students' content 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 related (sic!) animals are, Sponges, Venusus Flower basket, Portuges man of war, Sea Anomes, Jelly Fish and Hydra (year 3, student 23149).^2

Table 3-6.
The Level of Explanation Scale

<table>
<thead>
<tr>
<th>Rating</th>
<th>General Description</th>
<th>Specific Nature of Knowledge Produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pieces of facts</td>
<td>An idea consisting of a list or table of facts with hardly any integration or connecting linkages.</td>
</tr>
<tr>
<td>2</td>
<td>Partially organized facts</td>
<td>An idea consisting of facts that were loosely organized together. The facts were stated without relating them to each other by means of causal or some other semantic connections. Only a minimal amount of inference seemed to be involved in constructions of an idea so that the production did not represent any characteristics of an explanation.</td>
</tr>
<tr>
<td>3</td>
<td>Well-organized facts</td>
<td>An idea consisting of rather well-organized factual or descriptive information. Although the ideas did not explicitly provide an explanation, it was meaningfully organized and had a potential of facilitating understanding of the issue in question. Although the idea may have contained some causal or meaning connections, and it was organized toward explanation, it was descriptive in nature and did not rely on deeper explanatory relations.</td>
</tr>
<tr>
<td>4</td>
<td>Partial explanation</td>
<td>An idea represents an explicit attempt to construct an explanation, but explanation was only partially articulated. It was only an explanatory sketchy that was not further elaborated. These kinds of ideas may consist of only a few propositions in which an idea of the explanation was presented. A partial explanation differed from a well-articulated explanation by being clearly in need for further clarification.</td>
</tr>
<tr>
<td>5</td>
<td>Explanation</td>
<td>An idea consisting of an explicit explanation whether functional, empirical-physical or theoretical-physical in nature. Explanations contained postulation of common causes, cause-effect relations, reasons and other explanatory relations, or theoretical entities. In order to be classified as an explanation, an idea did not need to be formally correct; clearly identifiable intuitive explanations were regarded as explanations.</td>
</tr>
</tbody>
</table>

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 sepa-

^2 About each transcription of CSILE students' notes, I will give information about "year" of creating the note and the student number or initials of the "student" who is responsible of creating the computer entry in question. In the context of discussion notes, "author" refers to the (student) author of discussion note and "student" to a student who constructed an individual discussion entry.
rated 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. Frequently, however, these ideas were not very coherent or comprehensive. The following two examples demonstrate 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. (year 3, author 23164, JM)

Simple celled animals such as Sponges, Jellyfish, Portugese man of war, Hydra, coral and other such animals have only two layers of cells that surrounds a hollow interior ... (year 3, student 802)

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,

Protoplasm contains all the life forms. Cell is basic structure of all life. The human body has many cells, but there is a animal that has only one cell. It is a Ameba. Ameba has only one cell. Ameba was founded at the beach.(in the water). (year 3, student 804)

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. Absortive cells need to use their entire cell structure to move around. (year 3, author 23164, student JM)
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. For example, while answering a question, "Why do sponges and related animals have three ways of reproducing and other animal forms only have one?", a student produced the following explanation:

I think that the reason why sponges and other related animals have three ways of reproducing and other animal forms don't is because, They are simple multi - celled animals and other Animal forms aren't simple multi - celled (year 3, student 23107)

I think that the nerves controll themselves and that they send messages to the brain so that the brain can controll the body. The nerves are just there to tell the brain what is happening because the brain can't be every where at once. (year 3, student 23162)

Although the ideas were clearly intended to be explanations, there is an apparent need for further articulation; one or several pieces of explanation remain to be explicaded. 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.

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,
I think that Sponges and related animals have three ways of reproducing because they live in the ocean and there is a greater chance of them getting killed than there is for us getting killed because there are many more animals in the sea that would gladly kill a Sponge and also we fish and that means that there is a good chance that not many of them will make it past childhood. (year 3, student 802)

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. (year 3, author 23143, student AR)

MT: My theory of how the glial cells hold the brain together is that, they might be the bigger cells in the brain, that SH talked about. They might work in twos, one to cradle the neuron cells and the other one to sit on top of it to gently squish it, so it wouldn't move around. The glial cells themselves are stuck to the outer covering of the brain. (year 3, author 23393, student JH)

In assessing CSILE students' productions, I took into consideration that the current material represented elementary school students' first attempts to explain the problems being investigated, thus even the highest level of explanation did not need to be coherent or thoroughly articulated.

Finally, in order to analyze a CSILE student's relation to his or her productions, I analyzed whether he or she expressed personal ownership or involvement of their content ideas by using a variable called personalized epistemology. A student's epistemology was regarded as personalized if an idea contained an explicit reference to personal ownership (e.g., "my theory", "your explanation", "my idea"); otherwise it was regarded as non-personalized. Ideas that introduced pieces of facts or an explanation in a neutral and laconic way, without any reference to the author behind the ideas, were classified as non-personalized.
To analyze reliability of the classification, two independent coders (see page 99) classified 200 research questions and 200 content ideas selected by systematic sampling to represent each year in both classrooms A and B. Inter-coder reliabilities of the classification, presented in Table 3-7, indicated that the reliability of classification was satisfactory; the agreement coefficient exceeded .70 across practically all variables. Disagreements were discussed after the reliability analysis, and those ideas that were classified differently by the two coders were analyzed again and coded according to mutual agreement.

Table 3-7.
Agreement Coefficients in Classifying CSILE Students' Research Questions and Content Ideas

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>ANALYSIS I (100 cases)</th>
<th>ANALYSIS II (100 cases)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nature of research question</td>
<td>.83</td>
<td>.92</td>
</tr>
<tr>
<td>Origin of research question</td>
<td>.72</td>
<td>.86</td>
</tr>
<tr>
<td>Type of knowledge</td>
<td>.90</td>
<td>.91</td>
</tr>
<tr>
<td>Level of explanation</td>
<td>.89*</td>
<td>.71*</td>
</tr>
<tr>
<td>Personalized epistemology</td>
<td>.72</td>
<td>.79</td>
</tr>
</tbody>
</table>

Note. (*) Reliability of classifying level of explanation was measured by using Pearson correlation between ratings given by the two coders.

---

3 The agreement coefficients were calculated by using the following formula:

\[ k = \frac{y}{\frac{n}{m}} - q \]

where

- \( k \) = agreement coefficient
- \( y \) = number of cases of agreement
- \( m \) = number of classes in a variable
- \( q \) = proportion of randomness (number of cases of disagreement / \((m-1)\))
- \( n \) = number of cases analyzed
3.4.3 Classification of CSILE Students' Comments

CSILE students' peer interaction was analyzed by examining contents of their written communication mediated by the CSILE network. Categories of coding CSILE students' peer interaction (see Figure 3-4, page 111) were derived from a theoretical review of knowledge-seeking inquiry and socially distributed cognition. Analysis of comments was a very important part of the study for several reasons. First, communicative ideas reflected how the students themselves conceptualized their knowledge-seeking inquiry. Supportive or critical comments revealed information about the cognitive goals and objects of students' inquiry and how the students conceptualized learning tasks in question. Second, the analysis of communicative ideas gave information concerning how socially distributed cognitive resources were used in the process of knowledge-seeking inquiry by the students.

CSILE students' comments were classified according to type of communicative idea, i.e., whether an idea 1) supported the note commented on expressing agreement, 2) represented a neutral exchange of ideas or 3) was critical in nature expressing disagreement. A communicative idea was classified as supportive if it included expressions such as "your note is excellent", "I like your note", "your note gives important information about x", and so on. A communicative idea was regarded as neutral if it was neither critical nor supportive, i.e., did not contain any kind of evaluation. Asking and answering a question usually represented neutral communication. Neutral communicative ideas were, frequently, used to provide information or explanation di-
A communicative idea was classified as critical if it suggested some changes to the object note, otherwise it was regarded as neutral or supportive. Critical communicative ideas included direct criticism ("you do not explain your theory") or criticism was expressed in an indirect and constructive way ("why don't you add analysis of x into your note"). All suggestions for changes were considered to represent criticism. Communicative ideas in which a student said that "you should (must, have to) tell" such and such things were classified as critical.

![Figure 3-4](image)

**Figure 3-4. Coding categories of CSILE students' communicative ideas.**

In many cases, a comment contained critical as well as supportive ideas ("your note is good, but you should make such and such changes"). In these cases a student frequently argued that the note commented on was good, but it could be improved in some way. If a comment contained both supportive and critical ideas, these were classified as two distinguishable communicative ideas in order to examine objects of criticism and support.
Neutral communicative ideas were further divided into two subgroups according to *function of the neutral communicative idea*: communicative ideas in which a student requested information/explanation or asked a question, and communicative ideas which he or she provided information/explanation or answered a question.

The object of cognitive activity determines to a great extent the psychological nature of inquiry (cf., Leontiev, 1978). Communicative ideas within a comment were analyzed by specifying, in each case, the *object of inquiry*: i.e., whether the communicative idea was about 1) linguistic form, 2) research questions, 3) research methods, 4) information, 5) explanation, 6) other, or 7) unspecified. Each communicative idea was considered to represent only one of the above mentioned categories. In other words, the categories were mutually exclusive: If a communicative idea was considered to represent one object of inquiry, it was not considered to represent any other.

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 requests 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 reflectivity ("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 were either those designed to assess explanation constructed by the student being commented on or to provide an explanation generated by the student him- or herself. These 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. Unspecified communicative ideas were ideas whose main object could not be specified even with respect to the object of comment ("Your note is excellent", "bad").

The present investigator analyzed how CSILE students explicated the referential relations of their communicative ideas. The basic difference between spoken and written communication is that, in the former, the referents are contextual in nature and, therefore, usually familiar to all of the participants, while in the latter the referents have to be explicated and the context created. *Explication of referential relations* was analyzed through classifying the students' communicative ideas as *unexplicated* or
explicated. Some of the unexplicated ideas were completely unspecified; in these cases, the main object of the comment could not be specified at all, i.e., one could not determine whether a communicative idea focused on linguistic form or some aspect of the process of inquiry. Typically, in this kind of comment, reasons for disagreement or agreement were left completely open: "I like your note", "Your note is not good." The student being commented on would hardly have been able to make any improvements on the basis of this kind of communicative idea. Unexplicated referential relations made it impossible to determine what aspect of inquiry a comment was about or what was the specific aspect being criticized or supported. In some of these comments, the main object of the communicative idea was explicated (i.e., language, information, explanation), but the students neither specified what aspect of the object was being commented on nor explained reasons for disagreement (or agreement). On the basis of this kind of communicative idea the student receiving the comment would be able to give attention to some general aspect of his or her work, but not to make any specific improvements or answer the criticism in a specific way. In the case of a neutral comment, "partially explicated communicative idea" meant that the communicative idea's connection to the inquiry of the student commented on was left implicit. In explicated communicative ideas the referent of a communicative idea was explicated quite clearly although a student may not have completely justified his or her criticism or support. An explicated comment was self-explanatory; i.e., understandable without any background or contextual knowledge. For example, reading of the note being commented on was not necessary for understanding the comment's main con-
tent. On the basis of an explicated comment, the receiver would be able to make specific corrections to his or her note.

Finally, the number of words was counted for each comment in order to analyze relationships between the mean number of words in different categories of communicative ideas (e.g., explicated, unexplicated) in the context of different groups of CSILE students.

To analyze reliability of the classification, two independent coders (see page 99) classified 300 communicative ideas selected by systematic sampling to represent each year and both classroom A and classroom B. Inter-coder reliabilities of the classification presented in Table 3-8 indicated that the reliability of classification was satisfactory; the agreement coefficient exceeded .70 across practically all variables.

Table 3-8.
Agreement Coefficients in Classifying CSILE Students’ Communicative Ideas

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>ANALYSIS I (130 cases)</th>
<th>ANALYSIS II (100 cases)</th>
<th>ANALYSIS III (100 cases)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of communicative idea</td>
<td>.74</td>
<td>.79</td>
<td>.81</td>
</tr>
<tr>
<td>Function of a neutral comments</td>
<td>--</td>
<td>.84</td>
<td>.88</td>
</tr>
<tr>
<td>Object of comment</td>
<td>.63</td>
<td>.77</td>
<td>.83</td>
</tr>
<tr>
<td>Explication (explicated/not explicated)</td>
<td>.57</td>
<td>.76</td>
<td>.76</td>
</tr>
</tbody>
</table>

Disagreements were discussed after the reliability analysis, and those ideas that were classified differently by the two coders were discussed and coded according to mutual agreement.
3.4.4 Proportional Analysis: Nature of CSILE Students' Inquiry

Results of the qualitative content analysis were examined at two levels: by analyzing frequencies of the contents of CSILE students' productions and analyzing proportions of these contents in the context of an individual student. Because the classification of CSILE students' productions was made at the level of ideas, from each student was obtained several observations. On average, the students produced 64.8 ($SD = 39.0$) ideas per year. The relative importance of different contents in individual students' comments and notes were studied as proportions, i.e., by analyzing the proportion of certain kinds of content among a student's productions representing the reference category in question. Proportional analysis focused on identifying the most important differences within and between the groups of CSILE users, and changes in process of inquiry as a function of CSILE experience.

Frequency data produced by qualitative content analysis was transformed into proportional data by dividing the number of occurrence of a particular content by the number of all occurrences of contents representing the reference class in question. In the special case in which a student did not produce any ideas representing the category in question, the proportion was determined as 0 by using a corresponding conditional rule. In some cases, assumptions of proportional analysis such as normality of distributions and homogeneity of variances were violated due to varying frequencies in the background of proportions.
In the statistical analyses, carried out in the first two studies, I ignored the fact that some of the students stayed in classroom A or classroom B over the two-year period. This perspective was adopted because the number of students who stayed for only one year in a CSILE group varied considerably between the groups and across years. An analysis focused only on students working with CSILE for their first year would have caused the number of students in each cell to vary a great deal. In most cases both ways of analyzing the data — removing the children who appeared in consecutive years and leaving them in — led to the same kind of results. However, in the cases when there was only a small number of students in a cell, the results of proportional analysis were considerably affected if some students did not produce any notes representing a given category, such as research questions or comments. The mean proportion of explanation-seeking research questions would, for instance, appear to be low, not because these kinds of questions would not have been produced, but because some of the students did not produce questions at all. As a consequence, an analysis based entirely on students who worked with CSILE for one year would have given misleading information about the development of CSILE students' inquiry. Thus, I decided to conduct the statistical analyses by ignoring the fact that some students appeared in the statistical data twice. In that way the sample sizes were approximately equal even after excluding from analysis a few students without productions representing a given category. Further, this solution appears to be conservative in nature; although the fact that some of the children appear in the statistical data twice inflates the degrees of freedom, it increases the error variance. With a relatively large number of cases the effect of degrees of freedom is typically small compared to the
effect on error variance (especially if there is a fairly high correlation between the repeated measures, which one would expect to be the case).

Results of the qualitative content analysis were analyzed by multidimensional crosstabulation of frequency data and by examining proportions representing certain important aspects of inquiry within and between the groups and across years. In some cases 95% confidence intervals instead of statistical tests were used to examine results of the analyses in order to avoid violating statistical assumptions of multivariate analysis of variance caused by the naturally occurring data used in the study. In the present study, the purpose of both confidence intervals and statistical tests was to demonstrate reliability of inferences rather than generalizability of results: The analysis of the material establishes reasonable inferences rather than generalizable propositions because the material analyzed represents a unique stage in the development of CSILE experimentation that cannot in principle be replicated.
4. RESULTS

4.1 Study I: Emergence of Deepening Levels of Explanation in CSILE Students’ Culture of Inquiry

The purpose of the study was to examine changes in the epistemological nature of knowledge processed in two CSILE classrooms across a three-year period. The study analyzed whether the students were capable of approaching the problems being investigated according to deepening levels of explanation rather than being bound with surface phenomena and processing merely factual information; such processing would represent the first principal feature of scientific inquiry. A central objective of the CSILE experiment has been to foster a research-like process of inquiry in which generation of the students’ own research questions and intuitive theories plays an important role. However, CSILE provides only a technological infrastructure for higher-level practices of inquiry, and actual pedagogical changes are dependent on teachers’ and students’ commitment to explore and test new practices of learning and instruction. By comparing changes in the culture of inquiry in classrooms A and B, the present investigator aimed to examine constraints and conditions of successful implementation of the epistemology of scientific inquiry in computer-supported collaborative learning, and particularly to specify the roles of the teacher and the cognitive design of study projects in facilitating scientific practices of inquiry in computer-supported learning.
CSILE students' knowledge processing was analyzed at multiple levels in order to increase the validity of the study. The students in classrooms A and B studied biology during each year examined, and carried out the same kind of study projects concerning human and animal biology. The first analysis examined changes in the practices of processing biological knowledge in classrooms A and B across the three-year period. Further, classroom A carried out biological and physical study projects in each year. In order to obtain more detailed information of classroom A's inquiry, I analyzed how the explanatory level of knowledge processed by the classroom differed between the domains of biology and physics, and changed across the three-year period.

The first two analyses concerned change in CSILE students' culture of inquiry in classrooms A and B as a whole. From the fact that the students in question worked with CSILE only for one year follows that the results do not represent development of an individual student's inquiry, but appear to characterize evolution of the CSILE culture as a whole and of the teachers' abilities to guide their groups beyond earlier achievements. In order to analyze the effects of CSILE experience in the context of individual students, the analysis focused on examining how knowledge was processed by a small group of CSILE students, who stayed two years in the classes, and so who developed from their first and to their second year of CSILE study. The purpose of the analysis was to examine whether CSILE students' changed practices of inquiry concerned just new students coming to the class or also concerned students who worked with the CSILE environment through a two-year period. Further, the
study aimed to investigate to what extent an individual student’s inquiry was dependent on that of his or her study group.

The study was carried out by qualitatively analyzing knowledge produced by the students in CSILE's database by using methods described earlier in the method section. The material consisted of CSILE students’ research questions and content ideas in biology (both classrooms A and B) and physics (classroom A).

4.1.1 Analysis 1: Change in Explanatory Level of Knowledge Processed by Two CSILE Classes Across a Three-Year Period

Change in explanatory level of knowledge processed in classrooms A and B was analyzed across the three-year period by examining the epistemological nature of research questions generated and knowledge produced. The material analyzed represented 112 CSILE students’ postings to the CSILE database in the three academic years.

Analysis of CSILE students’ research questions as well as knowledge produced by them indicated that advanced forms of inquiry emerged through a complex process of experimenting and exploration. A direct discriminant analysis was performed using three variables representing the nature of CSILE students' knowledge production in biology as predictors of membership in a CSILE group. The predictors were the mean proportion of student-generated explanation-seeking research questions, the mean level of explanation of knowledge produced in biology, and the mean proportion of personalized epistemology. A composite variable of Year and CSILE
group (classroom A, year 1 [A1]; classroom A, year 2 [A2]; classroom A, year 3 [A3]; classroom B, year 1 [B1]; classroom B, year 2 [B2]; classroom B, year 3 [B3] was used as a grouping variable.

Three discriminant functions were calculated, with a combined $\chi^2(15) = 207.3$, $p<.000)$. After removal of the first function, there was still a strong association between groups and predictors, $\chi^2(8) = 46.7$, $p<.000$. The third discriminant function, however, was not significant. The first two discriminant functions accounted for 86.7% and 12.8%, respectively, of the between-group variability. As shown in Figure 4-1, the first discriminant function discriminates the students from classroom A from the students from classroom B as well as classroom A students in year 3 from the students working in the group during the two earlier years. The second discriminant function is more difficult to interpret. It seems to discriminate classroom A's practices of knowledge processing in year 3 from those of the first two years of the classroom.
Canonical Discriminant Functions

Function 1: Explanatory level of knowledge processed

Figure 4-1.
Plots of six group centroids on two discriminant functions derived from three knowledge-processing variables (the proportion of explanation-seeking research questions, mean level of explanation, and the proportion of personalized epistemology).

The loading matrix of correlations between the predictors and discriminant function, as seen in Table 4-1, suggested that the best predictors for distinguishing between the years of classroom A were the mean level of explanation and mean proportion of student-generated explanation-seeking research questions.
Table 4-1.
Results of Discriminant Function Analysis of Knowledge Processing by Students in Classrooms A and B Across the Period Analyzed

<table>
<thead>
<tr>
<th>Predictor variable</th>
<th>Correlations with the discriminant function</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>Univariate F (5,106)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean proportion of explanation-seeking questions</td>
<td>.73</td>
<td>-54</td>
<td>43.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean level of explanation</td>
<td>.73</td>
<td>-06</td>
<td>40.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean proportion of personalized epistemology</td>
<td>.59</td>
<td>.79</td>
<td>33.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canonical R</td>
<td>.88</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eigenvalue</td>
<td>3.52</td>
<td>52</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As seen in Table 4-2, the mean level of explanation for classroom A students' content ideas monotonically increased from year 1 ($M = 2.86$) to year 3 ($M = 4.18$). Although knowledge processed by classroom A students was descriptive in nature in year 1, it clearly represented explanatory scientific knowledge in year 3.

Table 4-2.
Cell Means and Standard Deviations for Mean Level of Explanation of Knowledge Processed by Students from Classrooms A and B

<table>
<thead>
<tr>
<th>Year</th>
<th>Classroom A</th>
<th></th>
<th>Classroom B</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M$</td>
<td>$SD$</td>
<td>$n$</td>
<td>$M$</td>
</tr>
<tr>
<td>Year 1</td>
<td>2.86</td>
<td>.41</td>
<td>20</td>
<td>2.08</td>
</tr>
<tr>
<td>Year 2</td>
<td>3.57</td>
<td>.50</td>
<td>19</td>
<td>2.13</td>
</tr>
<tr>
<td>Year 3</td>
<td>4.18</td>
<td>.25</td>
<td>21</td>
<td>2.39</td>
</tr>
</tbody>
</table>
Corresponding to change in level of explanation was a change in the mean proportion of explanation-seeking questions for students in classroom A from one year to another (see Table 4-3); in classroom B, by contrast, the mean level of explanation ($M = 2.24$) as well as mean proportion of explanation-seeking questions ($M = .17$) remained at approximately the same level across the whole period studied. In other words, classroom B's biological study projects focused on factual information and, correspondingly, fact-seeking questions, across the whole period analyzed. In accordance with the focus on explanatory knowledge, inquiry in classroom A was driven by explanation-seeking questions.

Table 4-3.
Cell Means and Standard Deviations for the Mean Proportion of Student-Generated Explanation-Seeking Research Questions

<table>
<thead>
<tr>
<th>Year</th>
<th>Classroom A</th>
<th></th>
<th>Classroom B</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M$</td>
<td>$SD$</td>
<td>$n$</td>
<td>$M$</td>
</tr>
<tr>
<td>Year 1</td>
<td>.69</td>
<td>.13</td>
<td>20</td>
<td>.17</td>
</tr>
<tr>
<td>Year 2</td>
<td>.85</td>
<td>.23</td>
<td>19</td>
<td>.22</td>
</tr>
<tr>
<td>Year 3</td>
<td>.94</td>
<td>.08</td>
<td>21</td>
<td>.15</td>
</tr>
</tbody>
</table>

One predictor, the proportion of personalized epistemology had a loading of .79 on the second discriminant function, which partially separates the classroom A students in year 3 from the two earlier years of the classroom, indicating that the proportion of personalized epistemology in year 3 ($M = .70$) increased substantially from that of year 1 ($M = .10$) and year 2 ($M = .25$) (see Table 4-4); the mean proportion of personalized epistemology did not change in classroom B, remaining at the .10 level during each year examined. Presumably, the increase in classroom A students' per-
sonalized epistemology was connected with change in the structure of CSILE students’ notes; use of discussion notes seemed to facilitate the expression of explicit ownership of ideas.

Table 4-4.
Cell Means and Standard Deviations for the Mean Proportion of Personalized Epistemology

<table>
<thead>
<tr>
<th>Year</th>
<th>Classroom A</th>
<th>Classroom B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Year 1</td>
<td>.10</td>
<td>.16</td>
</tr>
<tr>
<td>Year 2</td>
<td>.25</td>
<td>.27</td>
</tr>
<tr>
<td>Year 3</td>
<td>.70</td>
<td>.19</td>
</tr>
</tbody>
</table>

Pooled within-group correlations among the three predictors are shown in Table 4-5. Of the three correlations, two would show statistical significance at alpha = 0.05 level if tested individually. There is a positive relationship between the mean proportion of student-generated explanation-seeking research questions and mean level of explanation (.29, *p*<.05), indicating that students who asked explanation-seeking questions also produced explanatory knowledge. Further, the higher mean level of explanation also seemed to be associated with a higher proportion of personalized epistemology (.28, *p*<.05).
Table 4-5.
Pooled Within Group Correlations Among the Knowledge-processing Variables

<table>
<thead>
<tr>
<th>Predictor variable</th>
<th>Pooled within-group correlations among predictors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean proportion of explanation-seeking questions</td>
<td>0.29</td>
</tr>
<tr>
<td>Mean level of explanation</td>
<td>0.28</td>
</tr>
<tr>
<td>Mean proportion of personalized epistemology</td>
<td>0.07</td>
</tr>
</tbody>
</table>

With the discriminant classification procedure for the total usable sample of 112 students, 71 (63%) were classified correctly, compared to 21 (19%) that would be correctly classified by chance alone. The 63% classification rate was achieved by using sample proportions as prior probabilities. The likelihood of correctly classifying classroom A students in year 3 (95%, 20) and year 1 (90%, 18) was higher than that of classifying students in classroom A in year 2 (63%, 12). Further, classroom B students (74%, 20) were classified in a reliable way in year 3 whereas only 6% (n=1) in year 1 and 11% (n=1) in year 2 from the students in classroom B were classified correctly. The majority of the students in these two, classroom B groups were incorrectly classified as classroom B in year 3 students. Apparently, the groups of classroom B students representing different years of CSILE use could not be discriminated in a reliable way because their practices of knowledge production did not significantly change from one year to another.

The analysis revealed that practices of knowledge production differed substantially between classrooms A and B. Further, practices of knowledge processing in
classroom A progressively developed from one year to another, as an explanation-oriented process of inquiry had a more and more prominent role. The epistemological nature of knowledge processed by classroom B, in contrast, did not substantially change; the group focused on processing factual knowledge across the whole period.

The present results, however, should be taken with caution because an examination of the homogeneity of the variance-covariance matrices revealed a significant divergence from the assumptions of multivariate analysis (Box's M=102.1, p<.000). The unequal within-group variances seemed, however, to represent an important aspect of the phenomenon studied. Variance, for example, concerning the proportion of explanation-seeking research questions decreased from one year to the next because practically all students in classroom A engaged in producing this kind of questions. Thus, decreasing variances represented an important educational achievement instead of being just a statistical problem (compare Howell, 1987, p.181). Taking the robustness of statistical methods used as well as effect sizes of the phenomena measured into consideration, the results may be considered as providing a relatively accurate description of differences between the CSILE groups, and of the development of the students' inquiry across the period analyzed.

Examination of CSILE notes produced in classrooms A and B indicated that knowledge production in the groups did not differ in a statistically significant way according to gender or ability level of the participating students. In both of the groups practically all students, disregarding ability level or gender, processed either explanatory or factual knowledge. Presumably, the classroom culture and associated learning
tasks determined, to a great extent, what kind of knowledge was produced. Further, learning mediated by a public database as well as small group work seemed to set up norms for knowledge that is considered valuable and worthwhile to pursue.

4.1.2 Analysis 2: Change in Explanatory Level of Knowledge Processed in Biology and Physics

The students from classroom A studied biology and physics during each year analyzed. In order to examine how their practices of knowledge processing developed from one year to the next, I conducted a series of analysis concerning their practices of knowledge processing in biology and physics. The analyses examined whether the mean proportion of explanation-seeking research questions or mean explanatory level differed between these domains of knowledge across the period analyzed.

A repeated measures multivariate analysis of variance was performed in order to determine whether the mean proportion of explanation-seeking research questions and mean explanatory level of processed knowledge differed between biological and physical study projects and changed across years of CSILE studies. The between-subjects factor was year (1, 2, 3), and the within-subjects factor was domain (biology, physics). The dependent variables were (a) mean proportion of explanation seeking research questions and (b) mean level of explanation. The means and standard deviations for each cell are presented in Table 4-6.
Table 4-6.
Cell Means and Standard Deviations for the Mean Proportion of Student-generated Explanation-seeking Research Questions and Mean Level of Explanation

<table>
<thead>
<tr>
<th>Year</th>
<th>Biology</th>
<th>Physics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Proportion of Explanation-seeking questions</td>
<td>Proportion of Explanation-seeking questions</td>
</tr>
<tr>
<td>Year 1</td>
<td>M .72</td>
<td>.21</td>
</tr>
<tr>
<td></td>
<td>SD .16</td>
<td>.39</td>
</tr>
<tr>
<td>Year 2</td>
<td>M .84</td>
<td>.86</td>
</tr>
<tr>
<td></td>
<td>SD .20</td>
<td>.26</td>
</tr>
<tr>
<td>Year 3</td>
<td>M .92</td>
<td>.91</td>
</tr>
<tr>
<td></td>
<td>SD .09</td>
<td>.09</td>
</tr>
</tbody>
</table>

The analysis based on Wilks’ criterion indicated that there was a significant multivariate main effect for year \((F(4,172)=50.3, p<.001)\). The result reflected a strong association between year and the combined dependent variables \(\eta^2=.54\). Thus, overall knowledge processed by students in classroom A differed across years and domains of knowledge. Univariate tests were also conducted for both dependent variables. Significant main effects were found for the mean proportion of student-generated explanation-seeking research questions \((F(2,87)=119.0, p<.001, \text{ partial } \eta^2=.60)\) and for the mean level of explanation of knowledge produced \((F(2,87)=65.4, p<.001, \text{ partial } \eta^2=.73)\). Post hoc analyses of the univariate ANOVA for the combined knowledge processing variables involved pairwise comparisons to find out whether the epistemological nature of knowledge processed changed in classroom A from the first to the third year CSILE use. Tamhane’s T2 (conservative pairwise comparisons test based on a t test), that does not assume equal variances, was used for carrying out pairwise comparisons. The analysis indicated that students in classroom A pro-
duced a higher proportion of explanation-seeking research questions in years 3 and 2 than year 1. Further, the mean explanatory levels of knowledge produced by the students in year 3 and year 2 were higher than that for year 1. In addition, the year 3 students outperformed the year 2 students with respect to the mean level of explanation.

A significant multivariate effect was found for domain \((F(2,86)=17.8, \ p<.001)\). The results indicated a moderate association between domain and the combined dependent variables \((\eta^2=.29)\). The proportion of explanation-seeking research questions produced by CSILE students differed significantly between biology and physics \((F(1,87)=25.77, \ p<.001, \ \eta^2=.16)\). Further, knowledge produced by CSILE students in biology and physics differed in terms of mean level of explanation \((F(1,87)=16.7, \ p<.001, \ \eta^2=.23)\). Knowledge produced in biology was at a higher explanatory level than that of physics. In addition, a significant multivariate main effect was also found for Domain by Year Interaction \((F(4,172)=13.0, \ p<.001, \ \eta^2=.23)\). This interaction may be explained by the fact that the epistemological nature of knowledge produced by the students in the domains of biology and physics diverged substantially only in the beginning of the period analyzed. Towards the end of the period, the students started to process the same kind of explanatory knowledge in both of the domains (see Figure 4-2 & Figure 4-3).
The analysis revealed that the mean proportion of explanation-seeking research questions increased from one year to another. It was particularly noticeable that only 21% of the research questions generated by the classroom A students in physics were explanation-seeking in nature during the first year analyzed (see Figure 4-2). (This was partially caused by the fact that some students did not produce any questions of their own in their physical-study project, and so their proportion of explanation-seeking research questions was 0. However, even if the students who did not produce any questions (n=16) were excluded, the data indicated that only 44% of research questions generated by the students in physics during the first year were explanation-seeking in nature.)
A repeated measures multivariate analysis of variance was performed in order to test whether the classroom A students produced different proportions of intuitive explanations and personalized epistemology in biology and physics across years. The between-subject factor was year (1,2,3) and the within-subject factor domain (biology; physics). The dependent variables were the mean proportion of intuitive explanations and mean proportion of personalized epistemology. The means and standard deviations for each cell are presented in Table 4-7.

The analysis based on Wilks’ criterion revealed that there was a significant multivariate main effect for year ($F(4,172)=40.7$, $p<.001$). The results reflected a strong association between year and the combined dependent variables ($\eta^2=.49$) and indicated that overall the nature of classroom A students’ productions differed across years and the two domains of knowledge. Univariate tests were also conducted for
both dependent variables. Significant main effects were found for the mean proportion of intuitive explanations ($F(2,87)=106.4, p<.001, \text{ partial } \eta^2=.71$) and for the mean proportion of personalized epistemology ($F(2,87)=36.8, p<.001, \text{ partial } \eta^2=.46$).

Table 4-7.
Cell Means and Standard Deviations for the Mean Proportion of Intuitive Explanations and Mean Proportion of Personalized Epistemology

<table>
<thead>
<tr>
<th>Year</th>
<th>Biology</th>
<th>Physics</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Proportion of intuitive theories</td>
<td>Proportion of personalized epistemology</td>
<td>Proportion of intuitive theories</td>
</tr>
<tr>
<td>Year 1</td>
<td>M .01</td>
<td>.08</td>
<td>.27</td>
</tr>
<tr>
<td></td>
<td>SD .04</td>
<td>.14</td>
<td>.18</td>
</tr>
<tr>
<td>Year 2</td>
<td>M .21</td>
<td>.29</td>
<td>.53</td>
</tr>
<tr>
<td></td>
<td>SD .20</td>
<td>.28</td>
<td>.27</td>
</tr>
<tr>
<td>Year 3</td>
<td>M .59</td>
<td>.68</td>
<td>.54</td>
</tr>
<tr>
<td></td>
<td>SD .18</td>
<td>.21</td>
<td>.10</td>
</tr>
</tbody>
</table>

Post hoc analyses of the univariate ANOVA for the proportion of intuitive theories and proportion of personalized epistemology involved pairwise comparisons to find out how the nature of knowledge processed by the students in classroom A changed from the first to the third year of CSILE use. Tamhane's T2 test was used for carrying out the pairwise comparisons. The analysis indicated that the proportion of intuitive explanations was higher in year 3 and year 2 than year 1. Further, the students working in classroom A in year 3 outperformed the students of year 2 with respect to the mean proportion of intuitive theories. The analysis revealed also that the mean proportion of personalized epistemology produced by the classroom A students in year 3 was higher than that of year 1.
A significant multivariate effect was found for domain ($F(2,86)=57.7, p<.001$, $\eta^2=.42$), indicating that the nature of produced knowledge differed between biological and physical-study projects. The classroom A students produced a significantly higher proportion of intuitive theories in physics (adjusted mean = .45) than biology (adjusted mean = .27) ($F(1,87)=34.0, p<.001, \eta^2=.38$). Further, mean proportions of personalized epistemology differed between these domains of knowledge ($F(1,87)=54.0, p<.001, \eta^2=.28$). The results indicated that the students in classroom A expressed ownership of their ideas substantially more often in physics (adjusted mean .57) than in biology (adjusted mean = .35). In addition, a significant multivariate main effect was also found for Domain by Year Interaction ($F(4,172)=9.08, p<.001, \eta^2=.17$). This interaction may be explained by the fact that differences regarding the nature of knowledge produced and personalized epistemology were substantial only in the beginning of the period analyzed, and the students participated in production of more and more similar knowledge towards the end of the period analyzed (see Figure 4-4 and Figure 4-5, pages 136 and 137).
Detailed examination of the knowledge processed by the classroom A students revealed that the explanatory level of scientific information processed by the group increased substantially both in physics and biology. The mean explanatory level of scientific information sought by the students in their physical study project was 1.89 ($SD=.26$) in year 1, but the level was 4.14 ($SD = .25$) in year 3. Simultaneously, increased explanatory level of intuitive theories rose from 3.3 ($SD = .36$) to 4.14 ($SD=.16$). However, changes in the nature of scientific information processed explain a major part of the changes in the mean level of explanation. In the context of intuitive theories, a more substantial change was connected with increase in the number of students that produced intuitive theories. Although only a few students ($n=5$) produced intuitive theories in their biological study project in year 1, practically every student produced such theories during subsequent years.
To summarize, the analysis indicated that knowledge processed by the CSILE students was significantly affected by domain of knowledge studied. In the beginning of the period analyzed, only a small percentage of CSILE students' research questions in physics were explanation-seeking in nature. Correspondingly, the students were mostly processing factual information. This appeared to be connected to the design of their physical study project (Kinetic-molecular theory) that encouraged the students to carry out classroom experiments and describe their qualitative observations, but not to systematically search explanatory scientific information. Although the students were producing explanation-seeking questions in biology from the first year analyzed, the biological study project in question was not explicitly designed to facilitate learning of explanatory principles or core concepts. Nonetheless, the nature of classroom A students' biological study projects changed during the period analyzed,
and these projects were explicitly focused on explaining biological processes in terms of cells in the last year examined.

The results indicated that the students produced only a minimal proportion of their own intuitive theories in biology. Almost all textnotes produced in the biology project represented some kind of scientific biological information, and the students' own intuitive theories did not have an important role. In physics, however, the students' own theories had a relatively more important role from the very beginning of the period analyzed. Presumably, inquiry learning has a longer tradition in the instruction of physics than in the instruction of biology. However, during the period analyzed, CSILE students' practices of processing knowledge in biology and physics started to converge and resemble each other; students systematically focused on generating their own intuitive theories and searching for and processing explanatory scientific knowledge.

4.1.3 Analysis 3: Effects of CSILE Experience on Level of Explanation

The above analyses indicate that CSILE students' culture of inquiry progressively developed across the three-year period examined; the students in classroom A, and to a lesser extent in classroom B, were engaged in deepening levels of explanation in their inquiry. The purpose of the present analysis was to examine whether the students' individual level of explanation developed from one year to the next during the two years when they were in the class. The analysis concerned 25 students who stayed in one or another CSILE class over the two-year period. In the analysis, the
present investigator compared four groups of CSILE students; 1) students who studied in classroom A over two years (the A-to-A group, n=5); 2) students who studied in classroom B over two years (the B-to-B group, n=9); 3) students who moved from classroom A to classroom B after the first year of CSILE learning (the A-to-B group, n=5); and 4) students who moved from classroom B to classroom A after the first year of CSILE learning (the B-to-A group, n=4). Although the changes from one to another group were not designed for purposes of research (they were made in the normal administrative decisions of the school), the students who transferred from one to another group after the first year were as often average- and below-average, as above-average students, for both of the groups.

Actually, the number of CSILE students who used the system over the two years period was higher (33) than was selected for the analysis (25). However, the analysis concerning the evolution of CSILE culture revealed that year 3 differed from the first two years examined. Therefore, the analysis concerning effects of CSILE experience focused on students who worked with CSILE over a two-year period from the first to second year. A disadvantage of the solution was, however, that the sample size of the groups differed considerably. The students who participated in CSILE study over a two-year period produced, in total, 1135 content ideas in biology.

A repeated measures analysis of variance was conducted in order to analyze differences in the level of explanation between the groups as a function of CSILE experience. The between-subject factor was Group (A-to-A; B-to-B; A-to-B; and B-to-A) and the within-subject factor CSILE experience (one year; two years). The dependent
variable was mean level of explanation in biology. Of the original 25 cases, one case representing the B-to-B and one case representing the B-to-A group were dropped from analysis because the students in question did not produce any content ideas during their first year of CSILE use. The means and standard deviations for each cell are presented in Table 4-8.

<table>
<thead>
<tr>
<th>GROUP</th>
<th>n</th>
<th>First Year</th>
<th>Second Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-to-A group</td>
<td>5</td>
<td>M 2.37</td>
<td>3.62</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SD .36</td>
<td>.33</td>
</tr>
<tr>
<td>B-to-B group</td>
<td>8</td>
<td>M 2.14</td>
<td>2.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SD .49</td>
<td>.44</td>
</tr>
<tr>
<td>A-to-B group</td>
<td>5</td>
<td>M 2.46</td>
<td>2.37</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SD .37</td>
<td>.43</td>
</tr>
<tr>
<td>B-to-A group</td>
<td>4</td>
<td>M 1.89</td>
<td>3.33</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SD .44</td>
<td>.77</td>
</tr>
</tbody>
</table>

The analysis revealed that there was a significant main effect for Group \((F(3,19)=6.98, p<.002, \eta^2=.54)\) indicating that the mean level of explanation varied between the groups and across the years in a statistically significant way. A significant main effect was found also for CSILE experience \((F(1,19)=31.49, p<.001, \eta^2=.62)\). Thus, overall the mean level of explanation differed significantly in the groups as a function of CSILE experience. There was also an interaction effect for Group by CSILE Experience indicating that the effect of CSILE experience was different in each group \((F(3,19)=12.24, p<.001, \eta^2=.66)\) (see Figure 4-6).
From the first to second year of CSILE, the mean level of explanation increased substantially in the A-to-A and B-to-A groups. Post hoc pairwise comparisons were performed using Tamhane’s T2 test. The comparisons indicated that the mean level of explanation did not differ between the groups in a statistically significant way during the first year of CSILE work. However, the mean level of explanation was significantly higher in the A-to-A group and B-to-A groups than in the B-to-B and A-to-B groups during the second year of CSILE study.

To summarize, the analysis revealed that the mean level of explanation increased as a function of the experience of studying in classroom A. Simultaneously, however, CSILE students’ culture of inquiry was also changing. In order to analyze relations between individual students’ inquiry and the evolution of CSILE culture as a whole, mean levels of explanation of the students’ inquiry who studied over two years
period were plotted over the 95% confidence intervals for mean level of explanation in the CSILE groups as a whole (see Figure 4-7).

![Graph showing 95% Confidence Interval for Mean Level of Explanation](image)

**Figure 4-7.**
The 95% confidence intervals for mean level of explanation in CSILE groups year 1 and year 2. Means for groups of students who worked with CSILE over a two-year period are represented by lines.

Figure 4-7 indicates that the development of inquiry of the students who worked over the two-year period with CSILE, as measured with mean level of explanation, showed a correspondence with evolution in the whole learning community across the period analyzed. The results of the analysis suggest, on the one hand, that there was continuity in the CSILE culture across years so that the evolution can-
not be explained by referring to new CSILE students who started to work with the system yearly. On the other hand, one cannot rule out the possibility that changes in the students' level of explanation are explainable in terms of general increases from year 1 to year 2. The results indicated that there was a close connection between an individual student's inquiry and evolution of the groups' culture of inquiry as a whole. The changes in individual students' inquiry seemed to reflect evolution of the whole community's inquiry, indicating that the changes at the individual and communal level were reciprocally dependent.

4.1.4 Discussion

The results of this analysis indicate that CSILE students can be guided to engage in processes of inquiry in which they are approaching problems being investigated at deepening levels of explanation. In the two CSILE classrooms, the classroom culture changed over three years following the introduction of CSILE. In terms of the level of explanation scale, explanations made over a year by the children in their CSILE notes, especially those indexed under "My Theory," became deeper in tracking from year 1 to year 3. In one of the classrooms, the children's levels of explanation reached substantial depth as we pass from year 1 to year 3; here the difference on this temporal variable was large and significant. Both examination of CSILE students' research questions and of knowledge produced by them revealed that the inquiry of the students in classroom A was more and more explicitly focused on generating their own explanation-seeking research questions, construction of their own intuitive explanations, as well as searching for explanatory scientific information. In
classroom B, the increased depth of explanation was much more modest; processing of factual and descriptive information dominated the group's practices of inquiry during the whole period investigated.

The comparison between classrooms A and B across the period concerned CSILE students' culture of inquiry as a whole; the results cannot be generalized to individual students' inquiry because most of the students worked with CSILE only for one year. However, the analysis concerning effects of CSILE experience indicated that participation in inquiry in classroom A affected the epistemological nature of an individual student's knowledge production and facilitated participation in explanation-driven inquiry. It follows that the evolution of CSILE students' inquiry not only occurred in new groups of students coming to classroom A yearly, but also in students who studied in classroom A over the two-year period. Further, the analysis indicated that the students' inquiry was heavily dependent on their group; transference to classroom B led to a decreasing proportion of explanation-seeking questions as well as a decreasing mean level of explanation. The students who moved to classroom A after one year's experience in classroom B rapidly achieved the same level of explanation as the students working continuously in classroom A. Accordingly, practices of knowledge processing seemed to be dependent on group membership.

Further, the analysis revealed that knowledge production in classrooms A and B was not affected by the ability level or gender of the participating students. A significant educational achievement was that, regardless of gender or ability level, classroom A students were able to generate explanation-seeking questions, construct in-
tuitive explanations and introduce explanatory scientific information. This phenomenon seems to represent the fact that practices of inquiry are, to a great extent, determined by the culture of learning. Without a teacher's guidance or examples of advanced models of cognitive practices, all students, regardless of their individual cognitive competencies, might well remain at a more elementary level in their inquiry as observed in the case of classroom B.

The analysis revealed that there were large and significant differences in mean levels of explanation between classrooms A or B across the period investigated. In evaluating the results, one should take into consideration that the groups differed in several ways from each other, so that it is not possible to specify a single factor that would explain differences between the groups. Nevertheless, since most of the children stayed in the class for one year only, the main candidates to whom both the significant effects can be attributed, are the two teachers, who were the only persisting elements from year 1 to year 3. The teacher of classroom A systematically tried to go beyond his earlier achievements, i.e., use experiences from earlier years to carry out more demanding and challenging projects in subsequent years. It appears that over the three years the teacher of classroom A learned how to use CSILE to encourage the children to generate and explore explanations at deeper levels and go beyond their earlier achievements. The teacher of classroom B, in contrast, did not seem to be equally involved with CSILE projects and did not participate in guiding the students as intensively as did the teacher of classroom A.
The study indicates, further, that an important explanation for the differences between the two CSILE classes may be found in the implicit epistemological assumptions and cognitive design of CSILE projects conducted in the two classrooms. The most important difference between the groups seemed to be in the nature of learning tasks that the projects required. The projects of classroom B focused on observable, everyday phenomena that did not encourage the students to engage in deepening inquiry. The epistemological nature of classroom A’s projects was different from that of classroom B. The students were asked to specify their own research questions, generate their intuitive explanations, and search explanatory scientific theories. Increasingly, from one to another year the topics of classroom A were conceptually more and more challenging. It appears that the epistemological nature of study projects carried out had an important effect on practices of knowledge production, guiding the students either to focus on factual information or process explanatory knowledge.

In summary, the results of the study indicate that the teacher has an extremely important role in facilitating engagement in explanation-driven process of inquiry. The study furnished evidence that children can be encouraged, given both CSILE and appropriate teacher guidance, to pursue scientific inquiry in a way that is analogous to the first principal feature of scientific thinking – they can think with deeper levels of explanation than is generally believed.
4.2 Study II: Emergence of Explanation-oriented Culture of Interaction in Two CSILE Classes

4.2.1 Method

CSILE is designed to facilitate collaborative inquiry through providing each student access to his or her fellow students' productions (postings) as well as tools for adding written comments to other students' posted notes. The purpose of this study was to examine whether CSILE students were able to engage in social interaction focused on advancing their explanations; such interaction represents the third principal feature of scientific inquiry. The study focused on analyzing how the objects of CSILE students' peer interaction differed between the two classrooms and changed across the period investigated, and to what extent between-student interaction supported deepening inquiry in general and advancement of explanation in particular, instead of serving merely social purposes. Quality of interaction between the students was determined by examining their explication of referential relations in their comments, i.e., whether they explicated reasons for their agreement or disagreement in a way analogous to scientific discourse.

Further, CSILE students' peer interaction was examined by comparing peer interaction in classrooms A and B during the last year analyzed as a function of gender and ability level of the students. This approach was adopted because classroom B students did not produce comments frequently enough to allow examination of any subgroup of students during the first two years analyzed. The problem addressed was whether students representing both genders and all ability levels were able to
participate in explanation-oriented peer interaction with an equal intensity. It may be argued that discourse interaction focused on advancing explanation presupposes exceptional abilities and is attainable only for students with high-literacy backgrounds. In this study, these problems were addressed by comparing peer interaction of female and male students as well as low- and high-achieving students in classrooms A and B. Year 3 represented the highest level of CSILE students' inquiry in both of the classrooms. Although there were substantial between-group differences in practices of CSILE use across years, the types of activities carried out by the groups resembled each other in year 3. During that year the students in classroom B participated in CSILE-mediated communication as intensively as the students from classroom A. Moreover, the students were working in small groups in the same way as in classroom A.

In the analysis of CSILE students' peer interaction across the three-year period, I included all students (178) who studied with CSILE during the period because only a part of classroom B students participated in CSILE-mediated communication. Further, out of these 178 students, only those who actually participated in CSILE-mediated communication were included in analyses focused on detailed examination of the content of CSILE students' interaction. This approach was adopted because the students in classroom B produced only a few comments during year 2, and an analysis concerning relative proportions would have given misleading information concerning changes from one year to another: In cases in which a student does not produce any comments, the proportion of any subgroup of comments is 0. The sec-
ond analysis concerned 56 students representing different genders and ability levels that participated in CSILE use in classroom A (n = 28) and classroom B (n = 28) groups during year 3. The analyses of CSILE students' peer interaction were carried out using the methods of qualitative content analysis and analysis of relative proportions introduced in the method section.

4.2.2 Analysis 1: Change in Practices of Peer Interaction in Two CSILE Classes Across a Three-Year Period

The first analysis focused on comparing peer interaction in classrooms A and B across the three-year period analyzed. However, the number of comments varied substantially from one year to another (see Table 4-9). During the period, 156 out of 178 CSILE students participated in CSILE-mediated communication. There were 21 students who did not produce any comments; 14 of these students studied in the classroom B2 group, 3 in the classroom B1 group and 1 in the classroom A3 group. Apparently, CSILE-mediated communication was left to the students' own initiatives in classroom B during the first two years, whereas it was an integrated aspect of inquiry in classroom A.

<table>
<thead>
<tr>
<th>Year</th>
<th>Classroom A</th>
<th></th>
<th>Classroom B</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>n</td>
<td>M</td>
</tr>
<tr>
<td>Year 1</td>
<td>19.7</td>
<td>13.3</td>
<td>31</td>
<td>5.6</td>
</tr>
<tr>
<td>Year 2</td>
<td>14.8</td>
<td>9.8</td>
<td>28</td>
<td>4.6</td>
</tr>
<tr>
<td>Year 3</td>
<td>18.6</td>
<td>10.3</td>
<td>27</td>
<td>18.5</td>
</tr>
</tbody>
</table>
The subsequent analyses concerning the content of CSILE students' peer interaction focused on the subgroup of students that participated in CSILE-mediated peer interaction. Two aspects of CSILE students' peer interaction were addressed in the analysis; i.e., the object of their inquiry and quality of their communication as measured by explication of referential relations.

4.2.2.1 Object of Inquiry: from Linguistic Form to Explanation

Analysis of the classroom A students' communicative ideas showed that the object of their inquiry progressively changed from year 1 to year 3. Analysis of CSILE's database revealed that in the beginning of the period, many of the students commented on linguistic form ("your note is good because you did not make any spelling mistakes" and amount of information ("your note is good because you have a lot of information"). As the period progressed, the culture of discourse interaction in classroom A changed so that the students were not talking anymore about linguistic form but rather the process of inquiry in general and explanation in particular. In Table 4-10 are provided transcriptions from CSILE students' productions concerning the basic objects of their inquiry.
Table 4-10.
Basic Types of the Object of CSILE Students' Inquiry

| LINGUISTIC FORM | I have read your note, about I think electricity works like this, and when I read it it was very well done and also you do not have any mistakes, you have written all the capital letters, that you have to write And now this is all I am going to say about your note. (year 2, student 433) |
| RESEARCH PROBLEM | These questions are pretty good. I think you should do some more questions on HUMAN evolution, not just evolution in general. I can answer one of your questions, though. If humans are descendants from apes; then how come apes aren't considered homo sapiens? Well, apes aren't humans, are they? and humans took millions of years to become how they are now, so they're not just like the same as monkeys. Apes aren't considered homo sapiens because they're simply not humans like we are. (If you see what I mean) ... Your questions should take a lot of research to find the answer. (year 1, student 342) |
| RESEARCH METHOD | This sounds like you copied this out of a book in fact I'm almost positive you did, for I read a book that had that example word for word. I think it's okay to use the same example for very well thought out, but you could at least reword it a bit. By the way do you agree with Darwin? (year 1, student 350) |
| AMOUNT OF INFORMATION | Your note sure does have a lot of information. I had a good time reading it. I cannot think of any other information to add. I will surely use some of your information in my note. I will probably use the part about peat. THANKS! (year 1, student 302) |
| QUALITY OF INFORMATION | I think your note has some very good information but it is hard to understand. I think you should put your words in a clearer way. Because while your note has interesting information you should put it in such a matter that people can understand it and learn from it. I don't think that many people in this class know what a lysosome or a mitochondria is. Or you could put some of the hard to understand words in your vocabulary list. (year 1, student 310) |
| EXPLANATION | Your note on breathing rates is really good. It was interesting to find out how our rates actually change. But I think something was missing. Your note would have been more interesting if you could have given a detailed theory of how you feel after you run, and why you feel that way. Otherwise I think the note was really well written. (year 2, group cfg) |

The frequency distribution of the object of inquiry in the CSILE students' communicative ideas is presented in Table 4-11. Comments on linguistic form consisted of 147 (23.6%) out of 624 classroom A students' communicative ideas produced in year 1. A plausible hypothesis would have been that below-average students, presumably with writing difficulties, would focus their inquiry more often on linguistic form than the more advanced students. The analysis revealed, however, that both below- and above-average achieving students commented on linguistic form.
Table 4-11.
Frequency Distribution of the Object of Communicative Ideas Produced by Students from Classrooms A and B

<table>
<thead>
<tr>
<th>OBJECT OF INQUIRY</th>
<th>PERIOD</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Year 1</td>
<td>Year 2</td>
<td>Year 3</td>
<td>TOTAL</td>
</tr>
<tr>
<td></td>
<td>f</td>
<td>%</td>
<td>f</td>
<td>%</td>
<td>f</td>
</tr>
<tr>
<td>Classroom A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linguistic form</td>
<td>147</td>
<td>23.6</td>
<td>71</td>
<td>17.7</td>
<td>9</td>
</tr>
<tr>
<td>Problem+method</td>
<td>92</td>
<td>14.7</td>
<td>74</td>
<td>18.5</td>
<td>58</td>
</tr>
<tr>
<td>Information</td>
<td>277</td>
<td>44.4</td>
<td>180</td>
<td>44.9</td>
<td>167</td>
</tr>
<tr>
<td>Explanation</td>
<td>79</td>
<td>12.7</td>
<td>72</td>
<td>18.0</td>
<td>293</td>
</tr>
<tr>
<td>Unspecified</td>
<td>29</td>
<td>4.6</td>
<td>4</td>
<td>1.0</td>
<td>5</td>
</tr>
<tr>
<td>TOTAL</td>
<td>624</td>
<td>100.0</td>
<td>401</td>
<td>100.0</td>
<td>532</td>
</tr>
<tr>
<td>Classroom B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linguistic form</td>
<td>66</td>
<td>42.9</td>
<td>15</td>
<td>22.4</td>
<td>78</td>
</tr>
<tr>
<td>Problem+method</td>
<td>36</td>
<td>23.4</td>
<td>4</td>
<td>6.0</td>
<td>181</td>
</tr>
<tr>
<td>Information</td>
<td>45</td>
<td>29.2</td>
<td>42</td>
<td>62.7</td>
<td>228</td>
</tr>
<tr>
<td>Explanation</td>
<td>2</td>
<td>1.3</td>
<td>5</td>
<td>7.5</td>
<td>30</td>
</tr>
<tr>
<td>Unspecified</td>
<td>5</td>
<td>3.2</td>
<td>1</td>
<td>1.5</td>
<td>11</td>
</tr>
<tr>
<td>TOTAL</td>
<td>154</td>
<td>100.0</td>
<td>67</td>
<td>100.0</td>
<td>528</td>
</tr>
</tbody>
</table>

Change in the object of CSILE students' peer interaction was analyzed by distinguishing inquiry-related comments from comments that were focused on linguistic form or technical aspects of CSILE use. These inquiry-related comments consisted of comments on research questions, methods, information, and explanation. A factorial analysis of variance was performed in order to analyze whether the mean proportion of inquiry-related comments changed as a function of group and year. Mean proportion of inquiry-related comments was the dependent measure, and group (classroom A, classroom B) and year (1, 2, 3) were independent measures. Means and standard deviations for each cell are presented in Table 4-12.
Table 4-12.  
The Mean Proportion of Inquiry-related Comments Across the Period Analyzed

<table>
<thead>
<tr>
<th>Year</th>
<th>Classroom A</th>
<th></th>
<th>Classroom B</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>n</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Year 1</td>
<td>.75</td>
<td>.18</td>
<td>31</td>
<td>.65</td>
<td>.28</td>
</tr>
<tr>
<td>Year 2</td>
<td>.77</td>
<td>.20</td>
<td>28</td>
<td>.73</td>
<td>.34</td>
</tr>
<tr>
<td>Year 3</td>
<td>.96</td>
<td>.05</td>
<td>27</td>
<td>.80</td>
<td>.26</td>
</tr>
</tbody>
</table>

The analysis indicated that there was main effect for group \((F(1,155)=7.1, p<.009, \text{partial } \eta^2=.05)\); thus, a larger proportion of comments produced in classroom A were inquiry-related in nature. Further, the analysis showed a main effect for year \((F(2,155)=9.62, p<.001, \text{partial } \eta^2=.11)\): the mean proportion of inquiry-related comments increased monotonically in both of the groups as a function of year. However, there was no statistically significant interaction effect. Scheffé group comparisons revealed that the mean proportion of inquiry-related comments in classroom A in year 3 was higher than that of both classrooms A and B in year 1.

The transition from linguistic form toward inquiry was partially initiated by the students' discussion, in the end of year 1, of qualities of good comments; the discussion came to the conclusion that comments on linguistic form are usually not very helpful or interesting. Such comments were often very critical and unconstructive; for example:

Dear, ES your little note has so many spelling mistakes. ES let me give you some advice don't try to write like a big shot cause you are not a big shot and you will never be one. (year 1, student 348)
The following is typical example of comments that emerged in classroom A concerning principles of communication.

"Your comment to N was good, ... but all you said as that the note was good and it had no spelling errors. The point of writing comments is to help other students in the class to learn how to write good notes and to learn more about electricity." (year 2, student 23301)

In classroom B there occurred no corresponding discussion of the relative merits of different types of comments. However, the object of inquiry changed also in classroom B as a consequence of external intervention: the students were told not to comment on linguistic form by the teacher and CSILE staff.

Comments about research problems and methods appeared to have a very important role in the process of inquiry for students in classroom A. Many of these comments seemed to be metacommets in nature; they helped the students to focus on specific research questions as well as carry out their inquiry reflectively and in depth. During year 1, approximately 20 comments were produced which criticized direct copying of information. Further, it can be noticed in Table 4-11 that classroom B produced a large number of comments on problems during year 3. A major part of these communicative ideas was produced in a mathematics project in which the students were constructing and discussing math problems. However, classroom B did not produce the same kind of metacommets as the students in classroom A because...
they discussed the content and answers to problems rather than processes of inquiry (see study 5 for a more detailed analysis of classroom A students' metacomments).

In the beginning of the period, the concept of knowledge for students in classroom A appeared to be quantitative in nature. The students evaluated each other's productions on the basis of amount of information presented, producing about 100 comments like "your note is good because you have a lot of information." These information-related comments constituted 49% of the supportive communicative ideas ($f = 171$) from year 1. Comments on linguistic form (28%) and information (36%) accounted almost two-thirds of critical comments ($f = 363$) produced during that year. It was typical, for example, to state that "you should put more information into your note." The role of explanation in supportive and critical comments was not very prominent, only 8% and 12%, respectively.

A factorial analysis of variance was performed in order to analyze whether the mean proportion of explanation-related comments changed across years of CSILE use in the groups. Mean proportion of explanation-related comments was the dependent measure. Group (classroom A, classroom B) and year (1, 2, 3) were the independent measures. Means and standard deviations for each cell are presented in Table 4-13.
Table 4-13. 
Cell Means and Standard Deviations for the Mean Proportion of Explanation-related Comments

<table>
<thead>
<tr>
<th>Year</th>
<th>Classroom A</th>
<th></th>
<th>Classroom B</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>n</td>
<td>M</td>
</tr>
<tr>
<td>Year 1</td>
<td>.11</td>
<td>.09</td>
<td>31</td>
<td>.01</td>
</tr>
<tr>
<td>Year 2</td>
<td>.16</td>
<td>.13</td>
<td>28</td>
<td>.06</td>
</tr>
<tr>
<td>Year 3</td>
<td>.51</td>
<td>.19</td>
<td>27</td>
<td>.07</td>
</tr>
</tbody>
</table>

The analysis showed that there were main effects for group \( F(1,155) = 107.2, \ p < .001, \ \text{partial} \ \eta^2 = .42 \) and year \( F(2,155) = 49.0, \ p < .001, \ \text{partial} \ \eta^2 = .40 \). The mean proportion of explanation-related comments was at a significantly higher level in classroom A than classroom B. This proportion increased from one year to the next in both of the groups. Moreover, the analysis revealed an interaction effect, Group by Year \( F(2,155) = 32.9, \ p < .001, \ \text{partial} \ \eta^2 = .31 \), indicating that the mean proportion of explanation-related comments increased much more strongly in classroom A than classroom B. Scheffé group comparisons indicated that the respective mean proportions of explanation-related comments for students in classroom A in year 2 were significantly higher than those for students in classroom B in year 1 and year 2. Further, the analysis revealed that the mean proportion of classroom A students' explanation-related comments differed from those in the two earlier years for classroom A as well as for years in classroom B. One final analysis was conducted to address the hypothesis that classroom A's epistemology of inquiry would advance more than that of classroom B in terms of explanation-related communicative ideas. The difference in means between year 1 and year 3 for classroom A minus the difference in means
between year 1 and year 3 for classroom B was .35, \((F(1,150)=53.4, \ p<.001)\). The result of this analysis supported the hypothesis.

Gradually during year 1 and year 2, the object of the classroom A students' inquiry-related comments changed from the amount of information to the quality of information ("you have found very important pieces of information"). As shown in Table 4-13, the discourse of explanations was a part of inquiry for students in classroom A from the very beginning of the period analyzed, but its relative importance increased substantially. The mean proportion of explanation-related communicative ideas increased substantially from year 1 \((M = .13, \ SD = .10)\) to year 3 \((M = .49, \ SD = .21)\). Although only .14 of the students' comments concerned explanation during year 2, the analysis of their research questions and textnotes revealed that their knowledge production was already focused on construction of explanation. Yet they just did not appear to have proper epistemological concepts for talking about their inquiry. Further, examination of the material indicated that the emergence of explanation-oriented discourse held for classroom A as a whole, not only the most advanced students. Discourse interaction during year 3 was explicitly connected with construction of the students' own explanations. This type of discourse dominated classroom A although the students naturally were also concerned about the search for information.

An analysis of CSILE comments produced by the teachers of the classes indicated that the comments generated by the teacher of the classroom A were consistently explanation-related in nature, whereas the teacher of classroom produced only a few comments, hardly any of them focused on explanation.
To summarize, the analysis of CSILE students' comments indicates that there were substantial differences concerning epistemology of discourse interaction between classrooms A and B. In the latter group, the discourse of explanations never accounted more than 7% of communicative ideas. As in the preceding analysis concerning CSILE students' knowledge production, it can be concluded that only in classroom A did an explanation-oriented culture of interaction develop.

4.2.2.2 Quality of Communication: Explication of Referential Relations

The epistemic value of communication is dependent on the explication of referential relations. The analysis indicated that CSILE students did not use an explicit language in many of their comments during year 1 and year 2, and that the below-average students, especially, left the referents of their comments unexplicated or only
partially specified. Table 4-14 presents examples concerning explication of referential relations in CSILE students' comments.

Table 4-14.
Examples of Unexplicated Referential Relations in CSILE Students' Productions

<table>
<thead>
<tr>
<th>REFERENTIAL RELATIONS UNEXPLICATED</th>
<th>bad (year 2, student 23113)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>It dusent quiet sound right (year 1, student 332)</td>
</tr>
<tr>
<td></td>
<td>This is a good note. (year 1, student 355)</td>
</tr>
<tr>
<td></td>
<td>I think your notes need a little more. (year 1, student 327)</td>
</tr>
<tr>
<td></td>
<td>This note is very interesting, although It doesn't really meen anything. I sudgest you make it more interesting. ... (year 1, student 338)</td>
</tr>
<tr>
<td></td>
<td>I have read the note that says, THE WAY I THINK ELECTRICITY WORKS, and it was very good but there are some things that I don't understand, and this is all I'am going to tell you about your note. (year 2, student 433)</td>
</tr>
<tr>
<td></td>
<td>I don't want to to mean or anything but after I read your note it doesn't really explain to me anything. And I think that you should explain more of your note. (year 2, student 26119)</td>
</tr>
<tr>
<td></td>
<td>YOUR WORK IS GREAT EXCEPT THAT I ADVISE THAT YOU PUT MORE INFO. (year 1, student 311)</td>
</tr>
</tbody>
</table>

| REFERENTIAL RELATIONS EXPLICATED | I really enjoyed reading your note on "Human Evolution". I really liked the part on the speech, the reason I liked it was because ever since I started on my research I wondered what types of form did they speek and ways they pronounced words. If you ever came across any information on that it would be a great help to know. (year 1, student 314) |

The analysis indicated that discourse concerning both the linguistic form and the amount of information were at a very general level. Often the students did not explicate or specify what aspect of information they were referring to and why, or in what sense, use of this information would be desirable or useful. Explanation seems to require explication of referential relations by its very nature. Examination of relationships between the content of CSILE students' communicative ideas and explication of referential relations suggests that a discourse of explanation may require development of a more explicit interaction. During year 1 only 35% of communicative ideas
concerning linguistic form \((f=213)\) and 61\% of information \((f=322)\) were explicated, while as many as 80\% of comments on explanation \((f=81)\) were explicated.

A factorial analysis of variance was performed in order to analyze whether the mean proportion of explicated comments increased across years in classrooms A and B. The mean proportion of explicated comments was the dependent variable. Independent variables were group (classroom A, classroom B) and year \((1,2,3)\). Means and standard deviations for each cell are presented in Table 4-15.

**Table 4-15.**
**Cell Means and Standard Deviations for the Mean Proportion of Explicated Comment for Students in Classrooms A and B**

<table>
<thead>
<tr>
<th>Year</th>
<th>Classroom A</th>
<th></th>
<th></th>
<th>Classroom B</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>n</td>
<td>M</td>
<td>SD</td>
<td>n</td>
</tr>
<tr>
<td>Year 1</td>
<td>.54</td>
<td>.23</td>
<td>31</td>
<td>.35</td>
<td>.31</td>
<td>27</td>
</tr>
<tr>
<td>Year 2</td>
<td>.61</td>
<td>.22</td>
<td>28</td>
<td>.36</td>
<td>.37</td>
<td>15</td>
</tr>
<tr>
<td>Year 3</td>
<td>.78</td>
<td>.17</td>
<td>27</td>
<td>.26</td>
<td>.20</td>
<td>28</td>
</tr>
</tbody>
</table>

The analysis revealed that there was a main effect for group \((F(1,155) = 62.83, p<.001,\text{ partial } \eta^2=.30)\) as well as an interaction effect, Group by Period \(F(2,155) = 6.77, p<.002,\text{ partial } \eta^2=.08)\). However, there was no main effect for year, indicating that the mean proportion of explicated comments did not substantially change across years of CSILE use. Scheffé group comparisons revealed that the mean proportion of explicated comments in classroom A was higher than that of classroom B. Further, the comparison indicated that the mean proportion of explicated comments for stu-
dents in classroom A during year 3 differed from that of all years of classroom B and from the first year of classroom A.

A plausible assumption is that it usually takes a larger number of words to articulate an explicated comment than an unexplicated one. In order to test whether the mean number of words in explicated comments was higher than that of unexplicated comments, a paired sample t-test was performed. The analysis included 88 students who produced both explicated and unexplicated comments. The analysis showed that the mean number of words in explicated comments \((M=40.8, SD=41.7)\) was higher than that in unexplicated comments \((M=19.0, SD=6.7)\) \((t=4.77, df=85, p<.001)\). Many of the unexplicated comments consisted only in a few words whereas explicated comments sometimes represented very long and elaborate accounts of the issues being discussed. There were no significant differences between the groups or across years for the mean number of words in explicated comments.

In summary, the evolution of a culture of interaction in classroom A involved an increasing explicitness in the students' comments, from comments such as "I (dis)agree" to comments in which the referents were specified and reasons for agreement or disagreement explained. Classroom A students' mean proportion of explicated comments increased simultaneously with the development of explanation-related discourse from approximately 50% to 72% during the period analyzed. In year 3 only a few members of the group produced unexplicated comments, but they were soon guided toward use of more explicit language. Completely unspecified comments practically disappeared from classroom A during year 3. This change is even more
remarkable when one considers that classroom A students were working in small groups during year 3 and, therefore, the referents were in some cases familiar for all participants. Intentional attempts to construct as well as communicate one's explanations appeared to lead to gradually deepening discourse in which students improved their ability to communicate their ideas and criticize those constructed by the others.

The mean proportion of explicated comments in the context of classroom B was at a significantly lower level, and remained at 24% during the three-year period analyzed. Although explication of referent was associated with higher ability levels in both of the groups, the mean proportion of explicated communicative ideas was, remarkably, higher even in the context of the below-average students from classroom A (.42, SD = .31) than in the above-average students from classroom B (.34, SD = .28).

The problem of unexplicated referential relations was frequently experienced by the students. The following comment illustrates the difficulties produced by unexplicated referential relations:

I have just finished looking at your notes on electricity. They are interesting and well written. When I read your comment to X., certain parts were hard to understand so I looked at the note of X.'s that you were commenting on and still found it hard to understand even with X.'s note. Next time you comment on a vocabulary note you should explain the word and what part of the word you are talking about so it would be easier for everybody to understand. Your notes have a different sort of theory than everybody else. They are very good. (year 2, student 26137)

4.2.3 Analysis 2: Patterns of Interaction in Two CSILE Classes

The second analysis aimed to compare peer interaction of classroom A (n=28) and classroom B (n=28) students during year 3 as a function of their gender and ability level. However, some students did not take the CSBT test used for determining
ability level because they were away from school during the day of testing or come to the classroom later on. Therefore, the numbers of students in the present analyses were a bit smaller than in other analyses.

A direct discriminant analysis was performed using four variables representing the nature of CSILE students' communication as predictors of membership in a CSILE group. The predictors were mean number of comments, proportion of explicated comments, proportion of explanation-related comments, and proportion of critical comments. The grouping variable was a composite variable of class and gender (classroom A female (n=19); classroom A male (n=8); classroom B female (n=9); classroom B male (n=19)). Of the original 56 cases, 1 case representing classroom A was dropped from analysis because of missing data, i.e., no comments produced.

Three discriminant functions were calculated, with a combined $\chi^2(12) = 98.2$, $p<.000$. After removal of the first function, there was still a strong association between groups and predictors, $\chi^2(6) = 18.3$, $p<.006$. The third discriminant function, however, was not significant. The two discriminant functions accounted for 90% and 10%, respectively, of the between-group variability. As shown in Figure 4-9 (page 169), the first discriminant function maximally separates the students in classroom A from the students in classroom B. The second discriminant function partially discriminates classroom A females and classroom B males from classroom A male students.

The loading matrix of correlations between predictors and discriminant functions, as seen in Table 4-16 (page 165), suggested that the best predictors for distin-
guishing between classroom A and classroom B (first function) were the mean proportion of explanation-related comments and mean proportion of explicated comments.

**Canonical Discriminant Functions**

![Graph showing canonical discriminant functions](image)

**Function 1: Degree of explanation-oriented communication**

**Figure 4-9.**
Plots of four group centroids on two discriminant functions derived from four communicational variables: respective proportions for explanation related comments, explicated comments, critical comments, and number of communicative ideas.

The classroom A female ($M = .54$) or male ($M = .44$) students produced a higher mean proportion of explanation-related comments than classroom B females ($M = .13$) or males ($M = .03$). Further, a higher proportion of the classroom A female
(M = .77) and male (M = .81) students' comments were explicated than were comments of the classroom B female (M = .34) or male (M = .22) students.

Table 4-16.
Results of Discriminant Function Analysis of Communication Variables

<table>
<thead>
<tr>
<th>Predictor variable</th>
<th>Correlations with the discriminant functions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Mean proportion of explanation-related comments</td>
<td>-.78</td>
</tr>
<tr>
<td>Mean proportion of explicated comments</td>
<td>-.76</td>
</tr>
<tr>
<td>Mean proportion of critical comments</td>
<td>-.16</td>
</tr>
<tr>
<td>Number of comments</td>
<td>-.01</td>
</tr>
<tr>
<td>Canonical R</td>
<td>.89</td>
</tr>
<tr>
<td>Eigenvalue</td>
<td>3.9</td>
</tr>
</tbody>
</table>

Two predictors, number of communicative ideas and proportion of critical comments had a loading in excess of .50 on the second discriminant function, which separates classroom A females and classroom B males from the classroom A male students. Classroom A females (M = 22.6, SD = 9.3) and classroom B males (M = 20.5, SD = 12.7) produced a significantly higher mean number of comments than classroom A males (M = 9.1, SD = 6.0). Classroom B females produced a lower mean number of comments (M =14.3, SD = 9.3) than classroom B males but cannot be clearly separated from the latter group.

Pooled within-group correlations among the four predictors are shown in Table 4-17. There was a positive relationship between the mean proportion of explicated comments and the mean proportion of critical comments with r(52)=.29, p<.05, indi-
cating that critical comments were more likely to be explicated than other kinds of comments.

Table 4-17.
Pooled Within-group Correlations Among Predictors of Communication

<table>
<thead>
<tr>
<th></th>
<th>Proportion of explicated comments</th>
<th>Proportion of critical comments</th>
<th>Number of comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion of explanation-related comments</td>
<td>.24</td>
<td>.25</td>
<td>.12</td>
</tr>
<tr>
<td>Proportion of explicated comments</td>
<td>.29</td>
<td>.25</td>
<td>.13</td>
</tr>
<tr>
<td>Proportion of critical comments</td>
<td></td>
<td></td>
<td>.17</td>
</tr>
<tr>
<td>Number of comments</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

With the use of discriminant classification procedure for the total usable sample of 55 students, 41 (75%) were classified correctly, compared to 19 (35%) that would be correctly classified by chance alone. The 75% classification rate was achieved by using sample proportions as prior probabilities. The likelihood of classifying classroom B males (95%, 18) or classroom A females, 90% (17) correctly was substantially higher than the classification rate of classroom B females, 56% (5) or classroom A males, 50%, (4). Two classroom B females were classified as classroom B males and two as classroom A males. Three classroom A males shared characteristics with classroom A females and one with classroom B males.

The results indicate that male students dominated communication in classroom B, and the female students did so in classroom A. This appeared to be connected with the fact that the percentage of males and females differed between the groups; two-thirds of the students were males in classroom B and only one-third in classroom A. As a consequence, female students produced 24% (f=129) out of 528 communi-
cative ideas of classroom B, and male students 14% (f=73) out of 532 communicative ideas produced by the students in classroom A. However, results of the study should be taken with caution because an analysis of the multivariate homogeneity of the variance-covariance matrices revealed that the variances were not homogeneous (Box's M=68.7, p<.002). Variances of classroom A females and classroom B males were smaller than variances of classroom A males and classroom B females.

From the biased gender distribution of the groups it appears that the proportion of comments received from another student representing the same gender was .85 (SD = .16) in the case of classroom A female students and .48 (SD = .27) in the case of classroom A male students. Correspondingly, .79 (SD = .23) of comments produced by students in classroom B were received from another male and .50 (SD = .31) of female students' comments from another female in the class. Thus, a larger proportion of comments received by female students were given by female students in classroom A, whereas male students were receiving comments equally from male and female students. Correspondingly, classroom B male students received a larger proportion of comments from male students in classroom B, and female students received comments equally from both genders.
4.2.4 Discussion

Examination of the CSILE students' communication revealed substantial differences between classrooms A and B. The analysis indicates that the object of classroom A students' communication progressively changed from year 1; focus on linguistic form and quantity of information disappeared while a very advanced explanation-related discourse emerged. The proportion of explanation-related comments increased substantially in classroom A, and the students' discourse changed so that criticism was more and more focused on explanations instead of linguistic form or amount of information as such. Simultaneously with development of a discourse of explanations, there was increased explication of referential relations in the CSILE students' comments. Further, it was noticeable that the teacher of classroom A engaged actively with CSILE discourse facilitating explanation-oriented discourse interaction, although the teacher of classroom B produced only a few CSILE comments. In summary, an explanation-oriented and explicit discourse interaction came to play an increasingly important role in inquiry for students in classroom A. The results indicated that children can be encouraged to make input to other children's explanations, and this related to the third principal feature of scientific thinking.

The analysis, further, indicated that in classrooms A and B there were considerable within-group differences concerning participation in social interaction mediated by the CSILE environment during year 3. Discourse interaction within classroom A was dominated by female students, although the male students dominated interaction within classroom B. A possible explanation for the phenomenon is the biased gender
distribution of classroom A. Young students seem to prefer communication within their gender group, and in a classroom in which females formed a majority (60-70%) males may have found it difficult to participate as intensively as they would have otherwise. Another reason may be that the culture of young males is more competitive and might not support collaboration as well as that of female students. This assumption is supported by the fact that unexplicated and exclusively critical comments given during the period analyzed appeared to be far more typical for males than females. Nevertheless, as a whole, the male students also produced a large number of ingenious comments as well as content ideas. Discourse interaction of classroom A males did not differ in content from that of the females; they produced only a significantly smaller number of comments. In any case, the results suggest that special attention should be given to male students in order to find new ways of supporting the development of their collaborative learning culture.

Results of an earlier CSILE study carried out by Hakkarainen, Järvelä, Lipponen, Lonka, & Lehtinen (1996) suggested that the gender difference concerning engagement with computer-supported collaborative learning may not be only an artifact caused by the biased gender distribution of classrooms A and B. That study, in contrast to the present results, indicated that a special effort was needed in order to engage female students with the computer-supported collaborative learning; male students produced a large majority of CSILE notes and dominated discourse interaction within a Finnish CSILE class. The authors argued that insofar as technology-based learning environments are introduced as a technological innovation without profound
pedagogical changes, it might be difficult to get the female students, who are not equally interested in computer technology as male students, to commit themselves with participation in the computer-supported collaborative learning. Active participation of the classroom A female students in the present study may be explained by the fact that CSILE work was thoroughly subordinated to pedagogical goals.
4.3 Study III: The Nature of Intuitive Explanation and Conceptual Advancement in Physics and Biology

4.3.1 Method

The third study was intended to deepen the analysis of CSILE students' explanations through examining, within classroom A, the nature of intuitive explanations generated and scientific information sought by the students (n=28) in physical and biological topic areas. The students from classroom A were systematically guided by their teacher to generate their own hypotheses, conjectures, and theories about the physical and biological phenomena being investigated. The problem addressed in the study was whether the students were profitably able to engage, even in a rudimentary form, in progressively deepening explanation-driven process of inquiry genuinely representing the first principal feature of scientific inquiry. The intuitive theories generated by the students did not generally represent accepted scientific views. The teacher of classroom A 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 classroom A students' intuitive theories, particularly whether all basic types of explanation, such as functional, physical (Mackor, 1995, undated; Millikan, 1986) or theoretical (Salmon, 1984; 1989) explanation, were represented in these students' productions. The study focused on analyzing whether the students were able to overcome their, in many cases, inadequate intuitive theories, and to come to prefer more scientific physical and theoretical explanations, i.e., made conceptual advancement, during a study project.
The students’ conceptual advancement was assessed by analyzing 1) whether they were able to commit themselves to progressive improvement of their theories, 2) whether they succeeded in finding relevant explanatory scientific information, and 3) whether they preferred explanatory scientific theories over their intuitive explanations. Even if the students initially produced inadequate or mistaken conceptions, their inquiry could be regarded to be progressive in nature insofar as their subsequent conceptions were more articulated and elaborated than the conceptions with which they started.

The analysis concerned three different projects, Force, Cosmology, and Electricity, in physics and one project, Human Biology, in biology carried out in year 3. The purpose of the Force project was to explain different forms of force, especially gravity. In the Cosmology project the students were asked to answer four questions given by the teacher. The questions concerned how the universe began, what the universe was made of, how the universe changed, and how it will be in the future. Although the students worked in the Force and Cosmology projects in small groups to collaboratively solve their research problems, the design of the Electricity project was different in that each student worked individually to solve eight research questions common to the whole class. The project was based on the best questions constructed by the CSILE students during year 2 (selected 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?” Further, the students carried out some classroom experiments with circuits, electrolytes, and static
electricity during the project. The Human Biology project focused on examining biological processes in the human body, such as how cells or the circulatory system function.

The explanations generated by students from classroom A were analyzed at multiple levels in order to increase validity of the study (see Chi, 1997) (Figure 4-10). First, each explanation was classified using qualitative methods described below. This analysis revealed information concerning frequencies of different kinds of explanations and individual explanatory concepts used by students, but it did not give information concerning how the individual students advanced in their inquiry.

In the second level of analysis, the students' inquiry was assessed project by project using all of a student's productions as the unit of analysis. The students in classroom A produced a series of notes in which they articulated their intuitive theories and introduced the scientific information found by them. This content-rich material allowed an analysis of how each student advanced in his or her inquiry from initial beliefs to final explanations. Although the students were working in a close collaboration with each other, sharing research questions and scientific information, each student's conceptual advancement was evaluated individually. This procedure was an important condition for reliability of assessment and provided information concerning how students of different ability levels and gender succeeded in their CSILE study.
The assessment of advancement of CSILE students’ inquiry was carried out, on the one hand, by assessing how the frame of their explanations changed in the course of inquiry and, on the other hand, by examining the degree of deepening explanation achieved. The former assessment concerned change from functional, to physical and empirical, to a theoretical frame of explanations in the context of individual students. The latter represented the degree to which a student introduced new explanatory scientific concepts in his or her inquiry. Methods used in each level of analysis will be elaborated below.
Qualitative Classification of CSILE Students' Explanations

Frequencies of CSILE students' explanations were analyzed by qualitative analysis of content. The textnotes of students from classroom A representing an intuitive theory or explanatory scientific information (ideas that were given a rating of 4 or 5 in the level of explanation scale) were analyzed according to the nature of explanation. In the context of physics, the nature of explanation consisted in three categories, i.e., functional, empirical-physical, and theoretical-physical explanation. Functional explanations refer to and are grounded on human intentions, purposes and goals, whereas physical explanations do not use human agency as a basis of explanation. All explanations containing an explicit reference to human agency (goal, purposes or intentions) or considering the problem on the basis of human needs were regarded as functional. These included explanations which referred to how something is working properly or malfunctioning or how something may be made to work. Further, in the present study anthropomorphic and animistic explanations, which relied on some kind of agency in explaining physical phenomena, were also regarded as functional. Physical explanations, in contrast, explain physical relations and processes as such without reference to human agency. Physical explanations may be empirical (empirical-physical explanations) or theoretical (theoretical-physical explanations) in nature. Empirical-physical explanations refer to observable empirical phenomena and phenomenal properties of reality. Theoretical-physical explanations refer to unobservable theoretical entities constructed for purposes of explanation.
rence of theoretical concepts, such as molecule, atom or particle, was regarded as an important indication of theoretical-physical explanations.

In biology, explanations containing references to cellular and subcellular processes as well as principles or processes of evolution were regarded as theoretical explanations. Theoretical entities are involved only in physics because biological explanations are generally, perhaps disregarding molecular and evolutionary biology, functional in nature.

Further, in order to examine contents of the explanations generated by the students from classroom A more closely, occurrences of explanatory concepts used by CSILE students to construct and warrant their explanations were coded both in biology and physics. In each domain of knowledge there are certain explanatory, theoretical concepts adoption of which is crucial for deep conceptual understanding of the phenomena in question. 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.
Assessment of Change in the Frame of CSILE Students' Explanation

The purpose of assessment of change in the frame of CSILE students' explanations was to analyze the nature of their intuitive explanations and whether the students were able and committed to overcome their intuitive explanations in the course of their inquiry. The analysis focused on examining whether the students changed their initially functional or empirical frame for explaining physical phenomena toward a more physical and theoretical one. Thus, the comparison provided information primarily on relations between the students' own intuitive explanations and the nature of scientific information found by them; i.e., whether the students processed explanatory instead of purely descriptive scientific information in their inquiry.

Assessment of change in the frame of explanation was relative in nature, i.e., stronger initial functional or empirical assumptions imply stronger change. A student's intuitive explanations were compared with explanations he or she later proposed, so as to evaluate whether the frame of explanation substantially changed. If a student started initially with very sophisticated scientific explanations without explicating his or her intuitive explanations, change in the frame of explanation was relatively smaller compared with that of students who had to overcome their intuitive explanations in the course of their inquiry. Also in cases in which a student did not find relevant scientific information, the change remained small. In order to carry out a reliable assessment of how the frame of their explanations changed, it was necessary to use a rather complex procedure.
The analysis was carried out using four-step scales for assessing type and level of both their initial intuitive and final scientific explanations (see Table 4-18). The type of explanation scale was designed to assess whether a student's explanations were functional (reference to human goals, purposes and intentions) or physical (no reference to human agency) in nature. The purpose of the nature of explanation scale was to assess whether the students' explanations were empirical (reference to observable everyday objects or empirical regularities) or theoretical (reference to theoretical entities) in nature. Physical explanations referring to atomic and subatomic processes were regarded as theoretical. In biology, explanation in terms of external or observable functions were regarded as empirical; explanation in terms of cellular and subcellular processes was considered theoretical.

### Table 4-18
Summary of Measures Used to Assess Change in the Frame of Explanation

<table>
<thead>
<tr>
<th></th>
<th>Assessment of intuitive explanations</th>
<th>Assessment of scientific explanations</th>
<th>Measure of change</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type of explanation</strong></td>
<td>Assessment concerning functional vs. physical nature of intuitive explanations</td>
<td>Assessment concerning functional vs. physical nature of scientific explanations</td>
<td>Functional-physical change; subtracting scores of intuitive explanation from scores of scientific explanation</td>
</tr>
<tr>
<td><strong>Nature of explanation</strong></td>
<td>Assessment concerning empirical vs. theoretical nature of intuitive explanations</td>
<td>Assessment concerning empirical vs. theoretical nature of scientific explanations</td>
<td>Empirical-theoretical change; subtracting scores of intuitive explanation from scores of scientific explanation</td>
</tr>
</tbody>
</table>

The above procedure turned out to provide the most reliable and meaningful way of assessing how the frame of explanation for students in classroom A changed in the course of their inquiry. Although functional-physical and empirical-theoretical
changes are associated with each other, it turned out to be easier to assess these aspects of explanation separately. There were easily recognizable indications of both functional vs. physical and empirical vs. theoretical explanations, but parallel assessment of these indications would have been a much more difficult task. Separate assessment of a student’s initial intuitive and his or her final scientific explanations made it possible to avoid the problem of simultaneously evaluating both the degree to which a student was bound with functional or empirical assumptions and strength of change. The final scores for change in frame of explanation were obtained in each case by subtracting a student’s score for intuitive explanation from the score for scientific explanation, and by using the sum of these scores as a measure of that student’s total change in the frame of explanation.

In the following, ratings of the type and nature of explanation scales are described in a detailed way:

1) *Functional explanation*. A rating of 1 was assigned when practically all of a student’s intuitive/scientific explanations were functional in nature referring to human agency (goals, needs, purposes or intention) and well as functioning or malfunctioning of artifacts. Functional explanations clearly dominated a student’s conceptions.

2) *Partially functional explanation*. A rating of 2 was assigned when many of a student’s intuitive/scientific explanations had characteristics of functional explanation referring to human agency or functioning of artifacts, yet the functional aspects did not
dominate the students' explanations' as strongly as in the former case; there were some physical explanations.

3) Partially physical explanation. A rating of 3 was assigned when a student's intuitive/scientific explanations had clear characteristics of physical explanations but there were still some indications of reliance on functional explanation. Thus, the students explained many of the problems being investigated by referring to physical objects and processes without, however, consistently relying on physical explanation.

4) Physical explanation. A rating of 4 was assigned if a student's intuitive/scientific explanations were clearly and entirely physical in nature and did not at all refer to human agency, i.e., goals, purposes, or intention. Explanations were grounded on objects or processes of physical world whether empirical or theoretical in nature. The student relied consistently of physical explanation, even sometimes explicitly rejecting functional accounts of the phenomena being investigated.

Biological explanations are generally functional in nature. Therefore, the type of explanation scale was treated differently in biology; it was used to assess occurrence of intentional rather than functional explanations. Intentional explanation refers to decision making or other psychological processes (thinking, feeling, wanting etc.) as the basis of explanation in the context of biological processes. By following a corresponding procedure as in assessment of functional/physical nature of explanation, I assessed whether the students were able to overcome the intentional nature of their intuitive biological explanations in the course of their inquiry.
CSILE students' transition from empirical to theoretical explanations was assessed using methods corresponding assessment of functional-physical change. Accordingly, a four-step nature of explanation scale was used for both their intuitive explanations and scientific explanations. In the following, ratings of the nature of explanation scale are described.

1) *Empirical explanation.* A rating of 1 was assigned if a student's intuitive/scientific conceptions were empirical in nature, relying on observable immediate objects of reality as well as empirical regularities. All of a student's intuitive/scientific explanations were empirical in nature, and he or she never went beyond empirically bound explanations.

2) *Partially empirical explanation.* A rating of 2 was assigned when a student's intuitive/scientific explanations had some indications of reliance of empirical explanation, yet empirical explanations did not dominate as strongly as in the former case. There might have been some minimal references to theoretical concepts or explanations, but this minimal theoretical knowledge remained as a fragmented and disconnected aspect of their productions, and there were no significant attempts to use theoretical concepts for explanatory purposes.

3) *Partially theoretical explanation.* A rating of 3 was assigned if a student's intuitive/scientific explanations had some references to theoretical concepts or explanations, but there were still clear indications of reliance on empirical explanations. Thus, a student may have tried to explain some of the problems being investigated by
referring to theoretical entities, but, however, he or she did not genuinely explain theoretical concepts used or nor consistently rely on theoretical explanations.

4) *Theoretical explanation.* A rating of 4 was assigned if a student systematically relied on conceptions that were theoretical in nature referring to unobservable theoretical entities and processes. The student consistently relied on theoretical concepts and explanatory theories, possibly even explicitly rejecting empirical accounts of the phenomena being investigated. The students used theoretical concepts and explanations in a meaningful way even if there may have remained uncertainty whether he or she understood the theoretical entities in question.

The reliability of the scales was assessed by asking two independent coders (see page 99) to evaluate change in each student’s frame of explanation in two projects, Cosmology and Human Biology. Pearson correlations between the scores for all the cases given by the two coders were .82 for Functional-Physical Chance, .81 for Empirical-Theoretical Change.

Final scores for functional-physical change and empirical-theoretical change were obtained, for each case, by subtracting a student’s score of intuitive explanations from the score of scientific explanations (these subtracted scores varied from 0 to 4 after adding, for practical reasons, 1 to the raw scores). These scores were small if a student’s explanations remained at the same functional or empirical level or if he or she started directly with advanced scientific explanations. High scores were obtained if a student had to go beyond his or her intuitive functional or empirical expla-
nations in the course of inquiry. As a measure of change in the frame of explanation, the present investigator used a sum of the scores for functional-physical change and empirical-theoretical change. In the following analyses, as a measure of change in frame of explanation, the sum score for type and nature of explanations was used. Further, as a measure of change in frame of explanation, the difference between the sum score for intuitive and scientific conceptions was used.

**Assessment of Deepening of Explanation**

The purpose of the *deepening of explanation scale* was to assess whether a student progressed in the search of new explanatory scientific knowledge in the course of his or her inquiry. Degree of deepening explanation refers to in-depth advancement in a student's search for explanatory scientific information. Deepening explanation entails that knowledge produced by a student becomes increasingly sophisticated and articulated in the course or inquiry through adoption of explanatory scientific concepts and theories. Strong deepening of explanation entails that a student succeeds in answering his or her research questions by finding significant pieces of explanatory scientific information.

The degree of deepening of explanation appeared to be associated with, but partially independent of, change in the frame of explanation. While change in the frame of explanation represented the degree to which a student explicated his or her own intuitive framework, deepening of explanation was associated with in-depth search for new explanatory scientific information. Many CSILE students started their
inquiry from physical or even explanatory scientific theories so that, in their cases, neither type nor nature of explanation changed. These students, in the projects studied, apparently never produced functional or empirical intuitive explanations; thus the frame of their explanations did not change. However, the students advanced considerably through seeking and introducing new explanatory concepts and theories, and deepened their explanations. Moreover, some students were not only able to transfer from functional to theoretical-physical explanations, but also went beyond this and engaged in intensive research of the topic introducing several new explanatory concepts and theories. The deepening of explanation scale aimed to capture this in-depth conceptual advancement both in physics and biology. The scoring for the scale was based on the following guidelines:

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

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

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

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

The reliability of the scale was assessed by asking two independent coders (see page 99) to evaluate the students' conceptual advancement in two projects, Cosmology and Human Biology. The correlation between the scores for the two coders was .85 for the deepening of explanation scale.

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 students in classroom A. Two of the experts assessed two cases of CSILE students' group work in physics and two cases in biology; the third expert evaluated only one case in physics and two cases in biology. The experts were asked to estimate whether students' process of inquiry was progressive in nature leading to
advancement of their conceptual understanding (progressive nature of inquiry) and whether students' initial and final conceptions differed conceptually from each other, suggesting that the process led to conceptual change (evaluation of conceptual change). For practical reasons the experts were requested to assess advancement of a small group instead of an individual student. The cases evaluated represented the classroom A students' group work in biology and physics. The electricity project in which the students from classroom A were working individually was excluded because an important aim of the evaluation was to assess collaboration between students. Further, it was decided that the study group whose process of inquiry was evaluated should have included at least three but not more than four participants. Four cases were selected randomly from the remaining 20 cases (total number of groups with 3-4 members who had worked on the biological and physical study projects). Complete transcriptions of the four cases evaluated are presented in Appendixes C1, C2, C3, and C4.

For the evaluation the experts were given task instructions and an introduction to the scales of evaluation (see Appendixes B1 and B2). The cases to be evaluated were presented to the experts one by one; they were asked to think aloud while evaluating the cases. After they had finished working with a case, they were asked to summarize their evaluation of the case. The expert evaluations were recorded, and transcriptions of the evaluations were used to analyze the results.
4.3.2 Nature of Intuitive Explanation in Physics

The students in classroom A produced 1007 intuitive or scientific explanations and 141 pieces of factual information in physics. About 56% (f=565) of the explanations represented the students' intuitive theories, and 44% (f=441) involved scientific theories found by them. The students produced 226 intuitive explanations and scientific theories in the Force project and 213 in Cosmology; they produced 567 explanations in the Electricity project.

As mentioned above, in the context of the qualitative content analysis each content idea produced by classroom A in year 3 was classified according to its nature of explanation. CSILE students' intuitive explanations and scientific theories proposed by them were classified into three categories; functional explanation (i.e., explanation by referring to human agency), empirical-physical explanations (i.e., reference to empirical objects and events) and theoretical-physical explanations (i.e., reference to theoretical entities). A frequency distribution of the nature of CSILE students' explanations across physical study projects is presented in Figure 4-11.

CSILE students produced a large number of intuitive explanations or "my theories" in their study projects. Figure 4-11 indicates that the students' intuitive theories were frequently functional or empirical in nature. However, some of the explanations generated by CSILE students, those referring to unobservable theoretical entities, were regarded as theoretical-physical. These were frequently scientific explanations adopted by CSILE students as their own theories, and the students made use of such explanations in their subsequent processes of inquiry. Further, some of the scientific
theories concerned how physical artifacts (e.g., spacecraft) can be used, or referred to observable physical phenomena, and were regarded as functional or empirical-physical in nature.

Figure 4-11.
The nature of explanation in CSILE students' intuitive and scientific conceptions in physics: 1007 explanations produced by 28 students.

The role of functional explanations, however, varied considerably among the different study projects. Figure 4-11 indicates that CSILE students as a group were able to go beyond their functional and empirical intuitive conceptions and arrive at scientific conceptions more physical and theoretical in nature. This analysis did not, however, reveal whether each individual student advanced in the process of his or her self-regulated inquiry; i.e., succeeded in finding explanatory scientific knowledge to answer his or her research questions. Advancement of an individual student's inquiry
was assessed by using corresponding scales, and is reported in later sections of the study. In the following section, the nature of CSILE students' intuitive explanations and scientific theories is discussed in more detail.

4.3.3 Functional Explanations

The relative importance of functional explanation varied between the three projects in physics. The analysis of CSILE students' explanations revealed that 42.9% (12 out of 28 students) and 25% (n=7) of students in the Force project, 19.2% (5 out of 26 students) and 23.1% (n=6) in the Cosmology project produced, respectively, explanations functional or partially functional in nature. However, in the Electricity project none of the students produced functional and only 14.3% (4 out of 28 students) partially functional explanations.

Accordingly, in the Force and Cosmology projects a significant number of students explained physical phenomenon by referring to human intentions, purposes and goals. Many students explained gravity by contrasting it with a situation in which gravity would not "function properly." Some of the questions generated by the students appeared to encourage functional explanations such as the question, "why do you need gravity and where does it live?" (year 3, author 620, student JD):

MT: My Theory is that Gravity is a force that keeps all objects and people/animals in their atmosphere so the people/animals can breathe and not float off their planet and so the objects do not float off their planet. (year 3, author 26393, student AR)

MT: I think gravity is a force that holds everything down to a surface. Without gravity, we wouldn't be able to sit down on a surface because you would be floating around. I also think that without gravity, we wouldn't be able to live because the air is held down by gravity. (year 1, author 23300, student AK)
MT: I think that the reason that gravity is less on the moon is that there is no life form on it and it is so far out in space. (year 3, author 23334, student RD)

Functional explanations in the Cosmology projects particularly concerned the questions "What will the universe be like in the future?" and "How has the universe changed and how will it change?" In the functional explanations the Earth as well as human needs and future were given a central position, for example:

I ... think the universe will be more or less like it is now only I think people will know more about it and I think people go into space much more so it will be much more dirty than it is now. I think people might even use other planets to dump their garbage on so I think some planets will be too dirty for people to visit. (year 3, student 23120)

MT: I think that the universe has changed a lot. For instance our own world has become a lot more advanced in medicines and lots of other things. We have also found out a lot about space. We discovered the planet Pluto and I'm sure lots of stars and constellations. I think that in the future our world and other planets might find life on different planets and be able to communicate with them. (year 3, author 23096, student AR)

The analysis revealed that almost all of the students in year 3's Electricity project started from physical phenomena. The project was based on eight questions common to all students. Presumably, these questions facilitated construction of empirical-physical and theoretical-physical explanations. The electricity project of year 2, in contrast, had been based on a question, "how does electricity work?"; that question seemed to encourage mainly functional explanations, such as the following:

I think that the electricity works very much because all the people needs electricity, in their houses so thats why the electricity works very much. I don't know how the people made the electricity but thanks for them, without the electricity there will be no food to eat or no water to drink, and there will be nothing to do without it, so thats why we all need the electricity. ... (year 2, student 433)

These kinds of functional explanations were not, however, produced in the context of the Electricity project during year 3. Nevertheless, some of the students
initially produced one kind of functional explanation for the problem "What makes one material a conductor of electricity and another material a non-conductor of electricity?"

A material is a conductor of electricity when electricity can go through it easily. (year 3, author 23155, student AM).

These explanations are functional in the sense that they describe how conductors and non-conductors function instead of explaining physical reasons for this functioning. However, such explanations may equally well be classified also as non-explanations because they are circular in nature: the explanans repeated the explanandum without producing new understanding. In many physical problems, a function may be generally known and the thing to be explained is the underlying mechanism producing this function. In order to avoid circularity, it is necessary to refer to deeper, underlying theoretical entities in physical explanation. Sometimes the students used intentional concepts to explain functioning of physical artifacts. As an answer to a problem "How does a battery produce electric current?" a student generated the following theory:

MT: I think that when a battery feels [senses ] that it is attached to something it summons up all its "free flowing" electrons, puts them together and sends them along the wire. (year 3, author 23109, student JH)

4.3.4 Empirical-physical Explanations

Another category of classroom A students' intuitive explanations was the empirical-physical, i.e., the students tried to explain physical phenomena by using their intuitive knowledge concerning how things work in nature. The analysis indicated that 35.7% (n=10) of the students generated empirical-physical theories and 42.9% (n=12)
gave partially empirical-physical theories in the Force project. In the Cosmology project the numbers, respectively, were 19.2% \((n=5)\) and 38.5% \((n=10)\), and in the Electricity project 39.3% \((n=11)\) and 28.6% \((n=8)\). Examination of the students' intuitive conceptions revealed that they tended to use empirical categories representing the perceptual world to explain something outside direct perception. The students used frequently empirical concepts such as magnetism \((f=27)\), ground \((f=26)\), core of earth \((f=14)\) to explain gravity. In the following transcriptions, empirical concepts used for explanatory purposes by CSILE students are highlighted by the present author:

MT: I think that gravity comes from the earth's core and is just a large economy size magnet and it attracts particles of matter from space but can not any more because the earths ozone layer protects the earth now, but I think that when the earth was created the earths ozone layer was not yet strong enough to keep out asteriods or comets from being pulled in to the atmosphere. (year 3, author 23113, student NR)

MT: (gravity) My theory is related to the Earth's core because I think it is like a magnet and it pulls you down to the ground. That is why gravity is not as strong on the moon because the core is not as strong as the Earth's core. (year 3, author 23113, student BH)

As in the Force project, CSILE students' intuitive explanations concerning cosmology were based on certain basic empirical categories. They used a wide variety of empirical concepts such as "rock" or "land" \((f=6)\), gas \((f=6)\), "atmosphere" \((f=2)\), "water" \((f=2)\), or "explosion" \((f=3)\) for explanatory purposes:

I think that millions and millions of years ago here was just one gigantic piece of land, and there was an explosion. The pieces went flying everywhere and each section that stuck together was called a planet and some are bigger than others because more pieces or less pieces got stuck together. (year 3, author 23157, student ES)

My theory on how the universe begin is this. A VERY long time ago, there were extremely big rocks floating around in space. Then, after a very long time, the rocks started to bang into each other, until there was one big rock, still floating around in space. This happened a few times in different places until there were very many, but not all of them were as big as others. Some were little ones, called moons, circling the big ones. (year 3, author 23150, student SH).
Further, explanations of how electricity works also were often empirical-physical in nature. Concepts like “metal” (f=13), “iron” (f=3), “material” (f=6) “gas” (f=5), “ingredient” (f=2) or “magnet”, “grain”, “power” or “substance (f=9)” were used to explain electricity:

**MT:** I think that some material is a conductor of electricity because of the substances in it. Those things have electricity in them so they can conduct electricity. Things that don’t have electricity in them can’t conduct electricity. (year 3, author 23164, student JM)

**MT:** I think that some materials are conductors of electricity and some are not because some substances are made of materials that attract electricity and are able to be used as other things that can give electricity more power or are able to be one of the things electricity can run through. (year 3, author 23090, student NE)

I think that in some materials there might be a certain grain, like the grain in wood, that stops electricity or does not let it go by in it, but this "grain" is only in a few materials so the other materials would conduct electricity. I also think that if materials don’t conduct electricity very well then they have a little a bit of this grain in them but not enough to stop electricity totally. (year 3, student 23109, author JH)

Following Holyoak and Thagard’s (1995) analysis, these explanations can also be considered as *analogical explanations*. The students appeared to rely most on property analogies; they used a property of a better-known phenomenon to explain a property of a less-known phenomenon. Remarkable in these explanations was the ingenious way the students applied their knowledge of more familiar physical phenomena to explain what they did not understand so well.

### 4.3.5 Theoretical-physical Explanations

In the course of their inquiry, several CSILE students were able to arrive at advanced theoretical-physical explanations in the Force, Cosmology and Electricity projects. The analysis indicated that the students from classroom A succeeded in finding
several important explanatory concepts in the domains of physics being investigated (see Table 4-19, Table 4-20, and Table 4-21 below).

Table 4-19 presents explanatory scientific concepts used by the CSILE students in the Force project.

### Table 4-19.
**Explanatory Scientific Concepts Used by CSILE Students’ in the Force Project**

<table>
<thead>
<tr>
<th>EXPLANATORY CONCEPT</th>
<th>F</th>
<th>EXPLANATORY CONCEPT</th>
<th>f</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRAVITY (FORCE OF)</td>
<td>18</td>
<td>GRAVITY PARTICLE</td>
<td>5</td>
</tr>
<tr>
<td>FRICTION</td>
<td>18</td>
<td>MAGNETIC FORCE</td>
<td>3</td>
</tr>
<tr>
<td>STRONG NUCLEAR FORCE</td>
<td>13</td>
<td>ANTIGRAVITY</td>
<td>2</td>
</tr>
<tr>
<td>ELECTROMAGNETISM</td>
<td>11</td>
<td>WEAK NUCLEAR FORCE</td>
<td>2</td>
</tr>
<tr>
<td>MASS</td>
<td>10</td>
<td>WEIGHT</td>
<td>2</td>
</tr>
<tr>
<td>ORBIT</td>
<td>7</td>
<td>FIELD</td>
<td>1</td>
</tr>
<tr>
<td>FORCE (VECTOR)</td>
<td>6</td>
<td>INERTIA</td>
<td>1</td>
</tr>
<tr>
<td>GRAVITY PARTICLE</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A student, RO, answered the question "Why does the Earth have gravity?" by arguing that "the reason the Earth has gravity is the same reason everything has gravity" (year 3, author 26394, student RO), and introduced the particle theory of gravity to the group:

I found out how gravity works. But first you have to know [what] particle is. A particle is a very small thing; particles make up everything around us, even force. Gravity particles have a spin of 1, matter particles have a spin of 1/2. Matter particles send out force particles like gravity. So since everything is made out of matter everything has gravity. Gravity particles have no mass so they can travel over long distances. That's the reason why the Earth orbits the sun. The reason why we stay on Earth is because the Earth has a greater mass than us so its gravity is stronger. Gravity is the weakest force. I have made a chart to help you understand particles. (year 3, author 26392, student RO)

She even articulated the theory further in answering her question "why we can't block gravity?"
I think it has to do with the size and spin of force particles, and the fact that all matter emits gravity. But I think one force can block another force. If all matter particles emit force particles than antiparticles must emit antigravity force particles (antigravity). So I think that antigravity could block gravity. But, if an antiparticle meets a particle they will destroy each other. So it would be impossible to have an antigravity chamber made out of antiparticle matter in a nonantiparticle universe. (year 3, author 26394, student RO)

In the Cosmology project, the students were also able to find relevant theoretical-physical explanations. Studying of scientific theories concerning the future of the universe led to articulation of more physical and theoretical conceptions. Many students arrived at the Big Bang theory and or had other scientific theories concerning expansion of the universe:

I found out from X's book that one change in the universe that is always happening is when a star dies. This is how it happens. Inside a star it is very hot because of nuclear changes. As the star becomes hotter the star expands and finally explodes. Extremely large stars that explode are called Supernovas. Supernovas spread the exploded parts all out over space. Scientists think when the Big Bang happened (if it did) only simple atoms were formed by the explosion. But when Supernovas explode they form more complicated atoms. (year 3, author 23096, student AR)

MT: I think that there was a large disk of particles that were charged with electricity. There were two different kinds of charges (positive and negative), and there were particles with no charge. These particles bumped into each other to create atoms. The atoms kept bumping into each other to create molecules. Then the molecules got bigger and bigger until the gravity from the matter that was created caused the disk to collapse. It collapsed into the galaxies that we see today. (year 3, author 23334, student RO)

There were some examples of an astonishingly high level of discussion among the students in classroom A, such as the following piece concerning relations between space, time and dimensions:

MT: Through a lot of thought and discussion, R. and I have discovered that all four dimensions cannot exist on their own. It is impossible for there only to be length for every line has some width. It is impossible for there only to be width for width cannot exist without length. It is impossible for width and length to be without depth because everything has depth unless it is a part of something; which must have depth. Unless it is a part of something, and that is a part of something, etc.. But that is an unending infinity, which must also take up some depth, some space! Fourthly, there is time, which is only a human means of measuring events. Therefore, if there would be no events there would be no time. The universe would be entirely stationary, which
would be impossible because it would have to be infinitely stationary: never beginning, never ending. Since all four dimensions cannot exist without each other space, time and dimensions are linked. (year 3, author 26394, students RO, RS)

Table 4-20 presents the frequencies of explanatory scientific concepts in the Cosmology project.

Table 4-20.
Explanatory Scientific Concepts Used by CSILE Students in the Cosmology Project

<table>
<thead>
<tr>
<th>EXPLANATORY CONCEPT</th>
<th>F</th>
<th>EXPLANATORY CONCEPT</th>
<th>f</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATOM</td>
<td>18</td>
<td>DIMENSION</td>
<td>2</td>
</tr>
<tr>
<td>BIG BANG</td>
<td>13</td>
<td>DOPPLER EFFECT</td>
<td>2</td>
</tr>
<tr>
<td>EXPANSION OF UNIVERSE</td>
<td>9</td>
<td>GRAVITY (FORCE OF)</td>
<td>2</td>
</tr>
<tr>
<td>BLACK HOLE</td>
<td>7</td>
<td>MAGNETIC FORCE</td>
<td>2</td>
</tr>
<tr>
<td>GALAXY (ESCAPING)</td>
<td>6</td>
<td>MASS OF THE UNIVERSE</td>
<td>2</td>
</tr>
<tr>
<td>RED GIANT</td>
<td>4</td>
<td>REPEATED BIG BANG THEORY</td>
<td>2</td>
</tr>
<tr>
<td>BIG CRUNCH</td>
<td>4</td>
<td>STEADY-STATE THEORY</td>
<td>2</td>
</tr>
<tr>
<td>COSMIC RAYS</td>
<td>4</td>
<td>ANTHROPIC PRINCIPLE</td>
<td>1</td>
</tr>
<tr>
<td>WHITE DRAFT</td>
<td>4</td>
<td>DENSITY OF MATTER</td>
<td>1</td>
</tr>
<tr>
<td>QUARK</td>
<td>3</td>
<td>GRAVITATIONAL PULL</td>
<td>1</td>
</tr>
<tr>
<td>MATTER</td>
<td>3</td>
<td>LIGHT YEAR</td>
<td>1</td>
</tr>
<tr>
<td>NEBULAE</td>
<td>3</td>
<td>MAGNETIC FIELD</td>
<td>1</td>
</tr>
<tr>
<td>PARTICLE</td>
<td>3</td>
<td>MASS</td>
<td>1</td>
</tr>
<tr>
<td>SPACE</td>
<td>3</td>
<td>OSCILLATING THEORY</td>
<td>1</td>
</tr>
<tr>
<td>SPACE-TIME</td>
<td>3</td>
<td>PROTON</td>
<td>1</td>
</tr>
<tr>
<td>SUPERNova</td>
<td>3</td>
<td>RED SHIFT</td>
<td>1</td>
</tr>
<tr>
<td>PRIMEVAL ATOM</td>
<td>2</td>
<td>SOLAR WIND</td>
<td>1</td>
</tr>
<tr>
<td>CONTRACTION OF UNIVERSE</td>
<td>2</td>
<td>SPECTRUM</td>
<td>1</td>
</tr>
</tbody>
</table>

Theoretical concepts such as electron or field are critical for explaining and understanding electricity. During year 2's Electricity project only 4 out of 28 students used the concept of electron. This knowledge, however, was not systematically socially distributed through CSILE-mediated peer interaction, but remained individual. Remarkably, the concept of electron was used for explanatory purposes in 28.7% (f=163) out of 567 explanations produced during the year 3's Electricity project; 26 out of 28 students used the concept of electron for explanatory purposes in some of the
notes, and practically all students achieved some sort of theoretical understanding of electricity.

Atoms are made out of protons and neutrons and electrons. In the middle of a atom, there is a ball called neutrons and near that, some balls, that contain electricity, called protons. That part is called the NUCLEUS of the atom. Also there are things that go very fast around the nucleus, they are called electrons. Each particle is either positive or negative. The amount of electricity in a particle is called its charge. A particle with a positive charge and a particle with a negative charge pull weakly at each other if the charges are small and strong if the charges are large. (year 3, student 26150)

Given the attainment of such understanding, the Electricity project was the most successful of all physical study projects carried out by the students in classroom A. The fact that the Electricity project was more than twice as large, measured by number of notes, as the two other physical study projects, is implicated in this.

Table 4-21.

<table>
<thead>
<tr>
<th>EXPLANATORY CONCEPT</th>
<th>F</th>
<th>EXPLANATORY CONCEPT</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELECTRON</td>
<td>163</td>
<td>PROTON</td>
<td>6</td>
</tr>
<tr>
<td>STATIC ELECTRICITY</td>
<td>27</td>
<td>RESISTANCE</td>
<td>6</td>
</tr>
<tr>
<td>ELECTRIC CURRENT</td>
<td>24</td>
<td>DOMAIN (OF MAGNET)</td>
<td>5</td>
</tr>
<tr>
<td>FIELD</td>
<td>20</td>
<td>ELECTROLYTE</td>
<td>4</td>
</tr>
<tr>
<td>MAGNET</td>
<td>20</td>
<td>NEUTRON</td>
<td>3</td>
</tr>
<tr>
<td>ELECTRIC CHARGE</td>
<td>16</td>
<td>ELECTROMOTIVE FORCE</td>
<td>2</td>
</tr>
<tr>
<td>ATOM</td>
<td>14</td>
<td>ENERGY</td>
<td>2</td>
</tr>
<tr>
<td>CONDUCTOR</td>
<td>13</td>
<td>BLACK HOLE</td>
<td>1</td>
</tr>
<tr>
<td>ELECTROMAGNET</td>
<td>12</td>
<td>ELECTRIC PULSE</td>
<td>1</td>
</tr>
<tr>
<td>CHEMICAL REACTION</td>
<td>12</td>
<td>GRAVITY PARTICLE</td>
<td>1</td>
</tr>
<tr>
<td>IONIZATION</td>
<td>11</td>
<td>GROUNDING</td>
<td>1</td>
</tr>
<tr>
<td>POSITIVE/NEGATIVE CHARGE</td>
<td>7</td>
<td>INSULATOR</td>
<td>1</td>
</tr>
</tbody>
</table>

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

I need to understand how Gravity works. I know that Gravity pulls you down and keeps you on the ground but I still don't understand how Gravity works! (year 3, author 23090, student NE)

I found out that although the effects of Gravity are easy to see, an explanation for these affects has never been found. (year 3, author 23096, student AR)

A CSILE student expressed the problem of understanding theoretical-physical explanations in the following way:

I would need to understand what the weak nuclear force is, but even if I find good information I wouldn't be able to understand it in my own words. (year 3, author 23334, student RS)

4.3.6 Conceptual Advancement in Physics

The examination of CSILE students' conceptions revealed that functional and empirical explanations were characteristic of CSILE students' intuitive explanations. Each student's productions were, further, assessed as a whole in order to analyze whether he or she was able to go beyond his or her intuitive explanations and adopt a more adequate scientific frame of explanation. The analysis revealed that the students systematically preferred theoretical-physical explanations over their intuitive explanations, provided that an understandable scientific explanation was available.

As expected, the analysis revealed that CSILE students' frames of explanation in their intuitive (sum score $M=4.83$, $SD=1.5$) and scientific (sum score $M=6.5$, $SD=.97$) conceptions differed substantially from each other. The students in classroom A were apparently able to go beyond their functional and empirical intuitive conceptions in the course of their inquiry. Functional-physical change was relatively
smaller than empirical-theoretical change, yet many students continued to show empirical characteristics in their final explanations.

Further, the analysis indicated that there were substantial gender-related differences concerning change in frame of explanation. An independent sample $t$-test was performed to analyze whether mean change in frame of explanation differed according to gender of the students. The analysis indicated that the change was stronger in the case of female students ($M = 4.0, SD = 1.0$) than male students ($M = 2.67, SD = .55$) ($t=4.53, df=25.25, p<.000$). The 95% confidence intervals for scores concerning change in frame of explanation in classroom A female and male students' intuitive explanations are presented in Figure 4-12. Examination of the type of CSILE students' intuitive explanations indicated that the functional and empirical explanations had a more important role in the female than male students' production. Many male students appeared to be already more familiar with physical scientific theories as well as somewhat reluctant to externalize their intuitive conceptions; sometimes also they confused their own with scientific theories. As a consequence, the female students produced more functional and empirical-physical theories and made relatively more progress in change of the frame of explanation scale in the process of their inquiry.

Further, the analysis indicated that the students were also making further progress in their projects, as indicated by the deepening of explanation scale. Change in frame of explanation was not, however, correlated with degree of deepening of expla-
nation. It follows that the latter category of conceptual advancement represented a different aspect of inquiry, i.e., in-depth advancement beyond the former changes.

![Graph showing the 95% confidence intervals for male and female students' change in frame of explanation.](image)

**Gender**

**Figure 4-12.**
The 95% confidence intervals for male and female students' change in frame of explanation.

The analysis showed that there were considerable differences among the physical study projects concerning the degree of deepening of explanation. The mean degree of deepening of explanation was 2.46 (SD=0.86) in the Force project, 2.81 (SD = 1.1) in the Cosmology project, and 3.0 (SD=.96) in the Electricity project without statistically significant differences concerning gender or ability level. Table 4-22 presents a summary of the numbers of students representing different degrees of...
deepening of explanation in physical study projects. Advancement of CSILE students' explanations was relatively stronger in the Electricity and Cosmology projects than in the Force project. A majority of the students succeeded in attaining moderate or strong deepening of explanation through finding relevant explanatory theories.

Table 4-22.
Number of Students Representing Different Degrees of Deepening of Explanation in Physical Study Projects

| DEGREE OF DEEPENING OF EXPLANATION | FORCE | | | | COSMOLOGY | | | | ELECTRICITY | |
|---|---|---|---|---|---|---|---|---|---|---|---|
|   | n | %  | n | %  | n | %  | n | %  | n | %  | n | %  |
| No advancement | 3 | 10.7 | 4 | 15.4 | 1 | 3.6 |
| Small advancement | 13 | 46.4 | 5 | 19.2 | 2 | 7.1 |
| Moderate advancement | 8 | 28.6 | 9 | 34.6 | 10 | 35.7 |
| Strong advancement | 4 | 14.3 | 8 | 30.8 | 15 | 53.6 |
| TOTAL | 28 | 100.0 | 26 | 100.0 | 28 | 100.0 |

These distributions provide a conservative estimate of deepening of CSILE students' explanations because they were based on evaluation of individual students' explanations. However, CSILE students were working in small groups, and a group as a whole often succeeded in solving its principal research questions even if an individual member did not. Further, if a student introduced advanced explanation to the group, the other members of the group usually did not repeat the same information in their own notes. As a consequence, only the student who first introduced an explanation appeared to have advanced although the others could have adopted and understood the same information.
4.3.7 Intuitive Explanation and Conceptual Advancement in Biology

The task of the students from classroom A 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" (year 3, teacher). The students did not have any formal instruction in biology about the problems in question, and they themselves were responsible for finding relevant scientific information about the problems. The students produced 518 content ideas in biology; 66% (f=340) of them represented intuitive theories and 44% (f=178) scientific theories.

An analysis of intuitive biological explanations generated by students in classroom A revealed that they mastered functional explanations, frequently explaining both biological functioning and malfunctioning. In the following examples, one can see that some of the students' intuitive theories, such as their theories concerning functional organization of the brain, were very impressive:

I think that there is a part in your brain for every thing you do, for example thinking, moving and feeling. There are also parts that connect the parts together so that different parts of the brain can communicate. Also there would be a certain part that would coordinate the whole brain. I have made a chart that explains my theory called "Parts Of The Brain". (year 3, author 26394, student RO)

I think, as X said before, that there are different parts of the brain for thinking, moving and feeling, but I think that there are instead three main parts of the brain, one for thinking, one for moving and one for feeling and in each of these parts are other sections that control specific parts of the brain; for example in the moving section of the brain, there would be certain sections for moving the arms and certain sections for moving the legs. (year 3, author 26394, student JH)
Discussion concerning "what happens if your immune system does not work?" (year 3, author 23120, student EH) 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. (year 3, author 23147, student AD)

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. (year 3, author 620, student AK)

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 were frequently intentional in nature; i.e., intentional terms were used to explain biological functions. Students seemed 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. (year 3, author 23143, student MS)

MT: I think that the cells in any kind of animal tell the organs what to do. For example, a nerve cell tells the brain when the person or animal is hurt in any way. (year 3, author 23143, student AK)

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. ... (year 3, author 23096, student MS)

MT: I think a gene is an organelle in the cell (let's say this cell is an eye cell) that decides what colour it is, how big the pupil is. (year 3, author 23143, student AR)
An analysis of CSILE students' intuitive explanation by the type of explanation scale 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.

Table 4-23 displayed the frequencies of scientific biological concepts in CSILE students' explanations.

<table>
<thead>
<tr>
<th>EXPLANATORY CONCEPT</th>
<th>F</th>
<th>EXPLANATORY CONCEPT</th>
<th>f</th>
</tr>
</thead>
<tbody>
<tr>
<td>CELL</td>
<td>69</td>
<td>NERVE FIBER</td>
<td>5</td>
</tr>
<tr>
<td>NERVE CELL</td>
<td>48</td>
<td>RED BLOOD CELL</td>
<td>5</td>
</tr>
<tr>
<td>IMMUNE SYSTEM</td>
<td>40</td>
<td>SCHWANN CELL</td>
<td>5</td>
</tr>
<tr>
<td>GENE</td>
<td>26</td>
<td>MUSCLE FIBER</td>
<td>5</td>
</tr>
<tr>
<td>DNA</td>
<td>21</td>
<td>WHITE BLOOD CELL</td>
<td>3</td>
</tr>
<tr>
<td>ANTIBODY</td>
<td>20</td>
<td>MUSCLE CELL</td>
<td>2</td>
</tr>
<tr>
<td>NERVOUS SYSTEM</td>
<td>18</td>
<td>ORGANELLE</td>
<td>2</td>
</tr>
<tr>
<td>MESSAGE</td>
<td>10</td>
<td>RETINA</td>
<td>2</td>
</tr>
<tr>
<td>CIRCULATORY SYSTEM</td>
<td>11</td>
<td>SYNAPSE</td>
<td>2</td>
</tr>
<tr>
<td>CHROMOSOME</td>
<td>9</td>
<td>ABSORPTIVE CELL</td>
<td>2</td>
</tr>
<tr>
<td>PLANT CELLS</td>
<td>9</td>
<td>ANTIGEN</td>
<td>1</td>
</tr>
<tr>
<td>NEURON CELL</td>
<td>8</td>
<td>BONE CELL</td>
<td>1</td>
</tr>
<tr>
<td>RH-FACTOR</td>
<td>8</td>
<td>MACROMOLECULE</td>
<td>1</td>
</tr>
<tr>
<td>CELLULAR BREATHING</td>
<td>7</td>
<td>MITOSIS</td>
<td>1</td>
</tr>
<tr>
<td>LYSOSOME</td>
<td>7</td>
<td>MYELIN LAYER</td>
<td>1</td>
</tr>
<tr>
<td>MOTOR NEURON</td>
<td>5</td>
<td>NUCLEOLUS</td>
<td>1</td>
</tr>
<tr>
<td>BLOOD TYPE</td>
<td>5</td>
<td>NUCLEUS</td>
<td>1</td>
</tr>
<tr>
<td>DESERTIZATION</td>
<td>5</td>
<td>OXYGEN</td>
<td>1</td>
</tr>
<tr>
<td>GLIAL CELL</td>
<td>5</td>
<td>PHOTOSYNTHESIS</td>
<td>1</td>
</tr>
<tr>
<td>MEMORY SYSTEM</td>
<td>5</td>
<td>SENSORY CELL</td>
<td>1</td>
</tr>
</tbody>
</table>

The analysis revealed that CSILE students' conceptual advancement was relatively stronger in biology than in physics. Three out of four students succeeded in attaining considerable deepening of explanation, i.e., finding relevant explanatory con-
cepts and scientific biological explanations in the course of their inquiry. An important criterion for evaluating deepening of explanation was the transition from describing external functions to explaining biological processes in terms of cellular and subcellular phenomena. In their process of inquiry, the students frequently succeeded in adopting advanced scientific conceptions such as cellular explanations of the biological phenomenon being investigated (see Table 4-22). According to the assessment, 36% (n=10) students showed strong and 43% (n=12) moderate deepening of explanation. Only 5 students were regarded as attaining a small degree of deepening of explanation, and one student not appear to have advanced at all.

Adoption of a framework of cell biology seemed to require considerable conceptual advancement. 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. (year 3, author 620, student JD)

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. (year 3, author 26152, student JM)

Nevertheless, a majority of 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.
4.3.8 The Nature of Intuitive Explanation in Biology

In order to provide a concrete image of the students' inquiry, a study group's work in a biological study project is now described. In the group, there were three male students, two of them representing below-average academic performance. The group studied human perception in general and 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 (see Appendix C2). 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. I did not understand why the eye does this movement but I think it is because in order to send a message to the brain it has to reach the retina so the eye's message must meet there and continue moving. (year 3, author 26395, student AO)
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. (year 3, author 26395, student MS)

But the hypothesis that there has to be another lens which turns the picture right-side up again was challenged by 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. (year 3, author 26395, student AM)

I think that you should find out more information on your theory and try to find out how the lens work. (year 3, author 26395, student AM)

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. (year 3, author 26395, student AM)

I think that there is almost a kind of filter behind the eye where the picture goes through transforming it into waves which the brain understands. (year 3, author 23155, student MS)

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:

Your first MT [my theory]: is puzzling to me. In your theory you say that there is a filter behind the eye. What I am not clear on is the fact that you are saying the filter changes what the picture is into waves for the brain to receive. Do you mean that everything we see is little waves of different colours and shades? I don't agree with what you are saying. It is making it sound like the eye is not an organ ,it sounds like the eye is just a protector with a filter behind it. (year 3, student 26124)
Student AM 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' knowledge-seeking 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 seem 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.
4.3.9 Expert Evaluation of CSILE Students’ Conceptual Advancement

The experts agreed that the CSILE students were making relatively stronger progress in biology than physics. CSILE students' research projects in physics were connected with extremely complicated problems, and the students did not succeed in increasing their conceptual understanding as deeply as in their biological study project. Expert A noticed the functional nature of the students’ theories in which they connected gravity and survival: “That is a kind of an anthropomorphic thing. I mean, they viewed [gravity] from the point of view of survival and their own point of view which, I think, is understandable.” Expert B stated that, in the beginning of the Force project, the students:

were pretty confused about what gravity is. Students say that gravity is a kind of force but a lot of this seems to be very anthropomorphic in nature. And that the students see these things somehow being there for a purpose. They view gravity as helping us to survive and everything keep surviving. It is actually a teleological view of physical world.

He continued by stating that:

What does seem to be happening as they move along, is that they are getting more information, could be these experiments they mention that Mr. X, the teacher. They seem to be getting a bit better idea how gravity works. SM seems to be getting a slightly more general idea that gravity is a general force. AR ... seems to be getting a more empirical basis for it. But it is hard to say to what extent they are acquiring a physical conception of gravity and to what extent they are sticking with the teleological view of gravity as force.

Expert B concluded that “it looks to me like they are making at least a movement towards tying things together.” Expert A estimated that the students’ conceptual understanding progressed during the process, and that they were likely to make conceptual change. However, in the Gravity Case the progress “was much less than in
biological cases, maybe because gravity is a much tougher case - maybe because we still do not understand what gravity is..."

The experts acknowledged that the students were beginning to propose theoretical explanations concerning the physical and biological problems being investigated. However, expert A wondered whether the students were truly able to understand all pieces of information (e.g., spin, graviton) provided in the Gravity Case: "What is going on here about spin and so on. I mean just jumping from the information that they have under the problem how gravity works. ... The weight of a graviton is a rather long leap. Do not be sure the students understand the connection between planetary mechanics and gravity on Earth. Surely they do not have a clue what spin is." He was also uncertain whether the students completely understood the cosmological theories introduced. However, he stated that the process was progressive even if the students did not completely understand the phenomena in question: "If they understand what that [spin] is — that is a different kind of question. Even if you do not understand the details, so what. Who does?" Expert B stated that conceptual progress was:

... hard to judge because of course with these typing in things you are only getting a little bit of what they know, something reflecting a part of their knowledge, knowledge is in their heads. ... They are obviously acquiring a lot more of information as they go along. And instead of a sort of vague idea about universe is made out of a lot of gases, gases and rock, by the end they are actually talking about some pretty sophisticated things such as the Big Bang theory. So if that reflects where they were in the beginning and in the end, then that can be definitely classified as being progressive.

About the Neuron Cells Case (Appendix C1), 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 change], because of the new concepts they are bringing in that weren't there in the beginning." He estimated 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 B concluded,
thrown out. And that tends to be pretty hard to document. So I guess that I look at this from this skeptical point of view, probably because that is the way I tend to do history of the philosophy of science. Even if you could have a hour long interview with each student before and after, it would be somewhat difficult to tell because you are still copying a small part of their knowledge, and a small part of the structure of the concepts.

Expert A was particularly impressed about a piece of inquiry in which the students discussed how the scientists came to propose the Big Bang theory. According to the expert, the students spontaneously generated the serendipity theory of scientific discovery by stating that "scientists were looking for something totally different, and by accident came upon some information which led them to create and believe the Big Bang Theory (year 3, author 23157, student AR). Another student argued that "... scientists did a lot of research and thought that this theory made the most sense out of all the theories that could have been possible (year 3, author 23157, student ES). According to the expert A, "...this is a really nice piece of reasoning, kind of intuitive inference to the best explanation, sort of thing."

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 (see Cosmology Case in appendix C3):

Hmm ... These are two ... really quite different discussions. The first question doesn't make very much progress, it goes to a wrong, perhaps wrong direction in small details. But in this, concerning this other question there is, there is a clear progress. There is a kind of wrong approach on this side, but then there is the quite right theory that the universe, the universe is always changing and there is a continuous process, and then it leads to quite reasonable further ideas
how galaxies are formed, so I think this, this second question is better, ...[it] leads to a better question than the first one.

Hmm... This is somehow, somewhat short discussion and the main progress comes from this new information about big bang theory so ... I do not know if there is clear evidence that, that, that any other progress is really made. .... .... ... So this is of course something which is taken from new information and, so some learning has been made but no, not really any good ... my theories or these intuitions ...

When asked to clarify his assessment concerning “wrong theories”, expert C affirmed that,

It is quite normal also in history of science to have at least initially also a very wrong theory so, so there are degrees how wrong a theory really goes. So in that sense it is quite normal that 10 year-old kids are looking intuitive answers in quite quite wrong directions. So I am not saying they are ... surprising or unnatural to have them.

The differences between the experts may reflect somewhat the backgrounds of the experts. Expert C differed from the other two that he had not been engaged in empirical study of the history of science or conceptual change but rather in logical study of scientific knowledge. 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 helped 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 been instructive to to 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, two out of the three experts agreed that CSILE students' process of inquiry was progressive and likely to lead to advanced conceptual understanding. 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.

4.3.10 Discussion

The analysis revealed that the students in classroom A systematically generated their own intuitive theories and searched for explanatory scientific information to answer their research questions. Further, the students were able to go beyond their intuitive conceptions and adopt very advanced scientific explanations, provided that an understandable scientific explanation was available. For students to participate in an explanation-driven process of inquiry focused on comprehending very complicated physical and biological phenomenon is a significant cognitive achievement. 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 (the first principal feature of scientific thinking).

Analysis of classroom A students' intuitive explanations of physical phenomena indicated that these were frequently functional in nature referring to human purposes, goals or intentions as the basis of explanation. The analysis showed, further, that many CSILE students used intentional concepts to explain biological processes. Moreover, the students often constructed empirical-physical explanations to explain physical phenomena, i.e., their intuitive explanations were based on generalizations of the properties of our perceptual world to explain something outside direct perception.
Regardless of the functional or empirical nature of CSILE students' intuitive explanations, their conceptions were not trivial. Apparently, CSILE students' functional and empirical-physical explanations 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. Even if the reduction to familiar phenomena were not a general characteristic of scientific explanation (see Salmon, 1991, p. 6), it appears to be an integral aspect of the cognitive process of constructing explanations.

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. The students appeared to be trying to explain the complexity of the world using only a minimal set of assumptions, as scientists do. Even if their conceptions were empirically bounded, in most cases they focused on some general aspect of the objects of the world. In the context of cosmology, conceptions surprisingly resembled the four elements (e.g., land, air, fire, water) which formed the basis of ancient cosmologies or natural philosophies. Reliance on these basic empirical categories seemed to represent a sort of content recapitulation (Thagard, 1992). Naturally, CSILE students' intuitive explanations lacked generality, and the range of their explanation was quite limited. However, their explanations appeared to provide explanatory unification (see Friedman, 1974; Kitcher, 1980; 1989) by helping to make sense and understand reality, increasing explanatory coherence through organizing and sys-
tematizing one's knowledge. It appears that imperfect intuitive theories could provide explanatory unification if they help to eliminate some epistemic alternatives (Hintikka, 1986; Macmillan & Garrison, 1988). Of course the students were able to achieve only local coherence and rather limited systematicity.

The analysis revealed that the students from classroom A made relatively more progress in biology than physics. Further, the degree of advancement and the nature of explanations seemed to be considerably dependent on the nature of problems studied as well as questions asked. Advancement in the Force and Cosmology projects was more difficult to achieve than advancement in the Electricity project. Although many students were able to overcome the functional and empirical approaches in their intuitive conceptions, only a few students were able to arrive at well-articulated theoretical-physical explanations of the problems being investigated.

The analysis revealed that female students, compared with male students, produced more functional and empirical-physical explanations and, correspondingly, made stronger conceptual advancement in struggling to overcome their initial conceptions. The phenomenon can be explained by assuming that either the male students of the group were already more familiar with scientific physical theories in question, or they did not explicate their intuitive conceptions. Examination of the material indicated that both of these explanations were partially true. Many male students seemed to be somewhat familiar with physical explanations, and frequently started directly with scientific conceptions, sometimes labeling those as their own theories. However, examination of the material suggested that in some cases the male stu-
Students were confused about the scientific theories in question, starting to clarify the meaning of their scientific conceptions only later on in the course of their inquiry. Therefore, an interpretation according to which the male students generally did not externalize their intuitive theories about physical phenomena studied seems to be equally adequate. Further, the male students did not achieve significantly more deepening of explanation than the female students did, entailing that they did not succeed in going deeper into the topic, notwithstanding the fact that they frequently started with scientific theories. From the above results it follows that the male students made relatively smaller progress than the female students, who frequently succeeded both in overcoming their intuitive theories as well as engaging in deepening inquiry.

Assessment of two out of the three experts of the philosophy of science confirmed that the students in classroom A achieved considerable progress in their process of inquiry. Although the students were bound to teleological and anthropomorphic views in the beginning of their inquiry, they were able to attain advanced scientific conceptions in the course of their investigations. The third expert agreed that the students were making progress but criticized some of the students' intuitive theories for not being "right", and pointed out that there was no evidence concerning advancement of each individual student.
4.4 Study IV: Influence of Progressive Generation of Subordinate Questions on Conceptual Advancement

4.4.1 Method

The purpose of the study was to analyze the relationships between the progressive generation of subordinate questions (the second principal feature of scientific inquiry) and engagement in deepening levels of explanation, i.e., conceptual advancement (the first principal feature of scientific inquiry). Therefore, the study focused on assessing whether the students were able to transform their principal research questions to new, more specific ones and how commitment to an extended and in-depth interrogative process of inquiry affected a student's conceptual advancement. Although the first study revealed that the students in classroom A were systematically producing explanation-seeking research questions, the analyses have not, thus far, provided evidence that these questions actually facilitated deepening inquiry and conceptual advancement. Voss, Tyles, and Yengo (1983) had applied Toulmin's (1958) argument analysis to examine how extensively arguments were developed: In parallel, the present study was intended to examine how extensively the interrogative process of inquiry was pursued.

The study was based on an analysis of 28 grade 5/6 students' written postings to CSILE's database. The students worked with CSILE on four study projects; Force, Cosmology, Electricity, and Human Biology. The material analyzed consisted of CSILE students' research questions, intuitive explanations, scientific information sought by them, and written communication between the students. The students'
written productions were assessed according to qualitative analysis of content (see Chi, 1997).

The cognitive value of CSILE students' research questions was assessed by analyzing the extent to which they transformed their principal research questions into more specific ones. Each research question was classified according to whether it was a principal question or a subordinate question (Level of Research Question). All questions provided by the teacher and common to all students in the context of a study project were regarded as principal questions. Further, conceptually independent research questions generated by a student in the context of a study project were classified as principal questions. New research questions generated in the context of one or another principal question represented subordinate questions. All questions representing thinking type INTU (I Need to Understand) were regarded as subordinate questions. If a student was examining the same issue in several notes, the beginning problem (P) was interpreted as the principal question, and the subsequent problems (P and INTU) as subordinate questions. The reliability of classifying a student's research questions as principal and subordinate questions was assessed by asking two independent coders (see page 99) to classify 99 questions generated by the students in the Cosmology project. For information on questions common to the study project as a whole, and each note's principal research question, the agreement coefficient was .86. Mean number of subordinate questions was calculated by taking the mean of a student's number of subordinate questions in physics and number of subordinate questions in biology.
Further, a four-step deepening of explanation scale was constructed to assess each student's conceptual advancement in the context of each study project (see study 3). The deepening of explanation scale was designed to capture in-depth advancement of inquiry, i.e., the extent to which a student was able to propose new explanatory scientific concepts and theories in his or her inquiry. The reliability of the scale was assessed by asking two independent coders to evaluate deepening of the students' explanations in the Cosmology and Human Biology projects. Pearson correlation of the scores given by the two coders was .85. A score for mean deepening of explanation was obtained by taking the mean of a student's scores of deepening of explanation in the three physical study projects and his or her deepening-of-explanation score in biology.

The analysis of frequencies of CSILE students' subordinate questions did not, however, provide detailed information concerning relationships between progressive generation of subquestion and the process of the students' inquiry. In order to analyze relationships between question transformation and conceptual advancement and strategies of inquiry used by the students, graphical descriptions were constructed of the students' processes of inquiry in the context of the Electricity and Force projects. The analysis focused on examining strategies of CSILE students' inquiry. These descriptions are called inquiry-structure graphs in order to separate them from problem-behavior graphs that represent immediate verbalization of thought (see Ericsson & Simon, 1984).
CSILE students’ process of inquiry consisted of research problems, theories, new information, and comments that were regarded as elements of inquiry. Identification of the elements of inquiry was based on the qualitative analysis of content (see section 3.4). An episode of inquiry consists of a process of articulating research question, searching for new information and construction of an explanation. Articulation of a new research question involves beginning another episode of inquiry. Each step in a process moved a student from one epistemic state to another. Epistemic state refers to a student’s knowledge about the subject matter in question (see Macmillan & Garrison, 1988); epistemic change is a process of moving from one epistemic state to another. In the present study, epistemic change does not entail any particular change in an agent’s mental state (that cannot be inferred on the basis of a written document), but rather a change in an agent’s externalized knowledge that is in the form of written notes. Interrogative moves such as asking a question, obtaining of new information or explicating one’s presuppositions by generating a theory change a student’s manifest epistemic state. (Again, the student’s mental state is not the present focus). Initially a student has only a problem. Generation of a theory transforms the initial epistemic state into a state in which not only the problem is known, but also one of its possible explanations. Search for new scientific information, if successful, leads to further transformation of epistemic states. Construction of new intuitive explanations together with searching for new scientific information, in turn, leads to generation of new research questions. The process of inquiry can thus be seen as a continuous process of moving from one epistemic state to another.
During their study projects, the classroom A students were working in small groups, jointly to solve a set of research questions, except in the Electricity project which they carried out by working individually to solve eight research questions common to the whole class. Although the students were working in close collaboration, an individual student's contribution was identifiable. Although each student was responsible for investigating at least one particular problem, all members of the study group were required to support him or her by generating theories to explain the student's problem and articulate new research questions as well as introduce new information and participate in commenting. In order to handle the complexity of the material and assess individual students' strategies of inquiry, inquiry-structure graphs were constructed, by the present author, for each student separately from the functioning of other members of his or her study group. The reliability for identified characteristics of the inquiry-structure graphs was examined by asking two independent coders (see page 99) to classify the graphs, representing the Electricity project, according to their structural characteristics. The agreement coefficient was .84. Coding categories for inquiry-structure graphs are presented in appendix A1, and examples of applying the method for a student's inquiry in appendixes A2, A3, A4.

Finally, the cognitive value of CSILE students' research questions was assessed using expert evaluations. The three internationally regarded philosophers of science from well-known Canadian and Finnish universities that participated in the above reported study were asked to evaluate the cognitive value of CSILE students' research questions in two cases of the students' groupwork in physics and two cases
in biology. One of the experts, however, evaluated only one case of physics and two cases of biology.

4.4.2 Question Transformation and Advancement of Inquiry

An analysis of classroom A students' productions indicated that the students were themselves able to generate a series of research questions that were meaningful and valuable from the viewpoint of the cognitive goals of their inquiry. The qualitative content analysis revealed that 92.8% (SD=0.05) of the research questions (n=983) generated by the students were explanation-seeking in nature. On average, the students produced 35 (SD = 12.8) research questions across the four study projects. It follows that in each project, they articulated several subordinate questions to help answer their principal research questions.

Table 4-24 presents a series of a CSILE group's research questions concerning how the brain works (see Appendix B1). The research questions were generated over a period of approximately four weeks while students participated in the Human Biology project. The questions reproduced are from a large body of intuitive theories, pieces of scientific information, and so comments do not necessarily follow one another immediately. The series consists of two types of questions, i.e., the group's main research question (PQ) and new subordinate research questions (represented by new problems (SQ) or I-Need-to-Understand, INTU, questions) emerging in the process of inquiry. Table 4-24 shows research questions generated by a whole study
group. Notice that some of the group's subordinate questions (SQ) were classified as an individual student's principal questions.

Table 4-24.
An Example of Generation of Subordinate Questions in the Context of Neural Biology

| PQ: What kind of cells are there in the brain, and how do they differ from the other cells in the body? (RO) |
| INTU: How do the glial cells hold the brain together? (RO) |
| INTU: I need to understand what the glial cells look like before I can understand how glial cells hold the brain together. (JH) |
| SQ: What do neuron cells look like and how do they work? (JH) |
| INTU: I need to understand how many neuron cells are in the brain before I can understand how neuron cells work. (JH) |
| INTU: How do neuron cells know whether to pass on information or to stop the message? (RO) |
| SQ: How does the brain store information? (SM) |
| INTU: How does the long-term memory store the information? (JH) |
| PS: What are the different parts of the brain and what are they used for? (RO) |
| INTU: (....) RO said that the cerebellum controls the different parts of the body with its different parts. I don't understand how it uses these different parts and what those different parts are. (JH) |

Note: The research questions presented in the Table were generated over a period of approximately four weeks while students participated in the Human Biology project. The questions reproduced are from a large body of intuitive theories, pieces of scientific information, and comments and did not necessarily follow one another immediately. At the end of each question appears initials of the student who constructed it.

From Table 4-24, it can be seen that the group advanced from a rather general principal question (PQ) 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?" The students started from rather vague theories according to which the brain cells are "more developed" or "bigger" 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. New information seemed to make articulation of more specific research questions possible: "How do
glial cells hold the brain together?" and further, "what do neuron cells look like and how do they work?" The analysis indicated that the students continuously built on each other's work and further articulated problems and concepts generated by the other students, during the time period examined.

Another study group examined how the human brain processes visual information in the context of the Human Biology project (see Table 4-25). The group started from a rather vague question, "Where is the eye's control panel located" (see Appendix C2). Comments given by other students in the class pushed the group to articulate a more specific and promising principal question, "How does the eye function?" The table shows how the questions generated by the group became increasingly sophisticated in the course of inquiry.

Examination of CSILE students' productions revealed that as a consequence of constructing intuitive explanations and testing of the explanations against available scientific knowledge, new questions usually emerged. In the course of their inquiry, the groups repeatedly generated new subordinate questions in answering their principal questions. The students did not move randomly from one to another research question; former questions and tentative answers to those questions appeared to give an impetus to articulation of further questions and controlled the direction of subsequent inquiry. Setting up later research questions seemed to be conceptually dependent on conducting earlier episodes of inquiry, and grappling with corresponding research questions, intuitive theories and scientific information. Generation of new,
more specific, research questions seemed to push a student to deepen his or her inquiry, and, thereby, enabled construction of more advanced conceptions.

Table 4-25.
An Example of Generation of Subordinate Questions in the Visual Perception Case

| P0: Where is the eye's control panel located? (O) |
| PQ: How does the eye function? (M) |
| INTU: How the eye sends pictures to the brain. (AM) |
| (SQ) INTU: How the parts of the eye help get the message to the brain. (M) |
| (SQ) P: How is the eye similar to a camera? (S) |
| (SQ) P: I have researched the eye and the camera and found they are very similar in many ways. I have written this note because I found that both the eye and the camera see a picture upside down. I would like to know why that happens and how. |
| (SQ) P: How does the message that the eye is sending get to the brain? (S) |

Note: The research questions presented in the Table were generated over a period of approximately four weeks while students participated in the Human Biology project. The questions reproduced are from a large body of intuitive theories, pieces of scientific information, and comments and did not necessarily follow one another immediately. At the end of each question appears initials of the student who constructed it.

Examination of CSILE students' processes of inquiry at the individual and small-group level suggested that the process deepened when a student generated a new subproblem. Generation of a new, unrelated problem only extended the process, but did not deepen it. The analysis revealed that there was a close association between the mean scores of deepening of explanation and the mean number of subordinate questions generated with $r(28) = .63, p < .001$ (partial correlation controlled for ability level). A scatterplot of mean scores of deepening of explanation and mean number of subordinate questions is presented in Figure 4-13.
From the scatterplot presented in Figure 4-13, one can infer that regardless of the close overall association, it was possible to achieve the same degree of deepening of explanation with a varying mean number of subordinate questions. This apparently was because the relevance of questions generated varied between students and projects. Apparently, the number of subordinate questions provides only a rough estimation of one's engagement in deepening inquiry. Further, conceptual advancement
was partially dependent on other factors such as success in searching for relevant, explanatory, scientific information. Further, some students did not explicate, i.e., record, all steps of their inquiry in CSILE's database by articulating or externalizing corresponding subordinate questions. In any case, a strong positive correlation between the mean scores of deepening of explanation and mean number of subordinate questions suggests that generation of new specific research questions has a very close connection with advancement of inquiry.

Further, from the scatterplot presented in Figure 4-13 can be inferred that the overall correlation cannot be explained by assuming that the high-achieving students of the group would have reached deeper levels of explanation as well as been better at generating subordinate questions. However, certain academic skills of searching scientific information appear to be needed in order to successfully engage question generation and search of explanatory scientific information; the correlation between mean scores of deepening explanation and mean number of subordinate questions generated was .71 (p<.009) for the high-achieving students indicating that those of the high-achieving students that generated subordinate questions tended to reach deepening levels of explanation. By contrast, the correlation was not significant for the average-achieving or below-average students, indicating that they were not able to utilize progressive generation of subordinate questions in deepening of their explanations as effectively as the high-achieving students. Although the relation between the degree of deepening of explanation and mean number of subordinate questions is a correlational one, and cannot establish a causal relation, the results indicate that,
overall, the generation of new specific research questions is likely to facilitate engagement in deepening levels of explanation—especially in contexts in which students representing different school achievements are studying collaboratively and support each other.

4.4.3 Practices of Question Transformation and Strategy Inquiry

Examination of the inquiry-structure graphs revealed that articulation of a new research questions discriminated between basic strategies of CSILE students' inquiry. CSILE students' basic strategies of inquiry seemed to be closely associated with their practices of question transformation; generation of a large number of more specific, research problems appeared to carry the process of inquiry to a deeper level. The students apparently followed three basic strategies of inquiry; a) truncated inquiry in which inquiry was interrupted before generating one's first, subordinate questions; b) extensive inquiry in which a student moved to conceptually unrelated problems after some episodes of inquiry without articulating more than a few subordinate questions; and c) intensive inquiry in which a student went deeper and deeper into a topic by articulating a series of subordinate questions. These strategies of inquiry were abstracted from the inquiry-structure graphs, and there were some processes that represented intermediate states.

Truncated inquiry refers to a process that contained only a few episodes of inquiry without generating subordinate questions or carrying out in-depth searches for new scientific information. Truncated inquiry entails that the process ended when a
first plausible theory was generated or a relevant piece of information found. It means that there was usually not more than one episode of inquiry in the context of a given, principal research question (see Appendix A2 for a corresponding inquiry-structure graph). Unanswered research questions were frequently associated with this strategy.

Typical of extensive inquiry was the production of several, principal research questions without carrying out in-depth searches in the context of a particular problem (see Appendix A3). Characteristic of extensive inquiry was to move to work with another, but conceptually unrelated, problem, without in-depth advancement of inquiry through articulating more specific questions and search for new explanatory information. It was, however, typical for the strategy of extensive inquiry to actively participate in CSILE study and produce relatively more CSILE notes than it was for truncated inquiry. An example presented in Appendix A3 demonstrates how it was typical for those doing extensive inquiry to work with many problems, but not to explore any of the problems very deeply. Nevertheless, extensive inquiry allowed the students in many cases to make considerable progress, especially when it was carried out in collaboration with students relying on intensive inquiry.

Intensive inquiry, by contrast, characterized a process in which a student went deeper and deeper into the problem by articulating a series of new specific research questions and carrying out several in-depth searches in the context of each principal research question (Appendix A4). These subordinate questions were closely related conceptually to the principal question, leading to a deeper level of inquiry. Frequently, however, engagement in intensive inquiry meant that the student also worked with
several principal questions so that inquiry was often carried out both in depth and in breadth. Associated with students' intensive inquiry appeared to be their engagement in systematic generation of intuitive theories and testing of the theories by searching for new explanatory scientific knowledge. Further, social sharing of explanatory scientific information was associated with the strategy of intensive inquiry; students participating in intensive inquiry frequently introduced new explanatory, scientific information not only for solving their own problems but for solving the other students' problems as well.

Strategies of CSILE students' inquiry seemed to be closely associated with their cognitive achievement. Figure 4-14 (page 232) presents the 95% confidence intervals for strategy of inquiry and the degree of deepening of explanation in the Electricity project. The figure indicates that students engaged in intensive inquiry achieved a significantly higher degree of deepening of explanation than students participating in truncated inquiry. This expected relationship provides evidence that the patterns of the students' inquiry were not accidental, but represented an important aspect of their inquiry.

Examination of CSILE students' strategies of inquiry in the Electricity project reveals that truncated or extensive inquiry appeared more typical for male than for female students. However, the students' ability level was not associated with strategy of inquiry; students representing the combined group of both below and average students (n=13) were equally likely to participate in intensive inquiry, compared to above-average students (n=15).
Strategy of inquiry

Figure 4-14.
Strategy of inquiry and 95% confidence intervals for mean scores of deepening of explanation in the Electricity project.

Although 2 out of 3 average-achieving males engaged in intensive inquiry, none of the above-average male students (n=5) engaged in intensive inquiry. They either truncated their process of inquiry (n=2) or carried out extensive inquiry (n=3). The problem appears to be that the above-average male students did not engage with deepening inquiry as strongly as the other students or go very much beyond what they knew in the beginning of the project. For female students 5 out of 9 persons, representing the combined group of below- and average-ability students, in contrast, committed themselves to intensive inquiry and succeeded in making considerable progress. Although the strategies were more typical for certain groups of students in
the Electricity project, it should be noticed that the strategy of a student's inquiry varied from one project to another depending on his or her interests, background knowledge, and availability of understandable explanatory scientific knowledge.

4.4.4 Expert Evaluation of the Cognitive Value of CSILE Students' Research Questions

According to the experts' overall evaluation, CSILE students' research questions were 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 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 is, if you look at the process, is to find the questions that are likely to bring you closer to the initial question. So, of course, there are two different things about the questions, one is how is the, how valuable is the initial question, how the problem is defined to the children in the class initially. And the second question is, once they do have the big question, how likely is it that they are able to answer the question by ... with the help of the small questions, that's what I would call progress ...

While evaluating a case that represented the Force Project, expert A stated, "so we have actually a structure of problems: first what is gravity, then how we use gravity, and then how does gravity work, that's a how question." He concluded by asserting, "I think there is conceptual understanding all right. And I think the questions
did aim towards conceptual understanding because they divided their initial question into subquestions, how does gravity work... .” He argued that the process of inquiry was progressive, “because I can see a pattern of these questions here. The small questions are, so to speak, not un-aimed, they have a purpose. They are geared to making, to finding out more specific information.”

Expert A also judged that I-Need-To-Understand (INTU) questions are very useful from the viewpoint of conceptual advancement: "An I-need-to-understand question is precisely a question that brings in new information. I know that ... so it is not an inference from a piece of knowledge that is already available but is something that has to be found out.”

Expert B stated that the students were asking “basically very good and certainly very useful questions.” However, he criticized some of the questions for being teleological in nature, such as the question “what do gravity and oxygen have in common”:

There are lots of different questions here. I think some of them are more likely to be fruitful than the others. The question of similarity of gravity and oxygen is rather odd. It seems to point to the anthropomorphic sort of explanation because... I can’t imagine anyone asking that question with background of physics and chemistry. Because there isn’t anything in common. One is a substance and one is a force. Maybe pointing that up is useful. ... If you have seen some of the work of Mickey Chi has done in conceptual change, it is one of the big shifts that has to take place is to go from viewing motions like force as being substance as seeing them as relations.

He estimated that, “as the discussion goes on they talk less about the purpose of these things and more about how gravity works. So that’s quite useful. So asking general question about gravity, what kind of force is good, but that initial INTU sounds
problematic." In the context of the Visual Perception, expert B evaluated the research questions as very useful:

I presume that this was one of the student generated [question], where is the eye's control panel located. I guess this is using some sort of an analogy to a computer, which could to be, it is like a robot eye, and it has got to have a control panel. But AM 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 AM comes in and reroutes the investigation from the potentially problematic question AO would have started with. So I think that these are very good questions that they are asking. And there is nothing here like in gravity-oxygen case which is misleading. The misleading question, the eye's control panel, is immediately rerouted to more effective. So that looks good.

Expert C did not provide as detailed assessment of the students' research questions as the two other experts. Although expert C agreed with the other experts that many of the CSILE students' research questions were valuable, he criticized some of the students' research questions as being based on wrong presuppositions. In the context of the Cosmology Project, he noticed that more and less progressive discussions were going on simultaneously, and not all of the students succeeded in advancing in their inquiry. The study group focused initially on the Solar System and succeeded in focusing on the Universe only later on in their process of inquiry:

... These are two ... really quite different discussions. The first question doesn’t make very much progress, it goes to a wrong, perhaps wrong direction to small details, but in this, concerning this other question there is, there is a clear progress. There is a kind of wrong approach on this side but then there is the quite right theory that universe, universe is always changing and there is a continuous process, and then it lead to quite reasonable further ideas how galaxies are formed, so I think this, this second question is better ... than the first one.

In other words, the expert did not regard questions with wrong presuppositions as cognitively valuable. When asked to justify his assessment, expert C agreed that it is normal also in the history of science "at least initially" to have a wrong theory, and, therefore, "it is quite normal that 10 year-old kids are looking at intuitive answers in
quite quite wrong directions." Nonetheless, according to Expert C's overall assessment, the students were generating "pretty good questions" that were likely to facilitate advancement of their conceptual understanding.

4.4.5 Discussion

The knowledge-seeking activity of students in classroom A was structured by generating a series of questions which guided or controlled the process of inquiry, analogously to the interrogative model of scientific inquiry. The results of the study indicated that the research questions generated by the students were not random but followed a pattern of interrogative activity. The students answered their principal research question by generating a series of specific questions (the second principal feature of scientific inquiry). They tried to answer their questions by constructing intuitive, tentative explanations through activating their relevant background knowledge. As in scientific inquiry, intentional generation of explanations and finding of new information seemed to make new research questions accessible to the students, and this, in turn, elicited construction of more advanced conceptions (the first principal feature of scientific inquiry). Articulation of new research questions appeared to be a driving force of the CSILE students' inquiry, carrying an illocutionary force (Austin, 1962) that guided the students to deepen their inquiry. Setting up a question and finding a tentative answer did not mean the end of inquiry, as is often the case in school learning; it was only a beginning of a gradually deepening inquiry. This was one of the main characteristics noted by the experts in their evaluation of the CSILE students' process of inquiry as progressive.
In order to examine relationships between CSILE students' conceptual advancement and the structure of their inquiry, I constructed inquiry-structure graphs. The graphs show that engagement in in-depth inquiry was associated with engaging in deepening levels of explanation. Examination of the graphs suggested that abductive construction of new explanations, and challenges to them by finding of new explanatory scientific information, was associated with generation of new specific research questions. Students who did not themselves generate more articulated or specific research questions and theories did not usually succeed in improving their conceptual understanding as much as students engaging with the process of question transformation.

An analysis of the inquiry-structure graphs indicates that strategies of inquiry and, correspondingly, conceptual advancement varied between groups of classroom A students according to their gender. The analysis revealed that male students more likely engaged in truncated inquiry than did female students. Further, none of the high-achieving male students engaged in intensive inquiry. Intensive inquiry was typical for below-, average- and high-achieving female students as well as a few average-achieving male students. It was characteristic of several students to engage in extensive rather than intensive inquiry, i.e., to study several independent research questions without going deeper into the topic. As a consequence, these students often did not find new explanatory scientific information and did not make as much progress as the high-achieving females. Extensive strategy did not differentiate students according to their gender or ability level. It should be noticed, however, that the strategies of in-
quiry are abstractions formed in the data analysis, and a student frequently changed strategy when moving from one project to another. Further, in evaluating results of the study, one should take into consideration that the strategies arguably represented relative differences among the students from classroom A. In comparison to conventional educational practices in which student-generated explanation-seeking questions are hardly pursued at all, practically all of the CSILE students engaged in cognitively valuable, and frequently rather sophisticated, processes of inquiry.

The relation between the progressive generation of new subordinate questions and advancement of the students' explanation was correlational. It was somewhat difficult to separate the significance of generating new subordinate questions and finding of new scientific information. Question transformation appeared to facilitate and provide heuristic guidance for the search for new information. It also seemed to elicit making of cognitive commitments to answer one's questions. Simultaneously, finding new relevant information made new questions accessible to the student and encouraged him or her to set up new questions. Thus, there is evidence that, in the process of deepening inquiry, generation of new research questions and finding of new explanatory knowledge may be somehow linked. Therefore, it appears to be necessary, in future, to design carefully controlled studies in which the relations between question generation and conceptual advancement can be further examined.
4.5 Study V: Influence of Explanation-oriented Peer Interaction on Conceptual Advancement

4.5.1 Method

The purpose of the study was to examine whether between-student communication mediated by the CSILE environment fostered the students' conceptual advancement and provided socially distributed resources for organizing one's inquiry (relations between the third and first principal feature of scientific inquiry). The study was intended to examine in detail to what extent a student was able to share his or her explanatory theories and build on information introduced by fellow students. Further, it was proposed to examine whether discourse interaction between the learners helped a student to reflect on his or her own process of inquiry, focus on productive lines of inquiry, and engage in deepening inquiry as a response to the other students' request for explanation. It would be theoretically and practically very significant to demonstrate that CSILE students can and do guide each other to focus on specific and manageable research questions; thereby, the regulative function of inquiry becomes socially distributed. Further, Samarapungavan (1992) showed that children are able to select theories that are logically consistent and empirically coherent without, however, being able to articulate the metaconceptual criteria used. It would be a significant cognitive achievement if elementary school students learned to spontaneously apply metaconceptual criteria for evaluating explanations in assessing their fellow students' as well as their own productions.
The participants of the study consisted of 28 elementary school students representing classroom A. CSILE students were working in a public database so that each student's productions were accessible to the other inquirers. Further, CSILE provided tools that allowed a student to add his or her written comments to another student's notes. The students were working with CSILE on three study projects, Force, Cosmology, and Electricity, in physics; and one project, Human Biology, in biology. The study involved qualitatively analyzing discourse interactions between students in classroom A using methods introduced above in the general method section.

Further, in order to analyze how CSILE students' peer-interaction fostered well-organized and deepening inquiry, a new variable was formed called distributed regulation of inquiry (the DRI). Distributed regulation of inquiry consisted of comments that focused on helping the student receiving the comment to regulate and direct his or her inquiry in a productive way. These comments seemed to address the process of inquiry itself rather than the specific content of knowledge as such. CSILE students' peer interactions appeared to facilitate advancement of inquiry not only through providing explanations but also through helping students to focus on manageable research questions, use collaborative methods and engage with deepening inquiry. Comments representing the DRI were regarded as metacognitive in nature because they were likely to facilitate metacognitive reflection on one's inquiry. In these comments the students pointed out, for instance, that the student receiving the comment was not actually working with his or her research question, that research methods were not used in an effective way, that sufficiently deep inquiry was not carried out or
that an explanation generated was not understandable. CSILE students did not produce a large number of communicative ideas representing all of these categories of communication. However, careful examination of this type of comment yielded significant information about the nature of their distributed inquiry and suggested both actual and potential directions for facilitating more advanced forms of discourse interaction within the CSILE environment. Specific types of comments representing the distributed regulation of inquiry will be described in the following sections. The reliability of classifying the DRI was examined by asking two independent coders (see page 99) to classify 200 CSILE communicative ideas, and was found satisfactory (the agreement coefficient was .77%).

Further, in order to assess relationships between peer interaction and conceptual advancement, comments received by a student were evaluated, as a whole, by using a four-step cognitive value of peer interaction scale. Assessment of the cognitive value of peer interaction was carried out by estimating, in the light of a student's productions, whether the comments received were likely to significantly facilitate advancement of the student's inquiry. Particularly, metacomments on research questions, research method, and explanations that represented the DRI were regarded as having a high cognitive value. The cognitive value of peer interaction was analyzed project by project. The scoring of cognitive value of received comments is now described.

1) Low value. A rating of 1 was assigned if comments received by a students were not at all likely to foster advancement of inquiry. In this case comments received
did not have any special cognitive value or there were only a few low-quality com-
ments.

2) Small value. A rating of 2 was assigned if comments received by a student
had some potential of fostering advancement of inquiry. The comments encouraged
a student to continue his or her process of inquiry, pointed out some weaknesses, and
provided useful if not very critical information. However, the comments did not appear
to help the student to regulate his or her inquiry in a productive way or provide signifi-
cant pieces of new scientific information.

3) Moderate value. A rating of 3 was assigned if comments received by a stu-
dent were likely to foster advancement of his or her inquiry. Some of the received
comments helped the student in question to regulate his or her inquiry and facilitated
profitable engagement with question-driven and deepening inquiry. Further, fellow
students were providing explanatory scientific information that helped to answer some
of the student's research questions. However, there was still uncertainty whether the
comments received actually affected the course of the student's inquiry.

4) High value. A rating of 4 was assigned if comments received by a student
were highly likely to significantly foster advancement of his or her inquiry. The re-
ceived comments represented distributed regulation of inquiry and helped the student
in question to overcome his or her intuitive conceptions as well as profitably engage
with question-driven and deepening inquiry. Further, the student in question received
comments that provided very important pieces of explanatory scientific information.
Comments requesting explanation or providing explanation focused on quite substantial issues of the student's inquiry (e.g., wrong presuppositions), and, thereby, facilitated deepening inquiry. Advancement of the student's inquiry appeared to be critically linked with such received comments.

Further, the cognitive value of communication between students was not determined by the number of comments received; even one comment received may have a high cognitive value if it represented the DRI or provided significant explanatory scientific information. If there were several comments, however, the combined effect of those comments was assessed; thus a high cognitive value of comments was often associated with a large number of comments.

Finally, the cognitive value of CSILE students' interaction was assessed by using expert evaluations. The three internationally regarded philosophers of science, who participated in the above reported studies, 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. However, one of the experts evaluated only one case in physics and two cases in biology.

4.5.2 Categories of CSILE Students' Communication

The analysis indicated that two categories of CSILE students' communication significantly facilitated advancement of their inquiry. The first category consisted of comments in which a student helped his or her fellow students to articulate more ade-
quate conceptions and learn generally accepted scientific views by directly providing explanatory scientific information. The second category of comments, distributed regulation of inquiry (DRI), represented comments that did not directly focus on the content of theories, but helped the students to regulate their inquiry and engage with deepening inquiry. The category consisted of comments that focused on research questions, research methods or requested explication or clarification of explanation or information. A frequency distribution of the most important categories of CSILE students' comments is presented in Table 4-26.

Table 4-26.
Frequency Distribution Concerning Categories of Classroom A Students' Comments

<table>
<thead>
<tr>
<th>OBJECT OF INQUIRY</th>
<th>Providing knowledge</th>
<th>Regulating inquiry</th>
<th>Other comments</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research questions</td>
<td>2</td>
<td>22</td>
<td>9</td>
<td>33</td>
</tr>
<tr>
<td>Method</td>
<td>3</td>
<td>20</td>
<td>2</td>
<td>25</td>
</tr>
<tr>
<td>Information</td>
<td>59</td>
<td>38</td>
<td>70</td>
<td>167</td>
</tr>
<tr>
<td>Explanation</td>
<td>89</td>
<td>121</td>
<td>83</td>
<td>293</td>
</tr>
<tr>
<td>TOTAL</td>
<td>153</td>
<td>201</td>
<td>164</td>
<td>518</td>
</tr>
</tbody>
</table>

Although comments providing knowledge were usually neutral (not harsh or disapproving) in nature, distributed regulation of inquiry consisted of both critical and neutral comments. In addition, the students produced comments that did not represent either of the two above mentioned categories. About 76% (f = 124) of these other comments were supportive in nature. Although supportive comments may be cognitively valuable and encourage deepening inquiry, there did not appear to be a
direct relationship between these comments and advancement of CSILE students' inquiry.

The following analysis focus on examining how CSILE students shared their knowledge by providing explanations to each other and how they regulated each other's inquiry through their discourse interaction.

### 4.5.3 Providing Explanation as Division of Cognitive Labor

An analysis of CSILE students' inquiry 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. On other words, the students fostered articulation of each other's conceptions by systematically providing explanatory scientific knowledge to students who were trying to explain a problem by using functional, empirical or otherwise inadequate conceptions. However, the social support seemed to be dependent on a student's own sustained effort to solve the problem in question.

Qualitative analysis of CSILE's database revealed that 153 out of 518 communicative ideas produced by the students in classroom A during year 3 were focused on providing information or explanation. About 58\% (f=89) of these comments represented theoretical concepts, explanatory theories or analogies. In these comments, CSILE students provided each other with concepts like "electron", "ionization" or "field" that were critical for scientific explanation of the research problems being investi-
gated. 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 presented a theoretical explanation for conduction of electricity is a quite typical example of comments providing explanation:

The reason that some materials conduct and others don't is because only some materials are made up of atoms that have free electrons. Free electrons are electrons that orbit the nucleus of the atom but are only loosely held so they can be taken away into the current. A material conducts when it has free electrons that are taken into the current while the current is going through the filament. (Year 3, author 23164, student 23334, emphasis added)

C: R., 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. (Year 3, author 23334, student ML, emphasis added)

In trying to explain the problem "how does electricity turn an iron spike into a magnet?", several students failed to make progress. By introducing the concept of field, a student was able to push the whole group towards deepening inquiry:

C: A., 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. (Year 3, author 26386, student ML, emphasis added)

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.
A factorial analysis of variance was performed in order to test whether the mean proportion of providing explanation varied according to gender or ability of the students in classroom A (n=28). The mean proportion of providing explanation was the dependent measure. Gender (male; female) and ability (combined group of below and average; above average) were the independent measures. Means and standard deviations for each cell are presented in Table 4-27.

The analysis revealed that there was a significant main effect for Ability ($F(1,24)=9.53, p<.005$). Thus, a higher mean proportion of the high-achieving students’ communicative ideas represented providing explanation category. A significant main effect was also found for gender ($F(1,24)=8.16, p<.009$) indicating that the mean proportion of providing explanation was higher among female students than the male students. However, there was no significant interaction effect between gender and ability. Sheffé group comparisons revealed that the group of high-achieving females gave a significantly higher mean proportion of explanations in their communication than the group of below- and average-achieving males.

<table>
<thead>
<tr>
<th></th>
<th>Below and average</th>
<th>Above average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>(M = .35)</td>
<td>(M = .50)</td>
</tr>
<tr>
<td>Male</td>
<td>(SD = .17)</td>
<td>(SD = .20)</td>
</tr>
<tr>
<td>Female</td>
<td>(n = 9)</td>
<td>(n = 10)</td>
</tr>
<tr>
<td>Male</td>
<td>(M = .04)</td>
<td>(M = .36)</td>
</tr>
<tr>
<td></td>
<td>(SD = .08)</td>
<td>(SD = .25)</td>
</tr>
<tr>
<td></td>
<td>(n = 4)</td>
<td>(n = 5)</td>
</tr>
</tbody>
</table>
By providing explanatory scientific information, the students fostered advancement of each other's conceptual understanding. Although 57% (\(f=90\)) of comments providing explanation were constructed by high-achieving females, only 47.5% (\(f=75\)) of this kind of comment were received by high-achieving females. In other words, some of these comments given by high-achieving females focused on supporting the below-average and average students' advancement. Further, among high-achieving female students there seemed to prevail a division of cognitive labor so that a student who specialized in a particular area of investigation shared her or his knowledge with students focusing on other content areas.

### 4.5.4 Distributed Regulation of Inquiry

Distributed regulation of inquiry consisted of 39% (\(f=201\)) of communicative ideas produced by classroom A students. About 62% (\(f=124\)) of comments representing the DRI were critical, and 38% (\(f=77\)) were neutral in nature. The former comments focused on criticizing weaknesses in the fellow students' research questions, research methods, information or explanation. The latter comments were not explicitly critical in nature but requested explication of explanatory relations. Each category of communication representing the DRI, such as formation of research questions, methods of inquiry, and request for explanation, is analyzed in the following sections.

Specific categories of comments representing the DRI were not homogeneous or frequent enough to allow statistical analysis, so these categories of comment are
analyzed qualitatively in the following. However, I would argue 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, each category of these comments is 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 identifiable category of distributed regulation of inquiry. Although the frequency of these comments was not high (there were altogether 22), the comments on research questions appeared to have a very important role in the distributed regulation of inquiry. In their comments on research questions, CSILE students were requesting each other to engage with question-driven inquiry ("You should define some problems from your topic"). These comments were aimed to help fellow students 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 guided to focus on more productive research questions, for example:

I think that you should describe and tell more in your theory about how the UNIVERSE will change in the future and less about how the people will change in the future and how they will know more about the universe in the future because that is not really the question you are researching. (year 3, author 23147, student NE)

In your first theory you said that the Earth would change because the ozone layer would disappear. But your problem is "What is the fate of the universe" not the Earth so I think you should change your theory. ... (year 3, student 23096)

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

C: RS and RO, I think that your note is a good note except for 1 thing. RO, in your first INTU, you said that you wanted to find out how gravity works, where gravity comes from and what causes gravity. So I was wondering, did you find out what causes gravity. I saw that you have the other two things that you mentioned in your note. (year 3, author 23109, student JH)

C: EH and AB 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. (year 3, author 23120, student SH)

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

After reading your comment to K we decided that it did not really help her. 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. (year 3, author 26154)

In your comment you said this is very good. I think it would be helpful to your readers (and the other people in your group) if you said what you thought was good and what is good about that thing. ... (year 3, author 23109)
A student might have emphasized focusing on one main point and not working with too many topics simultaneously ("you should plan your group's work better and specify who is doing what"). These pieces of interaction seemed to be *metacommments* in nature: they concerned methods of carrying out the collaborative process of inquiry. They also appeared to represent gradually tightening norms of inquiry within the learning community, and seemed to contribute significantly to progress in the culture of communication.

Some comments requested the students whose notes had received comments to do their research in depth and search for new information in order to be able to answer their research questions. This kind of systematic request for deepening inquiry led, in many cases, to further articulation of the theories in question, pushing the student receiving the comment to do more research and articulate new explanations. Deepening inquiry was facilitated through communicative ideas that requested that the person receiving comment search out more information to support his or her theory.

Comments that were focused on requesting the fellow students to explicate, clarify and further articulate their theories represented an important aspect of the DRI. 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 "electron", "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.

C: In your INTU (above) you said you need to understand what gravity and oxygen have in common. And in your NI (above) 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. (year 3, author 26393, student AR)

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? (year 3, student 23089)

I was wondering in your MT: for the problem, "What kind of cells are there in the brain, and how do they differ from the other cells in the body?" When you say that you think the brain cells are more developed do you mean that they are cells that are completed in knowledge and are more complicated than most cells? (year 3, student 26124)

Classroom A students 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):

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. ... (year 3, student 26131)

C: 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. You should try to make your theories better by proofreading your work. (year 3, author 23300, student JG)

You said in your note that you thought the cell functions on the air we breathe in. But how? What's the process? (year 3, student 23089)

I think that you should put more information in your note about the universe and not about how the people on earth will change in the future but about how the UNIVERSE will be like in the future. I also think that when you say the universe will be more or less the same in the future you are not explaining very much in your theory. (year 3, student 23090)
Although high-achieving females produced a higher proportion of comments providing explanation than other groups of student, comments requesting explanation were equally attainable for all students regardless of gender or ability level. The relative proportion of this kind of comments was higher for below- and average-achieving students, although the absolute frequency of these comments was higher for the high-achieving females. While the high-achieving females provided explanations to the other students (and each other), the other students, in turn, fostered advancement of the high-achieving students' inquiry through their frequent requests for explanation. Moreover, examination of the contents of the comments suggested that high-achieving female students' search for new information was partially motivated by the other students' requests to explicate and further articulate one's theory.

In order to examine whether requests for explanation pushed students receiving comment to deepen their inquiry, I 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, I 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, I included only those students (n=22) who received a comment requesting explanation. Due to the fact that 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 commented 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<.000). Without requests for explanation the mean depth of inquiry was 1.74 (SD = .44) episodes and with requests for explanation 2.74 (SD = .90). In the context of the episodes of inquiry in which other students asked for explanation 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 had, I
would argue, an essential role in pushing students receiving comments to deepen their inquiry.

### 4.5.5 Comparison Between Intuitive and Scientific Theory

Comparisons between intuitive and scientific theories appeared to be an important source of the conceptual advancement for students in classroom A. Although the students did not ground their explanations on experimentation or experimental facts, they were able to change their conceptions when confronting new scientific information that contradicted their intuitive conceptions. In many cases, the students noticed that their explanations did not fit a generally accepted scientific view, and had only a limited range and power of explanation (see Table 4-28). Some students were even able to recognize inadequate presuppositions of their questions. The comparison between intuitive and scientific conceptions appeared always to be implicitly present in the students' inquiry, and seemed frequently to be in the background of conceptual advancement. 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.

CSILE did not have a thinking type to facilitate a comparison between intuitive and scientific explanations. However, while working on the Cosmology project, a group of students started to experiment with a new thinking type (CTNI - Compare Theory With New Information). This kind of thinking type seemed to encourage the
students to compare their own theories with scientific ones and, thereby, facilitated conceptual advancement.

Table 4-28. Comparisons of Intuitive with Scientific Theory

<table>
<thead>
<tr>
<th>I found that my theory was wrong and in a way so was my problem. I began my problem assuming that the planets evolved from pieces of rocks but as you see it is much different, I also said my problem was ruffly universe evolution when what I've actually been doing is the solar system. (year 3, author 23089, student NCD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I was wrong the strong nuclear force is responsible for holding the atom together. It is the force that holds the quarks together to make the protons and neutrons, and it holds the protons and neutrons toghther to make the nucleus of an atom. (year 3, author 26394, student RO)</td>
</tr>
<tr>
<td>I compared my theory with N.'s NI and found that if the universe is open my theory is wrong because it will keep expanding forever, but if the universe is closed it will make a new universe, so MT was a little bit right. (year 3, author 23089, student SM)</td>
</tr>
<tr>
<td>I know that my beginning theory was wrong because only the first few things on my list of things that can conduct electricity have metal in them, the rest don't. (year 3, author 23096, student AR)</td>
</tr>
<tr>
<td>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 to get to its destination. The is a tiny space between the two cells which is filled with a substance we call the neurotransmitter. ... (year 3, author 23089, student ML)</td>
</tr>
</tbody>
</table>

4.5.6 CSILE's Database as a Source of Knowledge

In addition to providing explanations, the students frequently used each other’s notes as a source of information. For example, in the context of the Electricity project, 17 out of 28 students explicitly mentioned the other students' notes or comments as a source of some pieces of their new information. In this case the arrangement of the project so that each student researched eight common research questions facilitated social sharing of explanatory information. The CSILE students appeared to be able to recognize the cognitive value of explanatory scientific knowledge, and, accordingly,
picked up corresponding pieces of information from other students' notes. The following transcription is a typical example of social sharing of knowledge:

I found out from R's and L's note that gravity works by matter particles sending out force particles, like gravity. Everything is made up of matter particles and matter particles send out gravity particles, so everything has gravity. Particles are very small objects. (year 3, author 23096, student AR)

CSILE students used socially distributed resources mediated by the CSILE network to articulate their own theories. Subsequently developed theories resembled each other, but a later theory was usually more articulated than the earlier ones. An earlier-developed theory might be again taken as an object of articulation, later in the process. Articulation of more elaborated research questions and theories was dependent on the acquisition of new information which contained new theoretical or explanatory concepts or principles which challenged the group's initial assumptions. Factual or purely empirical information was not equally effective, leading in many cases to a dead end.

4.5.7 The Cognitive Value of Peer Interaction

The above analysis revealed that the students in classroom made considerable conceptual advancement in their projects. In order to analyze relationships between conceptual advancement and communication between the students, comments received by each student were evaluated using the cognitive value of peer interaction scale. The analysis revealed that the mean cognitive value of peer interaction was 3.1 (SD = .64) indicating that a great majority of the students received comments that were likely to facilitate conceptual advancement. However, there was a statistically significant gender difference for the cognitive value of peer interaction, so that the
mean cognitive value of comments received by male students was lower ($M = 2.44, \ SD=.65$) than that of the female students ($M = 3.38, \ SD = .37$) ($t=-4.03, \ df=10.6, \ p<.002$). Comments received by the male students were not as likely to facilitate their conceptual advancement as those of the female students.

It was expected that a high cognitive value of comments received by a student would be associated with change in frame of explanation, i.e., would help a student to overcome initial functional or empirical assumptions. In order to examine relations between the cognitive value of peer interaction and conceptual advancement, a conceptual advancement score was calculated by taking the sum of scores concerning change in frame of explanation and the mean scores of deepening of explanation. The analysis revealed that there was a statistically significant positive correlation between the cognitive value of peer interaction and the sum score of conceptual advancement ($r(28)=.58, \ p<.001$). A scatterplot of the cognitive value of peer interaction and the sum scores of conceptual advancement is presented in Figure 4-15.

From the scatterplot it can be inferred that the cognitive value of peer interaction and conceptual advancement were closely associated; i.e., the students who received cognitively more valuable comments also obtained a higher conceptual advancement score. One of the students got an exceptionally high conceptual advancement score; she initially constructed explanations that were strongly functional and empirical in nature but succeeded in overcoming these theories as well as making considerable conceptual progress. The significance of the overall correlation is not, however, dependent on this particular student. Simultaneously, from the figure,
one can infer that varying degrees of conceptual advancement were associated with the same cognitive value of received comment. Apparently, there were reasons other than the cognitive value of received comments, such as, perhaps, commitment to a sustained process of inquiry and search for relevant explanatory information, that affected conceptual advancement.

![Figure 4-15. Mean cognitive value of received comments for individual students displayed in a scatterplot against mean scores of conceptual advancement.](image)
The cognitive value of received, and of provided comments appeared to be closely associated, i.e., students who received valuable comments also provided corresponding comments. However, the cognitive value of provided comments was not assessed because evaluation of the cognitive value of these comments would have required a parallel assessment of very different processes of inquiry (i.e., an assessment concerning how student A’s comments would have affected students B’s, C’s, D’s, inquiry).

4.5.8 Expert Evaluation of the Cognitive Value of Peer Interaction

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 focuses on expert A’s and B’s evaluation 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 estimated 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 requesting each other to clarify or explicate their explanations. They also estimated 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 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 that was in cosmology examples. 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."

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. I will give full four. 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."

4.5.9 Discussion

On the basis of written documents, one cannot conclusively infer cognitive effects of social interaction. However, the analysis of CSILE students' discourse interaction presented above indicates that higher cognitive value of received comments was associated with a higher level of conceptual advancement. That is to say, CSILE students' comments, focused on providing and requesting explanations as well as distributed regulation of inquiry, appeared to significantly facilitate advancement of the students' explanations so that, in their case, one sees an interaction between the third and first principal features of scientific inquiry. Although the relation was a correlational one, and should be confirmed by using further, controlled classroom studies, the results furnished suggestive evidence that interaction between the students facilitated advancement of their explanation in multiple ways. Providing explanatory theories helped many students to overcome conceptual difficulties regarding physical and biological phenomena and facilitate conceptual advancement. Critical evaluation of a student's concurrent explanation pushed the student receiving comments to deepen his or her inquiry. Critique of missing or weak explanations in general pushed students to develop more articulated, and in many cases, more physical explanations. Further, distributed regulation of inquiry guided students to do their inquiry in depth
and consider their conceptions from the viewpoint of the others. Examination of the productions of classroom A students revealed that they were spontaneously using metaconceptual criteria to evaluate explanations, such as simplicity, range of explanation or logical coherence. In addition, a comparison between one's own and a scientific theory, mediated by CSILE's database, apparently fostered conceptual advancement.

The analysis indicated that the students in classroom A socially shared their explanatory theories. An equally important form of CSILE students' communication that fostered deepening of each other's inquiry was a request to explicate explanatory relations. In these comments, students pointed out that a student's note or theory is not comprehensive, and requested making it more understandable or articulating it further. All students and the teacher in classroom A produced a large number of comments requesting explication of explanatory relations. The analysis of CSILE students' communicative ideas indicated that it was typical for the above-average female students to provide explanation in their comments, while the below- and average-achieving students frequently requested explication of explanations. In other words, between students representing lower- and higher-ability levels there seemed to take place a sort of division of cognitive labor: the former students focused on requesting explication of explanatory relations and the latter provided explanatory scientific information to the group. Although the more advanced students provided a great deal of explanatory scientific information to the other students, one should take into consideration that the explanatory knowledge was not only directed to the less advanced
but also to other more advanced students. The high-achieving students socially shared new information found by some members of the group, providing socially distributed resources for advancement of the whole group. To conclude, written communication between the students appeared to support all groups of students and to be an important resource for conceptual advancement.
5. GENERAL DISCUSSION

5.1 Methodological Limitations of the Study

The purpose of the study was to analyze whether elementary school children are able to profitably participate in processes of knowledge-seeking inquiry representing the principal features of scientific inquiry. In the study, I analyzed knowledge posted by students to CSILE's database that functioned as a local plane of objective knowledge, world3 (Scardamalia et al., 1994). Further, I conducted epistemological and qualitative analysis of students' textnotes and comments. The material gave detailed information about the students' process of inquiry, but did not provide direct information about actual psychological processes involved. The study was based on a working assumption that through qualitative analysis of CSILE students' productions one can obtain cognitively valuable information about sustained processes of inquiry that are difficult to study by any other means.

The methodological choice to focus the analysis on CSILE students' written productions was based on an assumption that writing mediated by a computer-supported learning environment requires explication and articulation of one's conceptions and facilitates reflective communication between students. However, analysis of students' written productions brings up certain other methodological problems. A general problem of analyzing verbal records of problem-solving processes is that some subjects do not verbalize all steps of their inquiry (see Chi, 1997). The incompleteness problem of verbal analysis is even more serious when analyzing written produc-
There were considerable individual differences concerning productivity of the CSILE students, particularly in classroom B. Some students produced only a small number of notes that did not provide sufficiently detailed information about their process of inquiry. A further problem was that conclusive inferences concerning cognitive changes involved cannot be made on the basis of written notes. Given that the focus of the study was on CSILE students' written productions, it should be understood that conclusions about cognitive processes and changes in the background of phenomena studied should be taken as tentative and inferential; such conclusions require confirmation from further, authentic classroom studies. However, taking pragmatic limitations of the study into consideration, it would have been very hard to find any other means of carrying out the study. CSILE's database represented a huge amount of unique and content-rich material concerning elementary school students' sustained processes of knowledge-seeking inquiry in an authentic school environment. In fact, there is "a trade-off between experimental control and richness and reality" in cognitive research on educational practice (Brown, 1996, p. 400).

Because the study was based on naturally occurring data, there were some unexpected methodological problems concerning the data analysis. Heterogeneous variances and unequal sample sizes caused problems in interpreting the results of some statistical tests used in the study. However, the methodological problems represented not only limitations of the naturally occurring data analyzed but also limitations of conventional statistical methods for analyzing complex cognitive processes outside the laboratory. Further, there were certain cognitively significant reasons for
the frequency distributions or variances that diverged from the statistical assumptions (see Howell, 1987, p. 181). Non-normal frequency distributions, for instance, reflected drastic differences between classrooms A and B and revealed that not all students participated in CSILE study with equal intensity. Moreover, lack of variance concerning certain variables within classroom A indicated that practically all students were participating in same sort of explanation-oriented knowledge production, and this is a significant educational achievement as such.

A further methodological problem was that there were no independent ways of evaluating the quality of processes involved. If it could have been possible to compare content-analytic data with some external criterion, for example learning outcomes, this would have obtained a quite strong form of validity (see Krippendorff, 1981; Weber, 1985). However, the present data did not allow examination concerning relationships between CSILE students' process of inquiry and their educational achievements in comparison with conventional classrooms. For purposes of the present study a reference to numerous studies (Scardamalia, Bereiter, Brett, Burtis, Calhoun, & Smith, 1992; Scardamalia, Bereiter & Lamon, 1994; Scardamalia & Bereiter, 1994; 1996; Lamon et al., 1996) which showed how CSILE studying produced higher-level school achievements and provided a considerable advantage over conventional school learning will have to suffice. However, a problem with conventional school achievement tests is that those may not provide a valid basis for assessing new kinds of epistemic processes fostered by socially distributed knowledge-seeking inquiry in the CSILE environment. An aim of the present study was to analyze CSILE students' processes of inquiry in a detailed way in order to create conceptual basis for devel-
oping ways of assessing cognitive outcomes in computer-supported collaborative learning in the future. In the study the problem of an external criterion was partially solved by assessing the quality of CSILE students' process of inquiry by using expert evaluations.

5.2 Epistemology of Inquiry and the Nature of Learning Tasks

The results of the study indicate that CSILE students can be encouraged, with appropriate teacher guidance, to approach the problems being investigated at deepening levels of explanation representing the first principal feature of scientific inquiry. However, the analysis revealed that there were large and significant differences in mean levels of explanation between classrooms A or B across the period investigated. An examination of the results indicates that the epistemological nature of learning tasks undertaken strongly influenced the nature of students' process of inquiry. It was characteristic of classroom A to conduct conceptually challenging study projects that focused on gaining theoretical understanding of the problems being investigated, while classroom B's study projects focused on acquiring factual knowledge and empirical generalizations that usually did not go beyond everyday phenomena. The students in classroom A were guided not only to specify their own research questions but also to articulate new questions as new information became available to them, to systematically build their own intuitive theories, and to explicitly search for explanatory scientific theories.
Analysis of CSILE’s database suggested that classroom B represented a completely different epistemology of inquiry. Typical of classroom B was to carry out conceptually unchallenging study projects that focused on the familiar everyday environment. The design of study projects carried out by the group guided the students in working with factual knowledge rather than searching for explanatory scientific concepts and information. Although the students in classroom B produced explanation-seeking research questions, the scientific information processed by the group was at a substantially lower explanatory level than that of classroom A. The projects of classroom B focused mostly on observable empirical phenomena such as selecting an interesting phenomenon (e.g., species, countries, places) and searching for basic information about it.

The most challenging task carried out by classroom B seemed to be to examine differences and similarities between phenomena being investigated. Cognitive studies of human reasoning reveal that there are two different approaches on categorization, i.e., similarity-based and explanation-based categorization (Murphy & Medin, 1985; Keil, 1989). Similarity-based categorization remains at the level of empirical generalizations being, by definition, incompatible with an explanation-based approach. The similarity-based approach, adopted by classroom B students, seemed to lead to generation of list-type solutions instead of elaboration, articulation, or integration of knowledge. Although the projects would have provided a good opportunity to learn to conceptualize biological taxonomies in a principled way (invertebrate, vertebrate, warm-blooded versus cold-blooded animals), these taxonomies were frequently
used as *labels*, and none of the students used a group membership as a tool for inference (cf., Thagard, 1990). Further, the students from classroom B did not come to discover deep biological principles, such as reproductive success (see Brown & Campione, 1996), in explaining the adaptation of the species studied. Although the projects carried out by classroom B would have provided a good opportunity to acquire conceptual understanding of deep biological or physical principles (see Brown & Campione, 1996), the students were frequently bound to surface-level phenomena. Only of a few projects carried out near the end of the period, such as Mammoth and Continental Drift, were clearly focused on generating students' own explanations.

Lampert (1995) pointed out that engaging students in a real process of inquiry is a very challenging task, requiring much effort from teachers. It requires building a new culture of learning in which generation of students' own theories has a legitimate role. A necessary prerequisite for the emergence of a constructive, scientific-style of inquiry appears to be a culture in which each student is encouraged to articulate his or her intuitive theories, and in which each theory is respected as well as critically evaluated. This kind of culture, of which classroom A in year 3 provided an excellent example, allows each student to participate in articulating explanations without being afraid of unavoidable mistakes. As Lampert (1995) pointed out, engagement in generating one's own theories and conjectures without knowing that these are correct is risky business, especially in a school environment in which one's success is evaluated with respect to well-established scientific knowledge. Kuhn (1962, p. 101) pointed out, correspondingly, that the price of making significant scientific discoveries is that one
has to take the risk of being wrong. The present analysis of the process of inquiry for students in classroom A has revealed that they were ready to take the challenge. They had been convinced both of the productivity of a more progressive approach and had experienced dissatisfaction with old ways of doing inquiry. White and Gunstone’s (1989) analysis has shown how difficult this kind of change may be to achieve.

Results of the present study indicate, further, that there is a very close relationship between the epistemological nature of knowledge produced by an individual student and the learning tasks carried out. Classroom culture and the nature of learning tasks appear to create an economy of inquiry that significantly constrain each student’s practices of inquiry. It would have required considerable mental effort from students in classroom B to transform the given learning tasks into more challenging ones and to go deeper into the topic when the learning tasks in question did not necessarily require in-depth conceptual understanding. The nature of knowledge produced was empirical across all students, and this seemed to reflect the nature of the learning tasks carried out rather than individual cognitive achievements. This contention was supported by the fact that differences between classrooms A and B were in most cases far more substantial than within-group differences between low- and high-achieving students. Hardly any of the classroom B students succeed in significantly breaking the boundaries of a narrow, empiricist epistemology by constructing their own explanations or focusing on explanatory scientific information. Engagement with complex cognition is very difficult and presuppose an intentional effort from both the teacher and the students (Perkins, 1992) as well as group support for advancement of
inquiry. For the classroom A students, the whole classroom culture facilitated participation in sustained processes of knowledge-seeking inquiry and taking on more challenging cognitive tasks. The results of the study suggest that regardless of individual cognitive competence, a student may not be able to break the boundaries of empiricist epistemology without an expert model.

Design of classroom B's study projects was based on an implicit assumption that 10-year old children are not capable of acquiring deep theoretical principles of physical, biological or social sciences, but are bound to phenomenal and vivid concrete images which can be compared and classified using elementary cognitive operations such as similarity judgment. Preliminary results of an ongoing four-year longitudinal CSILE study carried out in Finland indicate that this kind of empiricist educational epistemology is rather common in elementary level education (Hakkarainen et al., 1996; Lipponen & Hakkarainen, 1997; Järvelä et al., 1997). There were 26 grade four students representing the same age-level as Canadian CSILE students; this Finnish group used CSILE to carry out study projects in biology and environmental studies. Knowledge posted by them to CSILE's database was analyzed by applying the methodological tools developed in the present study. The analysis revealed that there were striking similarities between the present classroom B and the Finnish group in spite of different cultural backgrounds and educational contexts. Moreover, practices of knowledge production in these two groups diverged more from Canadian classroom A than from each other because CSILE projects designed by Finnish teachers represented the same kind of fact-oriented educational epistemology as those of Ca- 
nadian classroom B. The design of the Finnish study projects carried out did not encourage the Finnish students to go beyond their immediate observations to explain and understand the problems being investigated. In many cases students were explicitly guided simply to describe experimental procedures used and to form their own qualitative observations but not encouraged to construct their own hypotheses, conjectures or theories. Data from several other CSILE classes in Finland corroborate these observations. Thus, empiricist educational epistemology appears significantly to constrain participation in higher-level practices of inquiry at school.

5.3 Teacher Support for Advancement of Inquiry

Examination of the material indicated that classroom A’s distinct epistemic achievements presupposed a very strong engagement of the teacher; the conceptually challenging study projects could not have been carried out without the teacher’s guidance and active participation in CSILE discourse. He apparently gave the students a great deal of epistemological support by providing an expert model of higher-level processes of inquiry. Brown, Ash, Rutherford, Nakagawa, Gordon and Campione (1993) discussed the role of the teacher in discovery learning and argued that the teacher should take the difficult role of being in the middle ground of guided discovery learning. If a teacher takes control of all aspects of the learning process, he or she may not sufficiently encourage students' own thinking and facilitate their own cognitive efforts. On the other hand, teachers should not rely too much on unguided discovery learning, but should intervene if students are not able to make progress themselves. The teacher of classroom A seemed to adopt this kind of role. Like a facilitator in
problem-based learning, the teacher consistently communicated with the students at a metacognitive level by requesting explication of explanatory relations; he guided the students in monitoring the progress of their understanding without directly giving them information (compare Savery & Duffy, 1996). This orientation turned out to be very effective; the students were often able to detect their misunderstandings, revise their theories correspondingly and refocus their inquiry on the basis of the teacher's and the other students' requests for explication. With minimal instructional intervention, the teacher was able to guide the students to ask relevant questions, create ingenious intuitive theories and find explanatory scientific information. The students obviously still had certain inaccurate theories and misconceptions at the end of the investigation period, but analysis of conceptual advancement indicated that most of them, nonetheless, made considerable progress in their projects so long as understandable scientific information was available.

The teacher of classroom B did not participate in the students' process of inquiry as actively as the teacher of classroom A did. He provided certain preliminary questions for the students to answer, and only during the third year systematically commented on the students' productions. His comments were mostly supportive although reasons were not always explicated. He asked once in a while for a student to do some extra work, but he did not systematically request explication of referential or explanatory relations. Without actively engaging in a CSILE-type discourse the teacher can neither help the students to advance in their process of inquiry, nor to recognize significant contributions, nor to generalize emerging progressive practices
of inquiry. In order to successfully elicit higher-level practices of inquiry, the teacher should not let the students alone, but rather provide an expert model by his or her own example. It appears that elementary school students cannot break the constraints of concurrent pedagogical practices without the teachers' cognitive and epistemological guidance (Hakkarainen & Lipponen, 1998, Lipponen & Hakkarainen, 1997; Järvelä et al., 1997).

An important factor that explains the advancement of inquiry in classroom A was the teacher's continuous effort to find new ways to foster higher-level practices of inquiry. Examination of the development of the recent practices of inquiry within classroom A revealed that this new educational epistemology did not emerge immediately but through a long process of experimenting and testing of different kinds of cognitive practices. During the period analyzed, not only did the objects and methods of learning in classroom A change but so did the teacher's conceptions of what kinds of learning processes are attainable for elementary school students. Classroom A appeared to represent a second-order environment in which the teacher and students continuously went beyond their earlier achievements (Bereiter & Scardamalia, 1993). Breaking the boundaries of traditional educational practices might not be possible without this kind of progressive problem solving.

Further, it seems plausible to hypothesize that the logic of classroom A students' own inquiry contributed significantly to progressive changes in inquiry. By getting involved in intentional attempts to explain and understand the problems being investigated through collaborative processes of inquiry, the students appeared to con-
tinuously find new practices as well as develop new norms for regulating their inquiry. The analysis of discourse interactions between the students revealed that substantial changes happened in how the students saw what they were supposed to do in their knowledge-seeking inquiry. While CSILE students' conceptions of the relevant aspects of inquiry changed, the practice of inquiry changed as well; these changes happened progressively, one achievement leading to another, and so there was a gradual change in the epistemological nature of the group's inquiry. It seems plausible that the emergence of changes was linked with the interaction between classroom A teacher's constructive efforts and the students' intentional learning.

Advancement of the CSILE students' inquiry seemed also to be affected by efforts of the CSILE-project personnel to develop the system and facilitate higher-level processes of inquiry both in classroom A and classroom B. In classroom A the structure of the students' epistemic activity changed progressively when they started to use groupnotes in the end of year 2. The students' use of corresponding explicit thinking-types, such as MT (my theory), NI (new information) and INTU (I need to understand) structured their discussion notes, fostered making of a distinction between mere information and its use for construction of explanation, and helped them to conceptualize their epistemic inquiry correspondingly. This practice also fostered articulation of a series of small questions for answering one's initial principal question. It could be argued that during the earlier years analyzed, the students were working individually but developed their explanations collaboratively through a process of commenting mediated by the CSILE environment. During year 3, however, CSILE students worked in
closely collaborative small groups, and students working in these groups were collectively responsible of carrying out their question-driven inquiry. It is a plausible hypothesis that the implementation of a higher-level and more intensive collaboration significantly influenced the advancement of inquiry for students in classroom A. These external interventions also seemed to elicit emergence of higher-level practices of inquiry also in classroom B, during the last year examined.

In assessing classroom A's and B's epistemic achievements, it must be emphasized that the present study analyzed the epistemology of inquiry rather than the commonly constructed "educational value" of activities the students undertook. Yet there is no doubt that participation in CSILE activities, such as more intensive writing and peer interaction, was educationally valuable in both classrooms A and B. Comparisons of school achievements between the CSILE classes and other classes not using CSILE revealed that both of the groups achieved better results than students working in conventional classrooms (Scardamalia et al., 1992). One may distinguish between first-order and second-order effects of educational technology. The first-order effects refers to learning of skills of using information technology, developing skills of knowledge acquisition, increased motivation, and using extended sources of information. It is also likely to involve changed structures of classroom activities and changed division of cognitive labor between the teacher and the students; students engaged in computer-supported collaborative learning are not doing the same kinds of things anymore but are involving themselves in many different kinds of independent research projects. These first-order effects are a normal consequence of engagement
with computer-supported collaborative learning but do not, as such, break the boundaries of traditional empiricist educational epistemology. The second-order effects involve engaging students in a sustained question- and explanation-driven inquiry and progressive discourse analogous to scientific practice. It may lead to a profound change in the students’ conceptions of what learning and knowledge are all about. The results of the present study indicate that this kind of epistemological shift cannot be achieved without strong pedagogical support from the teacher.

5.4 The Nature of CSILE Students’ Intuitive Explanations

Results of the study revealed that CSILE students were engaged in a systematic generation of their own explanation-seeking research questions. Explanation-seeking research questions are intimately connected with problems of understanding, and, therefore, have a special cognitive value. The fact that practically all of the research questions produced by students in classroom A were explanation-seeking in nature indicates that they were engaged in intentional learning focused on understanding. Engagement in construction of these kinds of research questions is a significant educational achievement. CSILE studies carried out in Finland revealed that only 10 to 20% of research questions spontaneously generated by elementary school students were explanation-seeking in nature (Hakkarainen et al., 1996; Lipponen & Hakkarainen, 1997).

From the viewpoint of a pragmatic theory of inquiry, research questions and explanations are embedded into pragmatic problem-solving and epistemic situations
(Sintonen, 1985). As a consequence, there cannot be any absolute criterion for assessing an agent’s research questions or explanations (Laudan, 1977; Harman, 1986; Rescher, 1979; Stich, 1990). These should be characterized in relation to an agent’s “knowledge world” or “epistemic alternatives” (Hintikka, 1986; see also Macmillan & Garrison, 1988), the different possibilities that an agent can take into consideration given his or her background knowledge. Epistemic goals and background knowledge determine what questions the students are able to ask and what kinds of explanations they are able to generate. This relativity of epistemic evaluation should be acknowledged in order to fully understand conceptual problems involved in young students’ knowledge-seeking inquiry. A pragmatic theory of inquiry implies, further, that uncertainty and unanswered questions, questions with wrong presuppositions or incomplete and fuzzy theories or may still be useful in fostering advancement of inquiry (Macmillan & Garrison, 1988; see also Scardamalia & Bereiter, 1996). It follows that even if a student begins his or her inquiry with inadequate presuppositions and wrong theories, the process may still be progressive on the condition he or she focuses on improving his or her theory by generating more specific questions and searching new information.

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 (see, for example, Carey, 1985). The use of intentional explanations in biology projects appeared to represent a transition from psychological to biological explanations, a phenomenon discussed by Carey (1985). On the basis of the present
analysis, the transition from functional to physical explanations appears to be an impor-
tant aspect of conceptual development parallel to the transition from psychological to biological explanations (within functional explanations). Such a transition appears to cross clearly distinguishable ontological categories. It seems that the transition from substance to event-based ontology (see Chi, 1992) may be relevant only in the later stages of children's cognitive development, although the functional-physical tran-
sition is one of the main aspects of conceptual change in childhood.

Functional and intentional explanations were apparently more available for the students than physical or biological scientific explanations. In the background of CSILE students' intuitive explanations seems to be the students' difficulty in selecting an appropriate frame of reference (see Dennett, 1984). Their intuitive explanations appeared to be based on a too-narrow frame of reference — whether it is human agency or the perceptual world consisting of middle-size objects. 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, or a particle in physics. 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 lacked the epistemological knowledge of the appropriate level of explanation and of justification of one's theory (see Salomon & Perkins, 1988).
In some cases, however, the students may have used intentional concepts simply because they did not have an alternative way of conceptualizing the phenomena in question. There may not be a need to assume that functional or intentional explanations would represent very deep assumptions about the intentional nature of the phenomena in question. The students may not be intrinsically bound to functional or intentional explanations, but they did not have any well-articulated alternatives for talking about or conceptualizing the phenomena in question. I also noticed that certain kinds of research questions used in CSILE students' study projects tended to lead to functional considerations, although others tended to focus on physical processes behind the functioning of physical systems. Questions concerning a physical phenomenon's meaning to human beings or how a system works particularly seemed to encourage functional explanations.

The analysis indicated that CSILE students used empirical concepts for explanatory purposes. Thus, the functional role of certain concepts in their intuitive conceptions seemed to be analogous to explanatory scientific concepts (compare Harman, 1987). Although the starting point of CSILE students' intuitive explanations was empirically observable reality, these explanations appeared to go beyond mere empirical generalizations to make hypotheses about unobservable entities, hidden mechanisms and general principles (the nature of which may be empirical) which help to explain observed regularities. Thus it may be argued that some of the CSILE students' theories represented theoretical inferences. For example, when a student hypothesized that there must be another lens in the human eye in order for the brain to
see the picture of environment right-side up, this was not a mere empirical generalization. It was a theoretical hypothesis which helped the student to explain observed phenomena.

In the present investigation, the main difference between scientific and the CSILE students' inquiry is that theories were tested against scientific knowledge that the students found, instead of experimental test data. In other words, the CSILE students' inquiry was focused on Popper's (1972) world\(_3\) (objective knowledge) instead of world\(_1\) (physical reality); they were inquiring mostly in the hypothesis space, and only occasionally jumped to the testing space (see Klahr & Dunbar, 1988). The students did not have ways of confirming their theories empirically and their exploration in the testing space was limited to a few classroom experiments and examples. The basis of CSILE students' abductions was their own experiences and general knowledge of the physical, biological and social environment. Justification happened by showing that these theories were in accord with well-established scientific theories or were otherwise based on plausible assumptions. Evaluation of the plausibility of their theoretical constructions was based on their own empirical experiences and intersubjective agreement with the learning community. This was a natural consequence of the conceptual (see Laudan, 1977) as distinguished from the empirical nature of problems pursued by classroom A students, of their attempt to achieve some coherence between their intuitive conceptions and scientific explanations.
5.5 Engagement in Deepening Levels of Explanation in CSILE Student's Inquiry

The results of the study revealed that with the support of their teacher, the students in classroom A were capable of engaging in progressively deepening levels of explanation, and made considerable conceptual advancement in most of their projects. Therefore, the process of inquiry for students in classroom A during year 3 was assessed as clearly representing the first principal feature of scientific inquiry. Moreover, the advancement of the students' explanations appeared to be closely associated with progressive generation of new subordinate question, i.e., the second principal feature of scientific inquiry.

In physics, the students' conceptual advancement was analyzed as a transition from a functional frame of explanation to a physical frame and finally a theoretical frame. In biology, the advancement occurred by moving from descriptive or intentional explanations based on external functions, to explanation of biological processes in terms of cellular processes. Further, characteristic of their process of inquiry was engagement in deepening levels of explanation, i.e., systematic introduction of new explanatory concepts. The analysis indicated that the students were progressing in their inquiry even if they did not always succeed in solving their problems. Gravity and cosmology seemed to be particularly challenging domains of knowledge in which only a few of the students succeeded in moving towards a new conceptual coherency, and progress was relatively stronger in biology than in physics. In the inquiry-structure graphs, one notices that the students' advancement was not monotonic. In many
cases they came back to empirical conceptions of the problems being investigated. However, functional explanations were usually discarded after finding relevant explanatory scientific information. The iterative nature of CSILE students’ understanding resembles that of Miyake’s (1986) research subjects.

Examination of CSILE students’ conceptual advancement suggests that conceptual problems arising from an intentional attempt to genuinely understand explanatory scientific theories should not be underestimated. The analysis shows that whenever an understandable scientific theory was available the students generally were able, at least partially, to adopt the scientific approach and generate more articulated conceptions. However, when an understandable scientific explanation was not available, the students did not advance and many of them acknowledged the difficulty in question.

In their intentional process of genuinely making sense and explaining very complex problems, CSILE students produced many inadequate concepts or “misconceptions” (Driver & Easley, 1978). From the viewpoint of the dynamic theory of meaning, however, these conceptions should not be seen as an indication of failed learning processes, but, rather, as important aspect of knowledge-seeking inquiry. Karmiloff-Smith and Inhelder (1977, p. 306) have argued that “the construction of false theories or overgeneralization of limited ones are in effect productive processes” that reflect an attempt to find a unified theory. Without explicating and externalizing their intuitive theories, the students would not have realized that there was something wrong in their conceptions. If students are producing concepts that diverge from gen-
erally accepted scientific views, this may be regarded as an indication that they are engaged in an authentic cognitive effort to understanding the phenomena under investigation. If students had produced only correct conceptions, they might not have been engaged in intentional learning at all.

The progressive nature of mistaken hypotheses generated in this kind of epistemetic situation can be overlooked by considering only the end results of the inquiry, and forgetting the complex dynamic process of generating the conceptions in the first place. It appears that intentional learning leads to an increase in the number of surface inadequate or misconceptions rather than a decrease. On the basis of these considerations it can be argued that without explication and externalization of inadequate theories, there can hardly be conceptual advancement at all. However, Peirce's (1955; see also Rosenthal, 1990) dynamic theory of meaning implies that it is not meaningful to speak about inadequate theories or misconceptions as such without considering their relations to preceding and subsequent conceptions. Only when it is obvious that successive inadequate theories repeat each other, in spite of considerable cognitive effort, is there something to worry about.

Even though CSILE students succeeded well in improving their theories, they ended the period of investigation with a large number of inadequate theories. The problem is that scientific understanding cannot be gained by simply learning explanatory scientific concepts. The human mind does not function on the basis of individual concepts, but in terms of conceptual systems which are hierarchically organized knowledge structures and procedures for solving problems in the domain in
question (see Thagard, 1988). These conceptual systems are formed only through an extended process of applying the concepts in question to solve problems. It may not be possible to adopt "correct" scientific conceptions directly or immediately without conserving many sorts of wrong theories and misconceptions. The complexity of emerging knowledge structures guarantees that intuitive conceptions are never completely explicated or thoroughly overcome.

CSILE students were engaged in a process of knowledge-seeking inquiry focused on improving their theories of the phenomena being investigated. Intensive participation in the process appeared to facilitate understanding of the role of theories in scientific research. Further, the CSILE students' practices of inquiry seemed to help them to appreciate scientific, theoretical explanations: these explanations no longer constituted external knowledge structures to be memorized, but answered explanation-seeking research questions. The greater explanatory unification provided by advanced scientific theories appeared to make learning not only more efficient but also more meaningful.

As a whole, intuitive conceptions of CSILE students may be called progressive because they were progressing all the time through communicative attempts to explain the problems in question or confront scientific theories. Pea (1993) distinguished two approaches to conceptual change; the process view which emphasizes progressive changes in conceptions and the outcome view which focuses on the end results of the process of inquiry. According to the process view, an essential characteristic of conceptual change is that an agent's conceptions are continuously progressing rather
than remaining or achieving a fossilized state. In the present study, the former conception of conceptual progress was emphasized. Even though the students did not always succeeded in answering their research questions and achieving a constructive synthesis, their process of inquiry led to successive deepening of their explanations. The students in classroom A went beyond their initial conceptions, being able, systematically, to prefer explanatory scientific knowledge. Moreover, mediation of inquiry by the CSILE environment appeared to provide the students an opportunity to experience change in their own thinking (see Xiadong et al., 1996, p. 259); the progress in their own conceptions became salient to them.

5.6 Collaborative Effort to Advance Explanations

The students in classroom A 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 and, thereby, exhibited the third principal feature of scientific inquiry. This collaborative process of advancing explanations happened at several levels. CSILE's database as a public forum for sharing of knowledge provided ample opportunities for collaborative inquiry. The database provided each student with access to other students' productions. In the context of projects which were based on research questions common to all students, other students' notes were often used as a reference by a majority of the students; the notes referred to did not
represent a random selection, but almost always represented explanatory scientific theories and theoretical concepts. CSILE's database was always present providing access both to different practices of inquiry and ways of conceptualizing the objects of inquiry. Further, it seemed to mediate implicitly formed or spontaneously emerging norms of inquiry. Hence explicit references represented only the tip of the iceberg of the students' multiple and complex ways of influencing each other's processes of inquiry.

By sharing explanatory knowledge, the students in classroom A fostered development of each other's conceptual understanding. Their socially distributed process of inquiry was mediated by comments in which the students directly provided explanatory theories to each other. Fellow students' comments formed an important source of development of each student's own theories. Comments of high-achieving female students more often represented this type of communication than comments given by the male students. Moreover, the high-achieving students obviously seemed to have more developed cultural resources for independently searching and obtaining new scientific information, and they were ready to share emerging achievements with the other students. They appeared to have sophisticated skills of knowledge acquisition as well as metaknowledge concerning the relevance of explanatory knowledge. They sometimes picked up another student's unanswered research question and searched for information relevant to answering it. A scientific community shares new discoveries in an analogous way, and in this sense CSILE students' conceptual advancement was clearly a socially distributed process. The social distribution of ex-
planatory knowledge not only helped the low-achieving students' advancement, but also, in a very concrete way, the high-achieving students themselves. The students distributed their expertise spontaneously in the classroom so that each student tried to find his or her own area of expertise (compare Brown et al., 1993; Brown & Campione, 1996). This division of cognitive labor was built in the structure of small groups in which each student member was responsible for solving at least one principal question and had a right to expect support from the others.

The analysis showed that a substantial proportion of CSILE students' communicative ideas relevant for their conceptual advancement were neutral or non-confrontative. Further, their critical communicative ideas were usually very constructive in nature. The analysis did not support the contention that interaction between the subjects should be conflictual in order to foster conceptual advancement. When provided with pieces of explanatory scientific information, a student simply appeared to be grateful about pieces of information that helped to make sense of the problem being investigated or to gain some coherence in his or her view. The students did not appear initially to have any explanations, and they had only partial knowledge of the problems being investigated. Requests for explicating explanatory relations seemed to push the students to articulate their concepts more thoroughly, creating a kind of cognitive conflict. But in this case it was difficult to determine exactly between what beliefs the conflict existed. Interaction between the students seemed to create a general and unspecified cognitive or epistemic need to develop a more understandable and better explanation.
Salomon (1993) argued that there is a dynamic interaction between individual and distributed cognition. A study group’s advancement is dependent on that of an individual student, and an individual student needs the study group’s support in order to go ahead. Therefore, an important task for research on distributed cognition is to analyze how the participants’ cognitive competence progresses as a function of participation in collaborative inquiry. Although socially distributed resources may foster conceptual advancement, only an agent’s own cognitive efforts produce long-lasting changes in one’s conceptual system. In the present investigation, the process of generating one’s own research questions and intuitive explanations represented this kind of mental effort, and, arguably, facilitated deepening conceptual understanding. Examination of CSILE students’ inquiry suggests that a large majority of students used socially distributed resources provided by the database and communication to deepen their inquiry, not merely to replace their own cognitive efforts with other students’ efforts. Only a few students representing truncated inquiry appeared to directly adopt explanations generated by other students without articulating their own research questions or intuitive explanations (particularly in the Electricity project in which they were studying the same problems). In these cases, distributed resources of inquiry were used to avoid one’s own mental efforts: This led to an inverted pattern of inquiry in which explanations were sometimes provided before questions for which these were answers.
5.7 The Metacognitive Nature of CSILE Students' Peer Interaction

According to Grice's (1989) analysis of principles of cooperative communication, one should make his or her contribution as informative as required for the current purpose of exchange (Maxim of quantity). Obviously, many of CSILE students' written comments violated this maxim as they used referentially opaque language. Frequently, there was a mismatch between what the student meant and what they were saying in their writing (compare Olson, 1994). Some students tried unsuccessfully to use both text and context to reconstruct the author's meaning because not enough explicit information was provided. Cooperative written communication seems to require that the participants learn to see their own productions from the perspective of others and understand that what is transparent for themselves may not be understandable for other readers. This kind of process was seen in classroom A in the students' systematic requests to explicate referential or explanatory relations.

The analysis indicates that the requests for further elaboration of explanation, in turn, frequently fostered further articulation of concepts. In this sense the between-student interaction in classroom A appeared to be transformative in nature (see Pea, 1994) genuinely representing the third principal feature of scientific inquiry. The epistemic value of comments asking for explication is presumably based on the fact that weaknesses in one's conceptions are more easily available and salient to someone considering the problem from a different point of view. A request for explication of one's explanation means that an agent is forced to consider concepts not only from his or her own perspective, but also from the viewpoint of a "generalized other"
Hence, requests for explication apparently contained a metacognitive element: a note that appears to be completely transparent to the student writing it may be opaque in the eyes of others. The requests for explication tended to force a student both to develop a more articulated explanation and to become metacognitively more aware of differences between one's own and another student's "knowledge worlds" (see Hintikka, 1986). Further, the requests for explication of explanatory relations fostered conceptual advancement by pushing the student receiving comments to make his or her tacit background knowledge explicit and to do his or her research in depth.

Requests for explication are a part of metacognitive interaction, and were categorized as distributed regulation of inquiry. This category of communication was focused on regulating or monitoring the collaborative process of inquiry. These comments concerned not only requests of explanation but also research questions, methods and strategies of inquiry. In many comments, CSILE students asked each other to conduct their inquiry collaboratively, reflectively and in-depth. Comments in which the students requested each other to keep focus on their principal research question are good examples of distributed regulation of inquiry. This type of comment was needed when a student wanders around a topic without making progress. By participating in socially distributed process of knowledge-seeking inquiry, the CSILE students were taking some responsibility for controlling each other's process of inquiry, a task which has traditionally been carried out exclusively by the teacher (Bereiter & Scardamalia, 1987b).
Analysis of CSILE students' inquiry suggests that not only cognition but also metacognition can become socially distributed and provide qualitatively new resources for one's epistemic inquiry. Because human metacognitive resources are even more limited than our cognitive resources, it is understandable that cognitive activity aimed at solving complicated new problems may take so much cognitive resources that an agent temporarily loses sight of what he or she is doing. The cognitive value of peer interaction seems to be based on a process of overcoming limited metacognitive resources. In many cases, inadequate initial assumptions or inadequate 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 resources more effectively. This is also one of the main functions of scientific supervision. CSILE material suggests that even very young children are able to take a much larger social responsibility for their inquiry than has generally been assumed.

Peirce's Principle of Economy of Inquiry implies that an agent considers a belief to be true when inquiry "is carried sufficiently far", so far as it turns out to be "fruitful"; hence the pursuit of truth is pragmatically constrained (see Misak, 1991; Rescher, 1978; Delaney, 1993). Conceptual change research has showed that, in an educational context, inquiry is often not carried very far. Schoenfeld (1983) reported that if students did not find a satisfying answer to a math problem in five minutes, they considered the problem to be unsolvable. He argued that a person's interpretation of
the situation and his or her beliefs concerning what is useful in mathematics determined the cognitive resources likely to be mustered in a problem-solving situation. The epistemic value of CSILE students' socially distributed inquiry seems partially to be based on a process in which social communication changed what was interpreted to be "sufficiently far" by the students. Comments from others seemed to push a student to go further than he or she would have originally been ready to go. Social interaction established progressively changing criteria of acceptance of explanations and provided experiences of a gradually improving level of achievements; thus there was a process in which each student relied not only on individual but also on socially distributed cognitive resources. Standards of performance in classroom A gradually became more and more challenging. The evidence presented indicates that it is entirely possible for young students in the educational system to undertake some of the sophisticated knowledge-building inquiry approach of working scientists.

It is assumed that a successful process of knowledge-seeking inquiry may lead to *epistemological change*, i.e., the adoption of epistemological concepts under which an agent may become conscious of the ongoing process of inquiry. It is likely that concepts which do not refer to the objects of inquiry, but to the process of inquiry, facilitate development of the agent's metaconceptual or epistemological awareness of the process of inquiry (Olson, 1994). Therefore, it appears that epistemological concepts representing critical elements of knowledge-seeking inquiry facilitate metacognitive awareness of the process of the "activity of knowing" (Neisser, 1976). Without epistemological concepts such as "problem", "fact", "evidence", "theory" or "explana-
tion", it is very difficult to consciously be engaged in higher-level processes of knowledge-seeking inquiry. It may be hypothesized that consistent conceptualization of the process of inquiry by using these kinds of epistemological concepts leads to progressive epistemological changes in which the students' conception of knowledge, learning, and inquiry radically change. The process of inquiry for students in classroom A seemed to help them to gain metacognitive knowledge about the importance of problems, theories, and conceptual understanding within inquiry. Commitment of the whole learning community to improve their understanding appeared to facilitate development of each student's own metacognitive beliefs about importance of understanding (cf., Hatano & Inakagi, 1992).

These epistemological concepts were represented in the structure of students' notes in the form of CSILE's thinking types; the concepts were also used by the students in their texts. Hence, higher-order knowledge of the process of inquiry was represented both in the environment of cognitive activity and in the persons scaffolding development of the students' epistemological awareness of the process of inquiry (compare Perkins, 1993). This appeared to foster engagement in higher-level practices of inquiry as well as development of the students' epistemological awareness concerning the process of inquiry. The distributed, externalized resource of inquiry provided by certain thinking types was used systematically by the classroom A students, while classroom B students used thinking types only occasionally.

The present evidence indicates that the students in classroom A systematically expressed ownership of their productions by talking about "my (your) theory", "my
These aspects of inquiry seemed to provide the students a greater access to their own cognitive processes and facilitate a strong cognitive commitment to solve one's own research problems (see Brown & Palinscar, 1989; Brown & Campione, 1996). The importance of ownership is emphasized, among others, by Lampert (1995) and Savery and Duffy (1996). Following Scardamalia and Bereiter (1986; Bereiter & Scardamalia, 1987a; see also Geisler, 1994), it can be argued that the classroom A students were learning to function in parallel both in the content space and in the rhetorical space. There were some indications that CSILE students learned not to "take" (Olson, 1994) scientific information to represent infallible and ultimate truths, but rather as explanations constructed by scientists to answer certain problems connected with the natural, biological and social worlds. The evidence suggests that participation in collaborative knowledge-seeking inquiry in the CSILE environment fosters development of students' academic literacy (Geisler, 1994).

5.8 Implications

The results of the study indicate that it is entirely possible for children, with computer-support for collaborative learning and appropriate teacher guidance, to pursue processes of inquiry that exhibit the principal features of mature scientific inquiry. The study showed that in the self-organized process of inquiry guided by the students' own research question, students may not only engage in deepening levels of explanation but also use socially distributed cognitive resources to foster advancement of each other's inquiry. In this process, extended cognitive resources mediated by the CSILE environment provided valuable support. However, in order to facilitate partici-
pation in scientific practices of inquiry in education, constraints and conditions for successful application of computer-supported collaborative learning should be carefully examined.

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 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. This is, of course, a very difficult task; the culture of school learning cannot be expected to change immediately but presupposes a long process of exploring and testing of different kinds of cognitive and pedagogical practices.
Cognitive practices of inquiry, analogous to those in scientific research, examined in the present study can be facilitated in conventional classrooms or in classrooms relying on different kinds of computer support. However, one should take into consideration that different aspects of CSILE students’ inquiry are mutually dependent (compare Brown & Campione, 1996). It would not be possible, for example, to achieve substantially better results by encouraging elementary school students to generate their own research questions without simultaneously and more profoundly changing the classroom culture and the division of cognitive labor between the teacher and the students. Similar arguments can be applied to students’ own theories or independent searches for scientific information. The cognitive advantages of each these pedagogical practices are dependent on changes in the classroom culture as a whole and an emerging new economy of inquiry.

Results of both the present study as well as studies of Hakkarainen and Lipponen (1998) indicate that students need a great deal of pedagogical and epistemological guidance in order to participate in processes of inquiry representing the principal features of scientific inquiry. Students cannot be expected to discover these practices by themselves without guidance and expert modeling. A special effort should be made to provide epistemological guidance to the students; i.e., to make them aware of the cognitive value of question transformation, advantages of forming one’s own intuitive theories, as well as to help them to recognize the valuable kinds of explanatory scientific knowledge. However, implementation of scientific practices of inquiry at school is constrained by the fact that teachers themselves have seldom had personal
experience or become acquainted with the epistemology of scientific inquiry. From these considerations, it follows that more resources should be invested in teacher education, in giving preservice teachers personal experience as well as conceptual understanding of scientific practices of knowledge-seeking inquiry. Preservice teachers could be guided to participate in analyzing school children processes of inquiry mediated by CSILE or some other piece of groupware in collaboration with researchers. The same methods could be used to facilitate practicing teachers' professional development.

The analysis revealed that many CSILE students were spontaneously comparing their intuitive explanations with scientific explanations in a very sophisticated way. Often, the comparison between one's own intuitive and scientific conceptions led to rejection of the intuitive conception. The comparison seemed to help the students to become more aware of gaps in their knowledge and provided an important resource for their conceptual advancement. The specific Thinking Type (Comparing Theory with New Information) constructed by some students might profitably be used to elicit a more systematic comparison between intuitive and scientific theories. Through systematic comparison between intuitive and scientific conceptions one can also facilitate intentional and conscious use of metaconceptual criteria for evaluating explanations.

The students from classroom A participated in processes of inquiry representing the principal features of scientific inquiry and succeeded in making considerable conceptual progress. However, in order to facilitate practices of scientific inquiry in
education, it may be profitable to help students to constrain their intuitive theories through empirical testing of the theories. A remarkable achievement was to engage CSILE students in very fruitful working in the hypothesis space. In order to facilitate deeper conceptual understanding, however, a more systematic empirical testing of students' intuitive theories would be useful: not only to help them to constrain hypothesis space but also to scaffold metacognitive differentiation between theory and evidence (see Dunbar & Klahr, 1988; Kuhn, 1989, 1992, Olson, 1994). Further, by connecting CSILE students' inquiry more closely with empirical testing of theories, one would foster meaningful use of fact-seeking questions, not as an end in itself, but for assessing explanatory facts in relation to theories being constructed. This would help to achieve a balance between explanation-seeking and fact-seeking questions without giving up the epistemic goal of understanding, and provide further enrichment of the inquiry process.
REFERENCES


Mackor, A. R. (undated). The alleged autonomy of psychology and the social sciences. A manuscript.


conferences of the European Association for Research on Learning and Instruction, Athens, August 1997.


APPENDIX A1.
VARIABLES USED IN INQUIRY-STRUCTURE GRAPHS

The main elements of inquiry abstracted in the study were research problems (P), theories (T), information (I), and comments (C). These elements contained further subdivisions such as fact-seeking (PFA) versus explanation-seeking (PEX) questions, factual (IFA) and explanatory (IEX) information, functional (EFU), empirical-physical (TEP) and theoretical-physical (TTP) theories and providing information (CPI) or explanation (CPE) and requesting information (CRI) or explanation (CRE).

Inquiry-structure graphs were applied to analyze CSILE students' process inquiry. The elements of inquiry were

(1) Problems (Pn)

(2) Subordinate problem (Ps)

(3) Factual Information (IFA)

(4) Empirical-Physical (EPE) and

(5) Theoretical Physical (TPE).

(6) Comment requesting explication (Cre)

(7) Comment providing information (Cpi)

(8) Comment providing explanation (Cpe)
Appendix A2.
An Example of Truncated Inquiry
Appendix A3.
An Example of Extensive Inquiry

\[ P_1 \xrightarrow{Tep} \xrightarrow{Itp} \xrightarrow{Ps} \xrightarrow{Ttp} \xrightarrow{Cre} \]
\[ P_2 \xrightarrow{Tfu} \xrightarrow{Iep} \xrightarrow{Cre} \]
\[ P_3 \xrightarrow{Tep} \xrightarrow{Itp} \]
\[ P_4 \xrightarrow{Tep} \xrightarrow{Itp} \xrightarrow{Cre} \]
\[ P_5 \xrightarrow{Tfu} \xrightarrow{Itp} \xrightarrow{Ctp} \]
\[ P_6 \xrightarrow{Tep} \xrightarrow{Ps} \]
\[ P_7 \xrightarrow{Tep} \xrightarrow{Ps} \xrightarrow{Cre} \]
\[ P_8 \xrightarrow{Tep} \xrightarrow{Tfu} \xrightarrow{Ps} \xrightarrow{Iep} \xrightarrow{Cre} \]
Appendix A4.
An Example of Intensive Inquiry
APPENDIX B1.
SCALES FOR EVALUATION OF CSILE STUDENTS' PROCESSES OF INQUIRY

<table>
<thead>
<tr>
<th>EXPERT NUMBER</th>
<th>CASE NUMBER</th>
<th>LIKELIHOOD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1 = highly unlikely</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 = unlikely</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 = likely</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 = highly likely</td>
</tr>
</tbody>
</table>

Mark the correct alternative for each scale by O

1. COGNITIVE (EPISTEMIC) VALUE OF RESEARCH QUESTIONS

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research questions generated by students were not likely to lead to progress of their conceptual understanding</td>
<td>Research questions generated by students were likely to lead to progress of their conceptual understanding</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. EXPLANATORY VALUE OF INTUITIVE CONCEPTIONS

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intuitive conceptions (MT) constructed by students represented fragmented pieces of knowledge and did not have any explanatory value</td>
<td>Intuitive conceptions (MT) constructed by students represented attempts to generate explanations for the problems being investigated and had explanatory value</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. NATURE OF THE PROCESS OF INQUIRY

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students' process of inquiry was not progressive in nature, and did not lead to advancement of their conceptual understanding</td>
<td>Students' process of inquiry was progressive in nature leading to advancement of their conceptual understanding</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. EVALUATION OF CONCEPTUAL CHANGE

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students' initial and final conceptions did not differ conceptually from each other suggesting that the process did not lead to conceptual change</td>
<td>Students' initial and final conceptions differed conceptually from each other suggesting that the process led to conceptual change</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. COGNITIVE (EPISTEMIC) VALUE OF PEER-INTERACTION

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interaction between students was not likely to foster conceptual advancement, and did not have any special cognitive value</td>
<td>Interaction between students was likely to foster conceptual advancement having considerable cognitive value</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX B2.
INSTRUCTIONS FOR EXPERT EVALUATION OF CSILE STUDENTS’ PROCESS OF INQUIRY

As an expert in philosophy of science you are asked to evaluate 10-year-old students' process of inquiry in the Computer Supported Intentional Learning Environments, CSILE. CSILE is a hypermedia system based on a local-area network (used within classroom) designed to foster active production of knowledge. A central aspect of CSILE is a public database completely constructed by the students themselves. Each student's productions are public by default in order to foster interaction between students and sharing of conceptual advancement. You will be given written productions taken from the system's database, and asked to estimate whether the examples represent processes that are analogical with the progressive nature of scientific inquiry.

The students were using the system by carrying out 4-6 week projects in physics and biology. They did not receive any formal instruction before studying the problems in question. The students themselves were responsible for generating their research questions and finding relevant scientific information. They were writing entries (notes) individually to the database while working in small (3-4 students) groups for solving the problems being investigated. The students organized their inquiry by labeling their notes according to the following categories:

- P: Problem
- INTU: I Need To Understand (a new research question)
- MT: My Theory
- NI: New (scientific) Information
- C: Comment

The process of inquiry was guided by research questions which the students themselves constructed. While working with a project, the students conducted several cycles of inquiry so that after generating a research question, construction of a plausible explanation, and obtaining scientific information, they generated new questions, new theories (by incorporating new information to their theories) and searched new information.

In the following you will be given several cases of CSILE students' processes of inquiry. Each case contains a series of notes produced by a small group of students. I would like to ask you to evaluate the nature of the students' process of inquiry on the basis of the conceptual content of the productions. Your task is to evaluate whether conceptual advancement took place in the group as a whole. After intro-
ducing yourself to each case, you are going to be asked to evaluate the quality of stu-
dents' process of inquiry by using corresponding numerical scales (scores 1-4). Here, I would like to ask you to evaluate whether:

1) research questions generated by the students were likely to lead to progress of their conceptual understanding;

2) students' intuitive conceptions (My Theory) had enough explanatory value to be categorized as explanations;

3) students' process of inquiry was progressive in nature providing the students with gradually deepening conceptual understanding of the problems in question;

4) students succeeded in solving of their research questions and were likely to make conceptual change as the result of their inquiry;

5) the nature of interaction between students fostered advancement of their conceptual understanding.

In addition to using the scales, I would like to ask you to summarize your evaluation in your own words.

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.
APPENDIX C1.
CASE 1: HOW DOES THE BRAIN FUNCTION?

P: What kind of cells are there in the brain, and how do they differ from the other cells in the body? (RO)

MT: I think that the cells in the brain are more developed than the cells in the rest of the body. I also think that there are a lot of nerve cells in the brain. (RO)

MT: My theory is that the cells in the brain are bigger than the cells in the rest of the human body. (SM)

MT: My theory is the same as Rebecca's except, I also think that the cells in the brain are more developed in the way, that they would have more of one kind of organelle and less of another kind of organelle. (JH)

NI: I found out what kind of cells are in the brain. The brain is made of neuron cells and glial, or structure cells. The neuron cells are in the parts of the brain that sense things and the glial, or structure cells, hold the brain together. (RO)

Dear RS, SM & JH, I noticed your proposition 'cells of brain'. What I don't understand is why you did not make it 'cells of the brain'. If you can't find a good predicate then just make one yourself, it is just like making your own keyword. If the case is that you didn't know how to then I suggest changing it so it makes more sense.

I know that the brain is completely made of nerve cells and is very soft because it has no connective tissue. The brain is also part of the Central Nervous System. MS

Dear RO, I was wondering in your MT: for the problem, "What kind of cells are there in the brain, and how do they differ from the other cells in the body?" When you say that you think the brain cells are more developed do you mean that they are cells that are completed in knowledge and are more complicated than most cells? RD

INTU: How do the glial cells hold the brain together? (RO)

MT: My theory of how the glial cells hold the brain together is that, they might be the bigger cells in the brain, that Sonia talked about. They might work in twos, one to cradle the neuron cells and the other one to sit on top of it to gently squish it, so it wouldn't move around. The glial cells themselves are stuck to the outer covering of the brain. (See chart entitled "Different Cells in Brain") (JH)

MT: I think that glial cells have long appendages that look like arms, which hold the neuron cells in place. I have made a chart called glial cells that explains my theory. (RO)

INTU: I need to understand what the glial cells look like before I can understand how glial cells hold the brain together. (JH)

MT: I think that the glial cells are very thin and very small. I think that they form a ball around a neuron cell by joining together with other glial cells. See chart entitled "Glial Cells Connecting". (SM)

NI: I found out what glial cells look like and how they work. Glial cells are like a protective covering for the nerve cells. They insulate and serve as packing material, holding the neuron cells in place. Glial cells are sensitive to electricity so they act like an amplifiers strengthening the neuron's electric pulses. (RO)

INTU: I need to understand what neuron cells look like and how neuron cells work and Rebecca, Sonia and I are trying to find that out on another note by me with the keyword neuron cells. (JH)
C: 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? (JW)

P: What do neuron cells look like and how do they work? (JH)

MT: I think that neuron cells look like glial cells; they have long arm-like tentacles that hold the cell in place. If you don't understand then look at my chart called glial cells. (RO)

MT: My theory is much like Rebecca's. I also think that neuron cells look like glial cells except I think that glial cells might be a little bit bigger than the neuron cell. (SM)

INTU: I need to understand how many neuron cells are in the brain before I can understand how neuron cells work. (JH)

NI: I found some information that might be helpful. There are around 15 billion cells in your brain, and there are 10,000,000,000 (ten billion) neuron cells in the average brain. (SM)

NI: I found out what a neuron cell looks like. A neuron cell has long branch-like fibres that come out of either end. At one end of the cell there is a long fibre called an axon. The axon emits electric pulses (see my chart called Neuron Cells). On the other end of the cell is a group of fibres that attach one cell to another. They also receive messages in the form of electric pulses. When a cell receives a series of electric pulses it decides whether to pass the message on or to stop the message. (RO)

INTU: How do neuron cells know whether to pass on information or to stop the message? (RO)

MT: My theory is that one main neuron cell would sort out the information and decide which information it would pass on and where it would pass it on, for example if the brain receives information about science then the main neuron cell would pass it on to the cell that stores science facts. (See chart entitled Passing Information.) (JH)

INTU: I need to understand how the brain stores information before I can completely understand the answer to Rebecca's INTU above and Sonia, Rebecca and I are trying to find that out on another note by Sonia with the keywords brain and stored information. (JH)

P: How does the brain store information? (SM)

MT: My theory is that for example when you learn how to add 2+2=4 your brain catches on to it and stores it in a compartment and that makes you remember the concept. (SM)

MT: My theory is that there would be a certain part in the brain that would take care of the storing of information like, for example the math tables, and that part would have in it mostly neuron cells. (JH)

MT: I think that when you learn something new your brain stores the new information in electric pulses, which are stored in a neuron cell. When someone asks you the information, the brain senses that someone has asked you something, and sends out an electric pulse to all cells that store information. The cell that has the wanted information sends the information out in electric pulses and the brain tells the mouth to say the information. (RO)

NI: The brain stores information from the past. That is why you can only remember the past. The sensory register is for sorting information. The sensory register collects bits of information, but only holds it for a second, then transfers it to the encoder filters. The encoder orders the information and then sends the information to a short-term memory. Only some of the information reaches the long-term memory, the rest is forgotten but can be remembered in the short-term memory by going over the information again and again. The most important information is taken to a long-term memory, where the newly learned information and concepts stay all jumbled up. (SM)
INTU: How does the long-term memory store the information? (JH)

NI: The long-term memory stores the information by thinking of the past over and over again and by finally keeping it in your brain for whenever you want it. For example the address of a house in the past or your times tables. (SM)

C: Perhaps you could try to find out what a stroke is and how it affects the brain. The findings might give you some clues as to how the brain stores information. (JW)

NI: I found out what a stroke is, how it affects the brain and what are the 3 most common causes for a stroke. A stroke is also known as a cerebrovascular (cerebro for brain and vascular for blood) accident. A stroke involves damage to the brain through impaired blood supply or clots pressing against different parts of the brain. Stroke victims are generally elderly with a degenerated blood supply, but children and young adults are sometimes subject to strokes especially if they were born with diabetes or an inner blood vessel deficiency. Stroke victims often, after their stroke, have paralysis in some of their limbs as well as loss of speech, hearing or sight. The 3 most common causes for a stroke are cerebral thrombosis, cerebral embolism and cerebral hemorrhage. Cerebral thrombosis occurs when a clot or thrombus plugs one of the blood vessels that carry blood to the neck and head, such as a carotid artery, or blocks one of the arteries in the brain itself which then...

Cerebral embolism occurs when one of the arteries in the brain is blocked by a clot traveling from another part of the brain and so causes the same damage as cerebral embolism.

The third main type of stroke, cerebral hemorrhage, is like the bursting of a pipe. This type of stroke occurs when a defective artery in the brain, usually weakened and made inelastic by a combination of hypertension and atherosclerosis, bursts and tears, leaking blood into the brain which forms a clot. Now, not only has the part of the brain that before had been fed by this artery deprived of blood but the clot that forms often pushes against other arteries in the brain or against part of the brain itself.

All of those ways cut off blood supply to some part of the brain and without blood the brain cannot survive. (JH)

Dear SM, JH and RO, I think I can help you learn what a stroke is because my grandfather had a stroke and I learned some things about a stroke. First of all the left side of the brain controls the right side of your body and vice-versa. So when you have a stroke on your left side then the right side of the brain is affected and again vice-versa. When you have a stroke on the right side of your body and the left side of the brain is affected, your speech is affected and sometimes badly so that you never can speak again. If you have a stroke on the left side of your body and the right side of the brain is affected then you will start to have spatial problems. That means you will have trouble judging distances. I'm not exactly sure what causes strokes but I will check about that. -AR

P: What are the different parts of the brain and what are they used for? (RO)

MT: I think that there is a part in your brain for everything you do, for example thinking, moving and feeling. There are also parts that connect the parts together so that different parts of the brain can communicate. Also there would be a certain part that would coordinate the whole brain. I have made a chart that explains my theory called "Parts Of The Brain". (RO)

MT: I think that there are a lot of parts in the brain. Just like Rebecca said one for feeling, one for thinking and one for moving. I also think that we have parts in the brain for listening and for speaking. (SM)

MT: I think, as RO said before, that there are different parts of the brain for thinking, moving and feeling, but I think that there are instead three main parts of the brain, one for thinking, one for moving and one for feeling and in each of these parts are other sections that control specific parts of the brain; for example in the moving section of the brain, there would be certain sections for moving the arms and certain sections for moving the legs. (JH)
RO, I agree on your theory about the different parts of the brain; one for touching, one for hearing etc., and I think you should tell the location of the different places, and/or explain what sorts of things go on, to do these actions. RS.

C: I found out some information that might be helpful to you, Rebecca. I found out that what happens when a part of the brain is paralyzed by a stroke. What happens is this; after the stroke is past, since the part of the brain that was damaged by the stroke cannot do what it used to do, doctors train other parts of the brain to control the part of the body that before was controlled by the now damaged part of the brain. (JH)

NI: I found out a little about the different parts in the brain. The brain is divided into three parts, the forebrain, midbrain, and the hindbrain. The forebrain is located toward the front top of the brain. The parts in the forebrain are the cerebrum and the diencephalon. The hindbrain is located towards the back base of the skull. The parts in the hindbrain are the medulla oblongata and the cerebellum. The midbrain is in between the diencephalon in the forebrain and the medulla oblongata in the hindbrain. It includes the oblongata and part of the brain stem.

The cerebrum takes up 85% of the brain's weight. It has two hemispheres (right and left). Each hemisphere is just like the other one. They are connected by fibers called the corpus callosum. Each hemisphere is divided into five lobes and 4 of them are named for the bones that cover them. They are the frontal, temporal, parietal, and occipital lobes. The limbic lobe is the lobe that is in the middle of each hemisphere where the hemispheres meet. It is the only lobe that is not named after the bone that covers it. The hemispheres are separated by the central fissure and the lateral fissure. The sensorimotor is on each side of the central fissure. It is in charge of sensing for the body.

The largest part of the cerebrum is for memory, speech and thought. The cerebellum is the body's coordinator. Without it you would not be able to do such simple things as walking in a straight line or scratching your nose. The cerebellum can be trained to do difficult movements by repeating them again and again until they become as simple as clapping your hands. When you make a complex movement (let's say a dive) your cerebellum is getting messages from all over your body including your cerebrum. The cerebrum tells your cerebellum that you are about to dive and the cerebellum tells your cerebrum how you're going to do it. The cerebellum uses its many different parts during the dive to control different parts of the body. (RO)

INTU: (....) Rebecca said that the cerebellum controls the different parts of the body with its different parts. I don't understand how it uses these different parts and what those different parts are. (JH)

NI: The Anterior and the posterior ends are for giving the cerebellum a view of the body. VOR (vestibuloocular reflex) is a part of the cerebellum that focuses your eyes for you. (SM)
APPENDIX C2.
CASE 2: HOW DOES THE EYE FUNCTION

P: Where is the eye's control panel located. (AO)

P: How does the eye function? (AM)

MT: I think that there is almost a kind of filter behind the eye where the picture goes through transforming it into waves which the brain understands. (MS)

C: Your theory sounds as if you are sure of it and I think that you should make it sound like a theory. (AM)

INTU: How the eye sends pictures to the brain. (AM)

NI: I have gotten some new information on the eye. I have read that every object gives or reflects light. The eye reads that reflection and sends its message to the brain where it can be identified. (AO)

NI: There is a black panel behind the eye which absorbs the light and makes sure none can get out. (MS)

NI: An object that the eye is focusing on gives a ray of light and goes by the cornea, the aqueous humor, the pupil, the lens, the vitreous humor and then it reaches the retina. When the light hits the cells of the retina they react the nerve cells and then the optic nerve brings the message to the visual cortex hitting part of the brain which reads the message. (AM)

NI: Everything the eye sees is really light reflecting off the object. (MS)

INTU: How the parts of the eye help get to the message to the brain. (AM)

NI: When an object gives the light it hits the curved surface of the cornea. After leaving it, the iris increases or decreases the pupil and it goes by. If there is a strong source of light the pupil will decrease to shut off light that is not needed. After the light rays pass the pupil it passes the curved lens then it passes the vitreous humor and hits the retina where the light rays meet. If the light rays meet on the retina the image is clear and if it goes inside or in front, the image will be blurred. Then the light passes the retina and goes through the nerve cells to get to the rods and cones. The cones are in about the center of the retina, they also do most of the seeing during the day. They give clear images with a lot of detail. The image is brought by the optic nerve and is read by the

Dear AM. I think you should change your problem to: How does the eye function? Your note had a lot of information but MS's theory sounded so sure of himself. He should change it so it would sound more like a theory.

Dear AM, AO and MS, I have a theory on your problem: Why does the eye turn everything upside down. Last year I did a project on the camera and I found out that a camera sees the picture and takes it in. Then it has 2 mirrors positioned so that whenever a picture comes into the camera, the mirrors fold out and the picture is reflected onto the film upside down. The film is then wound and the next picture is imprinted on the next piece of film again upside down. So, my theory is the brain does the same thing and that is why pictures inside the brain are always upside down. (See my chart entitled The Camera) - JH

Dear MS, Your first MT: is puzzling to me. In your theory you say that there is a filter behind the eye. What I am not clear on is the fact that you are saying the filter changes what the picture is into waves for the brain to receive. Do you mean that everything we see is little waves of different colours and shades? I don't agree with what you are saying. It is making it sound like the eye is not an organ, it sounds like the eye is just a protector with a filter behind it. RS

P: How is the eye similar to a camera? (MS)
MT: I think the eye flashes a picture of the object to the brain where it is either identified or not identified like a camera where the picture is given to the owner and identified or not. I think that the shutter is like the eyelid, and the aperture is like the pupil. (MS)

MT: I think that when the eye looks at something the eye sends it to the brain almost instantly and it flashes it to the brain like the camera flashes it onto a camera film. (AM)

NI: The human eye is 100 times more sensitive than the most sensitive camera film. (MS)

MT: An eye is like a camera because both need light to read what the message is, and they both have to turn a message upside down before it is a statement. (AO)

C: Martin has the physical reasons on why an eye is like a camera but he doesn’t have the entire reasons which are the most important ones. (AO)

NI: An eye acts much like a T.V. camera as they both change light to impulses which aren’t light. The eye changes reflected light into nerve impulses which make muscles move or glands flow. The T.V. impulses make a T.V. set glow with a picture. (MS)

NI: A camera has a lens and so does the eye. It also is similar because the eye sends pictures to the brain and the camera sends pictures to the film. (AM)

NI: Both the eye and the camera send the picture upside down. With the eye, the optic nerve sends impulses to a special area of the brain called the optic center. This is where you "see" an object in the sense of recognizing and reacting to what your eyes are seeing. The brain has to learn by experience to analyze the message it receives from the eye correctly, as the lens system of the eye, (like that of the camera), sends its light pattern upside-down. The brain has to learn that the pulses sent from the top of the retina represent the bottom of the object sighted and vice versa. (MS).

NI: The camera's adjustable diaphragm is like the iris of the eye because it controls the light that is let in. (AM)

P: I have researched the eye and the camera and found they are very similar in many ways. I have written this note because I found that both the eye and the camera see a picture upside down. I would like to know why that happens and how.

MT: 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. I did not understand why the eye does this movement but I think it is because in order to send a message to the brain it has to reach the retina so the eye's message must meet there and continue moving. (AO)

NI: The eye sees a picture upside down because if it made a direct look at something you would only be able to see very little. So the eye sees some thing in large and turns it. It is little while it is still upside down and then is converted right side up and brought to the brain. (AO)

C: You have written a good theory but you must include more about how the lens turns the picture right side up. (AM)

MT: 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. (MS)

C: I think that you should find out more information on your theory and try to find out how the lens work. (AM)

MT: 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. (AM)

C: AM thanks for asking for more work. As you can see I have completed my new information. You are right and I will do some research on the lens, but I don’t think it has anything to do with this note.
P: How does the message that the eye is sending get to the brain? (MS)

MT: I think that there are another set of nerves different then the other nerves in your body which transmit the message from the eye to the brain. The reason for this different set of nerves is that the normal nerves are almost not strong enough for the rays. (MS)

MT: I think that the Eye can send messages to the brain by a small organ that is attached to the brain and the Eyeball which is like a circuit that brings the message from the Eyeball to the brain in a strange wave. (AM)

NI: The optic nerve sends impulses to a special area of the brain called the optic center. This is where you "see" an object the sense of recognizing and reacting to what your eyes are seeing. The brain has to learn by experience to analyze the messages it receives from the eye correctly because the lens system of the eye like that of the camera sends its light pattern upside down. The brain has to learn that the pulses sent from the upper part of the Retina represent the lower part of the object sighted and vice versa. (MS)
APPENDIX C3.
CASE 3: COSMOLOGY

P: What is the universe made of? (JD)

MT: I think that the universe is made of a lot of gases floating around. (JD)

MT: I think that the universe is made of gas and rocks. Some of the rocks are planets. Inside the universe there are stars, planets and asteroids. (AR)

MT: I think that the universe is made up of planets which are big rocks, and the planets are made up of billions and billions of tiny rocks. (ES)

NI/INTU: I know that in the universe there are planets, stars and asteroids plus lots of other rocks and gases. That means in the universe there are things that I just mentioned but does that mean the universe is made of them? (AR)

MT: I think that the universe is made out of space. What I mean by the universe is made out of space is that there is one thing lets say a star and there is another star on the opposite side that is far away and in between those two stars is space. In the universe there is a lot of emptiness. (JD)

MT: In the universe there are nine planets their names are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto. The universe has lots of galaxies and stars and all different things in the universe. (JD)

C: JD, you said that in the universe there are nine planets. But really you are talking about our solar system. There might be planets in other galaxies that we just don’t know about. (AR)

C: AR, That could be true but we have to find out where the other planets could be. (JD)

NI: I found out that the solar system was born 4.6 billion years ago. I also found out that the solar system was created from a contracting molecular cloud of dust and gas. (JD)

INTU: I need to understand what the universe is made out of besides what I wrote on my last theory. (JD)

MT: I think that, like JD, the universe is made of space but it is also made of gases. But in the universe there are planets, rocks and other substances. (AR)

C: AR, I agree with your theory. I wrote that I thought that the universe was made out of gases on my first theory. (JD)

MT/NI: The milky way is our galaxy and the earth is on the edge of the milky way. I think that the planet Saturn has gases around it. The ring is made of gas. The earth is just the right amount of distance away from the sun for it to have living things on it. All the other planets are too close or too far away to have something living on it. Nobody has really been on any of the planets. A little machine that can take pictures of the planets has been on the nine plane

INTU: If the Earth is round then why don’t people or things fall off the bottom since it is the opposite of the right side up.

NI/MT: I heard that someone thought that the Earth was flat until they saw a bump on the moon and they saw a shadow so they they knew from that that the universe was round. (JD)

NI: I found out that the hottest planet is Venus even though it is not the closest to the sun. The coldest planet is Pluto, since Uranus is pretty close to Pluto they are about the same temperature. (JD)

INTFO: I need to find out how hot Venus is and how cold Pluto is. (JD)

NI: I found out that the little machine is called the Voyager. (JD)
WHL: I have learned a lot on this note. One thing I have learned is, what planet is the hottest, and what planet is the coldest. I have also learned that the universe is made of galaxies and gases and planets and stars and moons. Some things I could know more about but I couldn't find things on them. (JD)

Dear JD, I think that your note is good, but you might want to research a bit on what the universe started out with, to find out what it's made of now. You could also draw some charts for theories you have.

JD, think in your note "What is the universe made of?" your new informations do not tell us what the universe is made of. It tells us what is in the universe. And what does WICTQ and WIFTI mean?

P: How has the universe changed and how will it change? (AR)

MT: I think that the universe has changed a lot. For instance our own world has become a lot more advanced in medicines and lots of other things. We have also found out a lot about space. We discovered the planet Pluto and I'm sure lots of stars and constellations. I think that in the future our world and other planets might find life on different planets and be able to communicate with them. (AR)

MT: I think that there will be more cures for diseases, and everything will be a lot more advanced. (ES)

MT: I think that the future will be a lot more advanced and that we might be able to communicate with living things on different planets but I think that the planets might get ruined by then. (JD)

MT: I think that first of all the galaxy has gained stars and it will gain more through the future. (ES)

INTU: How long it will take before the universe is almost totally changed, and will it change a lot. (ES)

MT: I think if the universe changes a lot, it will take hundreds, maybe thousands of years. (ES)

MT: I don't think that universe will reach some point where it is totally changed. I think the universe will always be changing and will never stop changing. (AR)

NI: Around the turn of the century people and scientists thought that the universe never changed and our galaxy was the universe because scientists couldn't see beyond the Milky Way. About 75 years later we have developed better telescopes so we can see farther out into space and people realized that there was more to the universe than our galaxy. Through the better telescopes we could see stars dying and being created, galaxies being formed and lots of other things dying and being created. This showed that the universe never stayed the same, it was always expanding and changing. (AR)

NI: I found out from JA's book that one change in the universe that is always happening is when a star dies. This is how it happens. Inside a star it is very hot because of nuclear changes. As the star becomes hotter the star expands and finally explodes. Extremely large stars that explode are called Supernovas. Supernovas spread the exploded parts all out over space. Scientists think when the Big Bang happened (if it did) only simple atoms were formed by the explosion. But when Supernovas explode they form more complicated atoms. (AR)

INTFO: How new galaxies are formed because that is a big change in the universe. (AR)

NI: Certain cameras have detected gas and dust around the star, Beta Pictoris. Scientists are asking the question, could

MT: I think that galaxies are formed just like the Big Bang Theory tells, only with a smaller bang. So all bits of matter at surround a certain spot are pulled tightly together and then an
explosion occurs and the bits explode out and form the planets and stars of the new galaxy. {AR}

WIHL: I have learned that the universe is always changing and will probably never stop changing. There are lots of changes happening in the universe all the time. For instance, when a star dies and is created and when a galaxy dies or is created. Also own Earth's knowledge of the universe has changed, we have developed new devices that can help us see farther into space to see the stars and galaxies dying and being created. To see all the changes that our happening in the universe. {AR}

Dear AR: I suppose your theory could be possible but astronomers think that a tenth planet was supposed to form between Jupiter and Mars but Jupiter turned out to be too big, so the material that should have formed the tenth planet just remained between Jupiter and Mars. From: NI

Dear AR, ES 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? {NI}. AR, In your comment you said I was only talking about the Earth, but what I meant was that out of all the planets in the universe only the Earth will undergo a drastic change.

PROBLEM: How was the universe formed? {ES}

MT: I think that millions and millions of years ago there was just one gigantic piece of land, and there was an explosion. The pieces went flying everywhere and each section that stuck together was called a planet and some are bigger than others because more pieces or less pieces got stuck together. {ES}

MT: I think that the universe started out as an extremely small bit of gas, this gas grew bigger and finally exploded. After the gas exploded it became a bunch of small bits of gas. Each bit of gas was VERY hot from the explosion and when it cooled down it became solid. {AR}

MT: I think that the universe was formed billions and billions of years ago. The universe was formed first by land on earth and the planets and galaxies came and a lot of other things joined in to the universe. {JD}

NI: There are lots of theories on how the universe was formed and how it expanded. One of them is known as the Big Bang Theory. For the Big Bang Theory to work all parts of the universe had to be pulled tightly together with a temperature of over a trillion degrees. All of the universe had to be mixed together with the two gases hydrogen and helium. When the fireball exploded it shot out substances at a very high speed and in all directions. Billions of years later all the bits and pieces from the explosion began to come together to make galaxies of stars. Our galaxy, the Milky Way, at the age of 15 billion years is still producing new stars from the explosion. {AR}

INTU: How scientists came up with this theory? {AR}

MT: I think that scientists were looking for something totally different and by accident came upon some information which led them to create and believe the Big Bang Theory. {AR}

MT: I think that scientists did a lot of research and thought that this theory made the most sense out of all the theories that could have been possible. {ES}

NI: I found out that two scientists were trying to listen for sounds of the universe. They were trying to get rid of all the interference so they could get even the quietest sounds. They were able to get a lot of Earth's interference but the heat from the machine they were using caused a lot of interference. The scientists got rid of it by cooling their machine with liquid helium to -269 degrees, which is only 4 degrees above the temperature where all movement in atoms
and molecules stop. They still found a small noise but it was spread evenly across the sky. The noise the scientists heard was a flash of the beginning of the universe.

MT: I think what they heard was a tiny explosion. This might have led them to believe that a gigantic explosion was the creation of the universe. {AR}

MT: I think that the noise that they heard was the beginning of the new universe. {ES}

NI: Another theory on how the universe started and expanded is called the Repeated Big Bang Theory. The Big Bang Theory says that after the explosion the universe is expanding faster than the gravitational pull. Then just keeps on expanding. The Repeated Big Bang Theory states that the universe is not expanding faster than the gravitational pull. When the gravitational pull becomes stronger, the universe is pulled back in where the first explosion happened. Then the explosion happens once again and everything is repeated. The Steady-State Theory states that the universe has no beginning and no end. Galaxies are just formed and by force the universe expands. {AR}

WIHL: I learned about the big bang theory and how it works. In order for this theory to work all of the universe had to be pulled together tightly with a temperature of over a trillion degrees. All of the universe must have been mixed together with two gases hydrogen and helium. When the fireball exploded it shot out substances at a very high speed in all directions. Billions of years later the pieces formed galaxies of stars. {ES}

Dear ES, I think that you have a good problem and good theories but you should put more new informations on your note because AR seems to be putting on all the information. I also think that JD should comment on your note more. It also seems that AR has been doing the whole last part of your note.
APPENDIX C4.
CASE 4: WHAT IS GRAVITY

P: What is gravity? (SM)

MT: Gravity is a kind of force. If we didn't have gravity we would be floating in the air. If we didn't have gravity we probably could not survive. (S.M)

NI: Throw a ball in the air. It goes up then it goes down. Then throw the ball in front of you. The ball stays in the air for a second. Then comes back down. With your arm sideways, hold the ball in your hand. Then let go of the ball. And it will fall. It will always fall to the ground because of gravity. (SM)

Dear SM, I agree with your theory and I disagree with your New Information because if you throw a ball in front of you and one just going up I think there is know difference because there the same weight or are they the same weight? (JD)

INTU: What gravity and oxygen have in common. (SM)

NI: Without gravity you could not survive and without oxygen you could not survive. Because without gravity your limp body would be floating around in space. And without oxygen you would not be able to breathe. (SM)

C: I think that your theory on gravity is right because it's true that without gravity we would not survive because we would float out of our atmosphere and would not be able to breathe. (AR)

MT: My Theory is that Gravity is a force that keeps all objects and people/animals in their atmosphere so the people /animals can breathe and not float off their planet and so the objects do not float off their planet. (AR)

C: I found some information which may be helpful to you. The gravitational pull of Earth makes objects fall to the ground unless they are supported. (AR)

C: In your INTU(above) you said you need to understand what gravity and oxygen have in common. And in your NI(above) 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. (AR)

NI: Gravity and oxygen are both related to air. (SM)

Dear SM: I think your note about gravity is very good and interesting! like your INTU part the best, I've never knew that gravity and oxygen have in common before. Now you brought it up. But I hope you'll write more for your problem What is gravity

C: In your NI(above) you explained better what gravity and oxygen have in common. (AR)

NI: I found that oxygen is part of air and that air is related to gravity. Here is how gravity is related to air. If you throw a piece of paper in the air it will come floating down because of air resistance. (SM)

P: How we use Gravity? (AR)

MT: My Theory is that we use Gravity to keep us in our atmosphere where we can breath and stay alive. We also use it to keep all the things on our Earth on the ground and the planets in their orbits. (AR)

MT: My theory is that we use gravity to keep us in our atmosphere where we can breath. We also use gravity to keep our planets in orbit. (SM)

INTU: Why we need Gravity (AR)

MT: My theory is that we need gravity to keep the planets in orbit and to be able to stay in our atmosphere. (SM)
MT: We need Gravity to live because without it we wouldn't be able to breathe because we would float out of our atmosphere.

NI: We need Gravity to stay alive because without it we would float right out of our atmosphere and die because we would not be able to breath in the new atmosphere.

INTU: How we use gravity

NI: We use gravity to keep all the things in are Earth on the Earth. We also use it to keep all the planets in their orbits so they don't crash into each other.

P: How does Gravity work? (AR)

MT: I think Gravity works by the force of the Sun, Moon and Earth together.

MT: I think that gravity works by pushing objects to the ground.

NI: I found out that although the affects of Gravity are easy to see an explanation for these affects has never been found.

Dear AR and SM, I found your note very interesting and I enjoyed reading it. I got a bit confused on one of the theories, but I understood it after I read it over again.

NI: In a experiment Dr. JW [teacher] dropped a hard ball and a tennis ball at the same level out our classroom window, which is on the third floor. The purpose was to see if the different weights of the two balls affected which one got to the ground first. The hard ball was heavier than the tennis ball. On every one of our tries the hard ball reached the ground first.

MT: I think that this is because the hard ball was heavier so it could fight the force of gravity to get to the ground first. The tennis ball however was lighter so it could not fight the force of gravity as well, so it got to the ground last.

Dear AR, Even though it seems that the heavier ball should drop first because it is heavier I am afraid it is not. The only reason the hard ball dropped first was because the tennis ball is fuzzy and there was more air resistant acting on it.

NI: What ever you weigh on Earth is how much pull of gravity is on you. So if you weigh 70 pounds than gravity is pulling on you with a force of 70 pounds. The Moon's force of gravity is alot smaller than Earth's. So if you weigh 70 pounds on Earth than you will weigh less than 12 pounds on the Moon.

MT: Now I know that because the hard ball was heavier than the tennis ball more pull of gravity was on it so it reached the ground first.

NI: I found out from RO's and LL's note that gravity works by matter particles sending out force particles, like gravity. Everything is made up of matter particles and matter particles send out gravity particles, so everything has gravity. Particles are very small objects.

[RO's NOTE: NI: I found out how gravity works. But first you have to know particle is. A particle is a very small thing; particles make up everything around us, even force. Gravity particles have a spin of 1, matter particles have a spin of 1/2. Matter particles send out force particles like gravity. So since everything is made out of matter everything has gravity. Gravity particles have no mass so they can travel over long distances. That's the reason why the Earth orbits the sun. The reason why we stay on Earth is because the Earth has a greater mass than us so its gravity is stronger. Gravity is the weakest force. I have made a chart to help you understand particles. RO]
APPENDIX D1.
TRANSCRIPTION OF EXPERT C'S PROTOCOL

CASE 1

The first theory about the brains, nerve cells in the brain is quite Ok, that's a good starting point. .... ....

I don't even remember all these ... details about the neurons myself, but it seems that they are making progress in this discussion. And there is too much emphasis on the idea that they are ... the cells are big instead of having some kind of organization, but let's see how it goes on. .... .... .... ....

(interruption by a student) .... .... .... ....

My impression is that this is a quite quite good discussion and it makes progress so I think that the research questions are likely to lead to progress so ... on the scale three. Maybe .... ....

and the explanatory value of the intuitive conceptions, intuitive conceptions are ... MT My Theory. INTU it is a little bit leading because it could be intuition ... Aha My theory. I think that they start from quite simple-minded models but they get, they get better, so there is improvement in those. So the research progress.

And. And then this discussion about stroke. I am not sure if this makes the discussion better or more illuminating so ... on the whole I put three.

Also the conceptual change, they .... .... there is, there is some progress also in the conceptual change ... coming from these cases, comments and ... information, how do you call it, new information, that helps them better understand what their neuron cells are ... so I could give three to all these.

CASE 3

.... Where does this new information usually come from ... from reading... yeah, reading .... .... .... Hm...

They start from a very large-scale question what is the universe, what is the universe made of and then they go to very small details to which is in fact Venus or some other planets. .... .... .... ....

(interruption by another student)

Hmm ... These are two ... really quite different discussions. The first question doesn't make very much progress, it goes to a wrong, perhaps wrong direction to small details, but in this, concerning this other question there is, there is a clear progress. There is a kind of wrong approach on this side but then there is the quite right theory that universe, universe is always changing and there is a continuous process, and then it leads to quite reasonable further ideas how galaxies are formed, so I think this, this second question is better, ... lead to a better question than the first one. .... .... Hmm...
Hmm... This is somehow, somewhat short discussion and the main progress comes from this new information about big bang theory so ... I do not know if there is clear evidence that, that, that any other progress is really made. ... ...

(What I have Learned) ... ... So this is of course something which is taken from new information and, so some learning has been made but no, not really any good ... my theories or these intuitions ... ... Hmm Hmm

But should I evaluate all three together because I think that they are slightly different but ... As the whole I think this, this, this is not so good as the former, the former ... and there were many, many bad questions raised, beside the point ... but of course some good ones. I put two here. And ... hmm... It is somewhat difficult to to summarize with these because some some intuitive theories maybe very good and some are worse, but ... some good intuitive..., but the process is not very good I think and not not very much conceptual change ... but the interaction works to some extent, and the information is taken taken into account so perhaps this scale.

CASE 2

... ... hmm hmm ... ... ...

Well, this seems to be quite straightforward ... discussion about the ... functioning of the eye, and I think the intuitive theories are here quite plausible and lead to quite natural questions about how the eye functions as a lens and another comparison of the eye to a camera ... operates. So in that sense I think this, this works quite nicely. On the other hand the question how, how then the message from the eye to to the brain is transmitted, there is not, not so much progress on that question, and it really comes only in the final piece of information how that functions, but the question is, seems to be, I think, the right one. So in that sense, I think, this is quite quite well-organized discussion. ...

So maybe this would the best thing to scale, I give these rankings. So the intuitive conceptions are good and the progress is good. I do not know if these is much conceptual change, there is some, the idea of lens and comparison with camera. And maybe ... Research questions, Well they lead, I think they lead to right direction, except the first one, where is the eye’s control panel located. It is a kind of dead ended discussion, it doesn’t lead anywhere but then when they start how the eye functions, and that lead, that lead is quite natural, so perhaps three.

Experimenter: What’s is your general impression about the material produced by 10 year-old kids?

I think they have quite, pretty good questions, in some cases quite advanced ideas are discussed.

Experimenter: But you said that they have some “bad theories” or “wrong theories." But isn’t it quite natural to have a wrong theory if you do not have a ... It is easy to produce a correct theory if you have formal instruction ...

It is quite normal also in history of science to have at least initially also very wrong theory so, so there are degrees how wrong a theory really goes. So in that sense it is quite normal that
10 year-old kids are looking intuitive answers in quite quite wrong directions. So I am not saying they are ... surprising or unnatural to have them.

**Experimenter:** Did you get an impression that they were able to overcome those wrong intuitive theories in their process of inquiry

Well, to some extent yes, because there was this new information coming that helped to helped 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 been instructive to to to learn from mistakes in a sense that when you have a wrong theory you would show in details why it is wrong, why it goes to a wrong direction.

**Experimenter:** Did you get an impression that they moved to another question without going in-depth? Change a problem.

In some cases, yes. Yes, they were jumping to another issue. But that also certainly depended on the available further new information that they could got from other sources.

And in some cases these these comments from the other class were quite good, I think.

**Experimenter:** Helped to make progress you mean?

At least in some cases these comments were quite good, really pointing out that this is a right direction and that is very strange. In that sense that communication in some cases was quite well functioning.