Knowledge Construction in Elementary School Science Projects

ABSTRACT Most current science education reform documents are placing much emphasis on having students become competent in identifying, accessing, and operating upon relevant information sources and in using the information to construct new knowledge. One of the means they suggest for achieving these aims is science project work. However, a review of the research literature indicates that little knowledge construction occurs during science projects. This article reports on a study in which a teacher used the collaborative development of a format-free computer database to facilitate the construction of knowledge by a group of three Year 6 students during a science project.

Most current science education reform documents (e.g., American Association for the Advancement of Science, 1989; Curriculum Corporation, 1994; National Research Council, 1996) are placing great emphasis on having students become competent in identifying, accessing, and operating upon relevant information sources and in using the information to construct new knowledge. One of the means for achieving these laudable aims suggested by most science curriculum reform documents is the use of science investigations which involve project work. In science projects, students working in groups are required to research a particular science topic such as herbivores and carnivores, tornadoes or dinosaurs and generate a report, booklet, or a poster about the topic. The research usually includes the collection and organisation of information about the topic from books and other media sources.Sometimes, it also may include the collection of data from scientific experiments or observations. The underlying rationale of science projects is that they empower children to increase their understanding of what they are learning (Cross, 1996; Krajcik, Blumenfeld, Marx, & Soloway, 1994). However, a review of the research literature seems to indicate that little construction of knowledge occurs in most science projects (Krajcik et al.). Instead, they only seem to facilitate the simple, routine compilation and presentation of information that students have copied (or recalled) from books, other media materials, experiments, teacher's blackboard notes, or comments made by the teacher. Thus, there is a need to investigate how the construction of knowledge in elementary school science projects can be enhanced.

Research conducted by constructivists seems to indicate that two possible approaches for enhancing the construction of knowledge in elementary school science projects could be to provide students during science projects with (a) cognitive scaffolding that helps them enter the zone of proximal development (Bruner, 1986; Vygotsky, 1978), and (b) teaching-learning heuristics that help them to reflect on both the learning processes and learning products (Driver, Asoko, Leach, Mortimer, & Scott, 1994; Roth & Roychoudhury, 1993; Tobin, 1993). One such teaching-learning heuristic that has been found to have positive effects in science education is concept mapping (Jegede, Alaiyembola, & Okebukola, 1990; Okebukola & Jegede, 1988; Ruiz-Primo & Shavelson, 1996). The key features of a concept map are its spatial or graphic properties that make use of labelled nodes to represent concepts and lines (or arcs) to represent relationships between pairs of concepts.

When large numbers of concepts are connected, a concept map is formed which ideally represents the content and the structure of a student's knowledge framework. Prepared by a group of students, concept maps can be viewed as expressing the meaning shared by team members.

The research on effective small-group learning (see Cohen, 1994) suggests that changing the students' viewpoint about a project from being a task to be completed to an opportunity to deepen their understanding of the topic being investigated may also be another effective approach for enhancing the construction of knowledge in elementary school science projects. Scardamalia and Bereiter (1989) claim that one of the best ways this can be achieved is by establishing knowledge-building communities. According to Bereiter (1994), what defines a knowledge-building community (e.g., a research team in the scientific community) is a commitment amongst its members to invest their resources in the collective pursuit of understanding. A knowledge-building community within a classroom thus is a group of students dedicated to sharing and advancing the knowledge of the collective. Furthermore, their primary focus is on the production of knowledge objects (e.g., ideas or interpretations) that can be discussed, tested, compared, modified, and so forth and not on the completion of a task.

Although concept mapping and establishing knowledge-building communities seem to hold much promise for enhancing the construction of knowledge during a science project, anecdotal evidence from teachers and evidence from the research literature seem to indicate that implementing either of these approaches is not easy. For example, many students experience much difficulty in creating and modifying concept maps (Harlen, 1992; White & Gunstone, 1992). In particular, they have problems generating the nodes and the spatial structure of a concept map and in identifying all possible relational links between the nodes in a concept map.

Similarly, many students and their teachers find it very difficult to establish knowledge-building communities because the existing patterns of discourse in their classrooms are antithetical to the notion of producing, discussing, testing, and comparing knowledge objects (Scardamalia & Bereiter, 1989).

However, the task of creating and modifying a concept map can be greatly facilitated by computer-based concept mapping tools because they enable students to experiment with different concept map structures and relational links (Ferry, 1996; Kopec & Wood, 1994). Computer technology has also been recognized as an effective tool for mediating knowledge-building discourse (Brown, Ash, Nakagawa, Gordon, & Campione, 1993; Brown & Campione, 1993; Scardamalia & Bereiter, 1993). Hence, it appears that the difficulties associated with the construction and modification of concept maps and the establishment of knowledge-building communities possibly can be overcome by the application of appropriate computer technology tools such as format-free databases.

FORMAT-FREE DATABASES A format-free database consists of a set of linked computer text screens. Each text screen contains some information presented in text notes and one or more keyword links embedded within the text notes. In the format-free database presented in Figure 1, the starting text screen (Sharks) contains some general information about sharks and four keyword links: appearance, features, food, and habitat. These four keywords directly link this text screen to four other correspondingly titled text screens: Appearance, Features, Food, and Habitat. By clicking on appearance, the user of the database is able to access the additional information on the Appearance text screen while clicking on food accesses the information on the Food text screen, and so on. In this way, the computer automatically links up like keywords, providing a complex series of links between information contained in the text screens, allowing a great variety in methods for exploring the database (Briggs, Nichol, Brough, & Watson, 1991). Thus, in the Sharks' database, seen in Figure 1, the user can explore the information contained in the database in many different ways. For example, he/she can explore the information about the sharks' habitat from the starting text screen (Sharks) directly via the keyword link habitat, or indirectly via the Food or Features text screens.

During the development of a format-free database, students are required to plan out the text screen headings they will use and how the information will be arranged under these headings. Also, with the aid of network diagrams, they need to plan carefully the structure of the database, that is, how these screen headings can be spatially related. The process of developing a format-free database thus closely parallels that of creating and modifying a concept map. Specifically, generating the text screen headings is analogous to generating the nodes in a concept map, while generating the network diagrams for the structure of the database is analogous to generating the structure of a concept map.

The scaffolding provided by format-free database software such as Keys88 (Briggs et al., 1991) systematises (a) the selection of text screen headings, (b) the establishment of a spatial relationship between the text screen headings to represent the structure of the database, and (c) the identification of relational links between the text screen headings. Consequently, the scaffolding could do much to facilitate the process of developing and modifying concept maps to represent the content and the structure of the students' knowledge about the topic being investigated during a science project.

The cognitive scaffolding provided by the format-free database software, Keys88, encourages the construction of higher-order representations and integrations of knowledge rather than the proliferation of loosely connected items of information. Also, Keys88 enables students to see their work, not solely in terms of its independent merits, but also in terms of its contributions to the advancement of the group's knowledge. Therefore, it seems highly probable that the scaffolding provided by Keys88 should facilitate the establishment of a knowledge-building community during a science project.

In addition to having the potential to facilitate the process of generating and modifying concept maps and the establishment of a knowledge-building community, format-free database software such as Keys88 has two other characteristics which further indicate it has the potential to do much to enhance the construction of knowledge in school science projects: simplicity and flexibility. Unlike most other computer technology tools (e.g., traditional databases or spreadsheets), format-free database software requires minimal computing skills. The process of data entry and interrogation is flexible, easy to operate, and powerful for all users. For these reasons, students are able to begin database construction as soon as they begin working with the software. If changes are needed to the database, the data structures are easily varied, allowing for the addition or deletion of keywords or text at any time. The simplicity of format-free database software enables the primary focus of students to be the construction of knowledge and not the mastering of complex software protocols. The flexibility of the data structure enables it to be responsive to the students' changing needs as the process of database creation proceeds.

Format-free database software such as Keys88 thus seems to warrant consideration for being included in the category of computer technology tools which can enhance the construction of knowledge by students during elementary school science projects. The general aim of the present study, therefore, was to investigate whether having a group of elementary school students collaboratively develop a format-free database using Keys88 software would enhance their construction of knowledge during the completion of a school science project. Subsumed within this general aim were three specific aims. They were to investigate how the collaborative development of a format-free database during the course of a school science project influenced (a) the complexity of the students' mapping of their data structure; (b) the quality, amount, and degree of integration of knowledge constructed; and (3) the quality of intellectual discourse between the students.

METHOD

PARTICIPANTS The participants in this project were three 11-year-old students from mid-level socio-economic backgrounds (i.e., neither disadvantaged nor wealthy) who were members of a Year 6 class at an elementary school in Eastern Australia. The three students had volunteered to work on a "computer project" and had indicated to their class teacher that they were willing to work together as a group on the project. The group consisted of one girl (Megan) and two boys (Tom and Peter) [all pseudonyms].

Megan was described by her teacher as a very quiet, cooperative, and academic student who had very good reading, writing, and researching skills. The teacher based his assessment of Megan and the other two students' reading, writing, and researching skills on general classroom performance and on the students' scores on standardized tests administered earlier in the school year. Tom was described as being more interested in sporting than academic pursuits and as having average reading, writing, and researching skills. The third student, Peter, had a major reading problem and was withdrawn to special learning support classes with a remedial reading teacher twice a week. Because of his reading problems, Peter had rather limited writing and researching skills. However, despite these learning problems, Peter was a very conscientious student whom Megan and Tom knew could be depended upon to do his share of the work in a group project. According to their class teacher, both Megan and Tom were very considerate and supportive of Peter. Thus, even though they were aware, based on prior group work experiences, that Peter's contribution to the group project probably would be affected by his limited reading, writing, and researching skills and that he would need much support and encouragement, Megan and Tom indicated to their teacher that they were more than willing to work with Peter on the project.

PROCEDURE This interpretative study, in which the students' regular classroom teacher acted as a participant observer, occurred over a period of 6 weeks during the students' regular science classes (approximately 3 hours per week). Whilst the three students worked on the generation of a format-free database, the other members of their class carried out normal science class activities such as science projects and science experiments. The study proceeded in four phases: Phase 1--Introduction, Phase 2--Evaluation of students' prior knowledge, Phase 3-Development of database, and Phase 4--Evaluation of students' post-project knowledge.

Phase 1: Introduction. The study began with the three students being advised by the teacher that they were being given an opportunity to create a computer database which other students in their class would be able to access and use. This was followed by a series of three half-hour discussions about databases in general. Among the specific issues discussed in these sessions were (a) types of databases, (b) reasons for database use, (c) types of organisations that need databases, (d) how school databases can be used, (e) categories of information found in school databases, and (f) ideas for database use in the classroom. By the third half-hour discussion session, the quality of the students' comments and questions about databases convinced the teacher that the students clearly understood the issues he had raised about databases.

The teacher then introduced the database project topic, Mars, to the students. Mars was chosen as the topic for the database because (a) it was of interest to the students involved, (b) it was suitable for the science and language curriculum level and academic progress of the students, and (c) there were large amounts of information in a variety of media formats about the topic in the school library. The students' reactions to the topic were very positive. They volunteered to the teacher that it was an interesting topic which they would enjoy researching. They also told him that they thought that a database about Mars would be of great interest to their peers.

Phase 2: Evaluation of students' prior knowledge. After the topic had been introduced to the students, the teacher conducted one-on-one clinical interviews with the students at meal breaks or during class quiet time. The interviews were taped and transcribed. All three students were interviewed on the one day to ensure that information could not be shared. Each interview began with the student being advised, "Your topic area is Mars. Think about Mars and tell me all the information you know about Mars." Once she/he had completed speaking on the topic in this way, the teacher asked a series of open-ended questions to discover the tacit knowledge the student had about Mars.

After each student had completed the clinical interview, she/he was instructed to go back to his or her home desk and write as much information about Mars as she/he could. She/he was given the choice of writing it as a poster, a travel brochure, a report, a booklet, a cartoon, or a book. All of the students completed a poster which included both text and drawings. The posters were completed and handed into the teacher at the end of Week 1.

A Data Summary Sheet, which summarised data from the clinical interview and the poster, was created for each child by the teacher. The Data Summary Sheet listed in tabular form what correct and incorrect information the child had about Mars (Figure 2).

Phase 3: Database development. At the beginning of Week 2, the students began the project by individually researching the topic in the school library. The individual research was rather unsystematic and uncoordinated in nature. For example, before they began their individual research, the students neither determined any parameters for their research nor did they identify a focus area for each student to research. Their individual research also showed little evidence of analysis, synthesis, or evaluation. Indeed, most of the notes that they produced were direct transcripts of text from books or other media materials they had read.

The teacher noted that the students seemed to be generating little new information after about 3 hours of individual research. Thus, late in Week 2 of the study, the three students were brought back together as a group to develop an initial data structure. The process began with the students generating an initial list of headings. Most of the headings on this list were taken verbatim from the books the students had read. In order to refine this process, the teacher suggested to the students that they should refer to their research notes to find out what information they collectively had acquired about each heading and that they should then write down information in point form about each heading. This initiated the process of analysing, synthesising, and evaluating the collected information. Whilst analysing, synthesising, and evaluating the collected information, the students found it necessary to make modifications to their list of headings. In some instances, large amounts of information necessitated the division of a heading into two headings; in other instances where little information about a heading had been found, the students either rejected or subsumed that heading within another heading. When the students were satisfied that their list of headings, as a whole, covered the topic, they used these headings to produce an initial data structure (Figure 3).

Once the students had completed their initial data structure, they received instruction that focused specifically on format-free databases. The goals of this instruction were (a) to familiarise the students with the structure and organisation of a format-free database, and (b) to introduce the students to the procedures for producing and interrogating a format-free database.

With the aid of a diagram taken from the Keys88 manual (Briggs et al., 1991), the students were made aware of the way a format-free database has screens of text notes linked by keywords. To assist the students' understanding of format-free databases, a small pen-and-paper "hand-run" format-free database on "sharks" then was produced by the teacher with the assistance of the students. The students had recently completed a unit of work on sharks, hence they were very familiar with the subject matter. This familiarity with the subject matter enabled the students to focus their attention on the structure and organisation of the database. Five linked data screens containing information were produced on a blackboard (see Figure 1). During this activity, the teacher played the role of a facilitator and did not transmit any new information about sharks to the students. The teacher prompted for information regarding content knowledge, appropriate headings, and keyword links. The teacher also provided cognitive scaffolding and encouraged discussion and debate, playing devil's advocate where necessary to draw out ideas from all three group members.

The students were then given the opportunity, over a period of a few days, to explore and manipulate some examples of format-free databases produced with Keys88 software, such as the Athens and the Creapsville files. The Athens file is a format-free database which contains information about life and times in ancient Athens. Creapsville is a database about a town in which a number of mysterious crimes have occurred. By interrogating the database, the students can solve the crimes. The primary purposes of this exercise were to consolidate the students' understanding of format-free databases, to familiarise the students with the Keys88 software, and to clarify the students' expectations about the final product they could construct with the Keys88 software. The students moved between the data screens and received information about the amount and type of data that can be included in each data screen and how keyword links can be used in a Keys88 format-free database.

At the end of Week 2, when the period of familiarisation with the Keys88 software had been completed, the students began the process of generating the Mars database. This began with the students searching for more information about Mars in the school library. Unlike their original search for information in Week 1, this search was systematic, purposeful, and coordinated. For example, this time they used the headings from their initial data structure to determine the parameters for their research. They also used a jigsaw approach (Aronson, 1978) where each student was given certain topics to research. As each student collected information, he or she continuously reported back to the group to ensure that other members of the group were fully informed about what he or she was currently doing. The students also met regularly to review the information that had been collected. These group discussions were often very animated, with debates over the quality and accuracy of information often arising. Decisions were made about whether information should or should not be included in the database and whether the information was relevant for a heading. Decisions also were made about how the search for information should proceed in the future (e.g., to continue the search for information about a heading or to follow new lines of search). This part of the project was approached in a very positive manner by all three students. Quite clearly, the students believed that they were in the process of developing a database which not only would be of value for them, but also to their peers.

As information was collected and organised, passages of text about each of the headings were either being written or redrafted. Megan was perceived by Tom and Peter as being the best writer; they thus deferred to her during the redrafting of the text notes. The two boys however played a significant role in writing the original drafts of the text notes and insisted that significant parts of their original text remained in the final drafts of the text notes. Furthermore, both boys also had significant editorial roles during the preparation of the final drafts of the text notes. Because Peter had rather limited reading, writing, and research skills, by group consensus, he was given fewer headings to research than either Megan or Tom. Both Megan and Tom also peer-tutored Peter as he attempted to write original drafts of the text notes for his assigned headings.

A form to systematise the process of collecting, organising, and recording information was developed by the students. This form was modelled on the data screens in the Keys88 software. An example of one of these completed forms is found in Figure 4. As this example illustrates, each form not only contains information in text form about a particular heading, but also a list of keywords contained within the text which provides links between the information presented under this heading and information presented under one or more other headings. Once sufficient research had been done to allow students to complete a text note and list of keywords for a heading satisfactorily, the data on the form were entered onto a Keys88 data screen. Each heading (with its text notes and list of keywords) then became a separate data screen in the Mars database.

Over the final 4-week period of the study, the students kept systematically searching for more information about Mars. As they did this, they continuously re-analyzed, re-synthesized, and re-evaluated the information that they had collected and organised. (Examples will be presented later in the Results and Discussion section.) The students willingly engaged in this process. This resulted in modifications continuously being made to the text notes and/or list of keywords on each of the text screens in the computer's database, the list of text screen headings contained in the database, and also to the overall structure of the database. In order to systematize their restructuring of the database and to help them reflect on both the learning processes and learning products, the students were encouraged by the teacher to continuously modify their concept map representations of the data structures. The results of these modifications can be noted by comparing the concept maps for weeks 3 (Figure 5), 4 (Figure 6), and 5-6 (Figure 7), respectively.

Phase 4: Evaluation of students' post-project knowledge. Three weeks after the database had been completed, the teacher conducted one-on-one clinical interviews in which each student was once again asked to tell the teacher all the information she/he knew about Mars. Once she/he had completed speaking on the topic in this way, the teacher asked a series of open ended questions to discover the tacit knowledge the student had about Mars. After each student had completed the clinical interview, she/he once again was instructed to go back to his or her home desk and write as much information about Mars as she/he could. All of the students completed a poster which included both text and drawings. A Data Summary Sheet similar to that shown in Figure 2 which summarized data from the clinical interview and the poster was created for each child by the teacher.

COLLECTION AND ANALYSIS OF DATA During the 6-week study, the following types of qualitative data were collected and analyzed:
1. clinical interview and student poster data which were transformed into data summary sheets as in Figure 2;
2. the students' progressive work on the production of the data structures and the construction of the database;
3. the final version of the database;
4. field notes from the observation of student-student interactions; and
5. research record forms in which individual students recorded at the end of each session: (a) what they had done in a session, (b) what they had learned in that session, (c) what they perceived they needed to do in the next session, (d) what the planned to do in the next session, and (e) any other relevant information.

In accordance with the research questions framing this study, these data were analysed to ascertain changes in (a) the complexity of the data structure, (b) the students' corpus of knowledge about Mars, and (c) the quality of discourse.

Specifically, changes to the complexity of the students' data structure were determined by analysing the headings and the keyword links between headings for each version of the database. Changes to the students' corpus of knowledge about Mars were ascertained by analysing the progress that occurred in the students' conceptualization about Mars during the course of the study. This analysis focused on the conceptual understanding evident in (a) the quality and amount of information presented in the text notes, and (b) the degree of integration of the information in the database. Changes to the students' corpus of knowledge about Mars also were ascertained by comparing the students' knowledge about Mars prior to the generation of the database with that 3-4 weeks after the completion of the database. The quality and the amount of information manifested by the students in the pre- and post-database clinical interviews and posters were also compared.

Analysis of changes to the quality of the discourse between the students was based upon (a) the ways students shared information and negotiated meaning, and (b) their commitment to sharing and advancing the knowledge of the collective. The results from the three sets of analyses then were integrated in order to ascertain whether having the group of students collaboratively develop a format-free database using Keys88 software enhanced their construction of knowledge.

RESULTS AND DISCUSSION

COMPLEXITY OF THE DATA STRUCTURE During this study, the continuous re-analysis, re-synthesis, and re-evaluation of the information collected and organised by the students resulted in a number of marked changes in the overall complexity of the data structure the students generated from Week 2 to Week 6 (refer to figures 3, 5, 6, and 7).

First, changes were made to the number of headings. In the initial data structure from Week 2, 10 headings were listed (see Figure 3). However, soon after they began analyzing, synthesizing, and evaluating the information, the students realized that they had found no relevant information about either the inhabitants or the characteristics of Mars. As a result, these corresponding headings were dropped from the list of headings for Week 3 (see Figure 5) reducing the number of headings in Week 3 from 10 to 8.

After more information had been collected, analysed, synthesized, and evaluated in Week 3, the number of headings was subsequently increased from 8 to 13. The increase in the number of headings was caused by the reinclusion of Characteristics into the set of headings, the creation of two new headings, Moons and Gravity, and the creation of two sub-headings from the Features heading, Mountains and Polar-Caps (see Figure 6). The heading, Characteristics, was reincluded because new information had been discovered and also because the students realized it provided them with a very effective means of comparing and contrasting Mars with their home planet, Earth. The two new headings, Moons and Gravity, were the outcomes of new information that they had collected and evaluated. The two new sub-headings, Mountains and Polar Caps, were included because the students considered that the text notes on the Features screen were now getting too long. They also believed that because the polar caps and the mountains were such important features on Mars, both should be assigned their own text screen.

Second, changes were made to the structural relationships of the headings. The headings in the initial data structure from Week 2 (see Figure 3) were a set of sub-topics placed on the page in a manner that was aesthetically pleasing to the students. No overt attempt was made to organise the headings into an hierarchical or other type of structure. However, as the group collected, analyzed, synthezised, and evaluated new information about Mars and re-analyzed, re-synthezised, and re-evaluated existing information about Mars, significant changes were made to the structure of the headings. Hierarchical relationships between some of the headings began to emerge by weeks 3 and 4 (e.g., Mountains and Polar Caps as sub-headings of Features). In addition, some of the headings were modified to become more inclusive. For example, the sub-heading Mountains was modified to Surface in Week 5 so that not only could information about Mars' mountains be presented in the text note, but also information about related sub-topics such as canyons, craters, and volcanoes. Changes in the number and the structural relationships of the headings described above are clearly evident in figures 3, 5, 6, and 7.

Third, changes were continuously made to the links between the headings. The group progressed from the early stages of little organisation and no linkages to a final product where associated data screens were linked in a variety of ways by keywords in a complex data structure. The earlier attempts at including data linkages produced connections which were cyclic, daisy chain in nature and showed little evidence of being informed by the information (see figures 3 and 5). The final data structure (see Figure 7), however, demonstrates a more complex and sophisticated level of data linkages. At the time the students were constructing the final data structure, they were actively involved in adding data screens to the computer database and indicating keywords for each screen. The students realized that how they linked the screens was very important. They therefore decided, through group decision-making processes and discussion with the teacher, to group and link related screens together. As a consequence, the final data structure has a number of linked data screens which then link through other screens to the database as a whole. For example, the heading of Setting, which describes Mars' place in the solar system, was considered to relate closely to the Time heading, detailing information about the length of the Mars year and thus linkages were set up between these screens. In the same way, Gravity and Size were related and thus linked via keywords.

STUDENTS' CORPUS OF KNOWLEDGE ABOUT MARS The continuous re-analysis, re-synthesis, and re-evaluation of the information collected and organised by the students during the course of the study brought about quantitative and qualitative changes to the group's corpus of knowledge about Mars. These changes were greatly facilitated by the structure of the format-free database with its text screens linked by keywords contained within the text notes. This structure forced the students continuously to re-organize, re-integrate, and make meaning out of all of the information they had collected.

Changes to one text screen's notes had consequences for those of other text screens. For instance, the students decided that more information needed to be added, the text notes had to be restructured, new keywords links needed to be made, and so on. These changes were also facilitated by the simplicity and flexibility of the Keys88 format-free database's data entry and interrogation procedures that enabled the students to modify the database continuously as they became more knowledgeable about Mars. The changes to the group's corpus of knowledge are reflected in two ways.

First, there was an increase in the quality and the amount of information. An analysis of the early versions of the text notes for each of the headings seems to reveal that the sum total of the group's knowledge about Mars consisted of rather shallow, unrelated lists of information copied from books and other media. For example, the first version of the text note about polar caps did little more than reveal that Mars indeed has polar caps. This contrasts markedly with the final version of the text note about polar caps (Figure 8) which reveals much more information such as the discovery of polar caps was very important because it revealed that Mars does have water and carbon dioxide on its surface and that the polar caps are cold enough to freeze carbon dioxide. This text note (and other text notes in the final database) clearly indicate that by the end of the study, the students had converted all of the information they had collected into a corpus of high-quality, indepth knowledge about Mars.

The increases in the quality and amount of information presented in the text notes of the database were mirrored in the data collected from the clinical interviews and posters. An analysis of the data from the pre-project clinical interviews and posters revealed that the students had small repertoires of knowledge about Mars and that much of their knowledge was incorrect. For example, Megan produced 16 chunks of correct information and seven chunks of incorrect information; Tom produced 12 chunks of correct information and three chunks of incorrect information, and Peter produced eight chunks of correct information and three chunks of incorrect information. However, when the students were interviewed and asked to complete a poster about Mars 3 weeks after the completion of the database, all three students had increased the quality and amount of information that they could access and exploit. Megan was able to generate 26 chunks of correct information about Mars, Tom 21 chunks of correct information, and Peter 14 chunks of correct information. Furthermore, the quality of the information assessed in terms of correctness also had increased. Megan only produced two incorrect pieces of information, Tom one, and Peter one. These increases in the quality and amount of information that the students were able to access and exploit in the clinical interviews and posters provide further evidence that by the end of the study, the students had converted much of the information they had collected into a corpus of high-quality, in-depth knowledge about Mars.

Second, there was an increase in the degree of integration between chunks of information. The information presented in the early sets of text notes tended to be rather fragmented and unrelated in nature. However, as the students further re-analyzed, re-synthesized, and re-evaluated the information they collected and organised, the integration of information between notes increased. For example, there was a high degree of integration between the information contained in the final text notes about Setting and Time (see Figure 8). In the Setting notes, the students pointed out that because Mars is farther from the sun, it takes more time to travel around the sun than the Earth. This information is related to information in the Time notes explaining why Mars has a longer year than the Earth. Information integration is also found in the Size and Gravity notes where it is pointed out that because the mass of Mars is 0.11 that of the Earth, the force of gravity on Mars is much less than that on the Earth. The high level of information integration evident in these two text notes indicates that by the end of this study, the students were well advanced towards a scientifically acceptable understanding that gravity is influenced by mass and distance.

The increase in the degree of integration between chunks of information was also reflected in the clinical interview data. The information presented in the pre-project interviews was disjointed and unrelated. However, the post-project interview data revealed that Megan and Tom had converted the information they had collected into well-integrated, for their age and experience, repertoires of knowledge about Mars. This integration was manifested in the ways in which they linked information given in response to one question to the information accessed and exploited during the answering of previous questions. The post-project interview data for Peter indicated that his repertoire of knowledge about Mars contained unintegrated chunks of information.

QUALITY OF THE DISCOURSE Significant changes in the quality of discourse occurred during the 6 weeks of the project. These changes closely paralleled those that occurred with the complexity of the data structure and the quality, amount, and level of integration of the knowledge about Mars. Changes in the quality of the students' discourse were manifested by (a) changes in the ways they shared information and negotiated meaning, and (b) changes in the focus of their discourse.

In weeks 1 and 2, each student tended to regurgitate the information she/he had collected and little negotiation of meaning occurred. However, in weeks 3 through 6, each student became immersed in continuously redrafting his or her text notes so that the information on these notes could be meaningfully linked and integrated with the information on the text notes researched and authored by the other two students. Of course, this meant that the students found it necessary to negotiate meaning with other members of the group. The negotiation of meaning was clearly evident in the process Megan developed for writing the final draft of a text note originally authored by Peter or Tom. Megan first read Peter or Tom's text note. She then asked Peter or Tom to clarify aspects of the notes she did not fully understand or believed were either inconsistent or incorrect. She then set about the task of redrafting the note. Following this, she went back to the original writer to ensure that her draft was consistent factually with the original text note. The process was repeated until both Megan and the boys were satisfied with the final draft. This cyclic negotiation of meaning was replicated to a lesser extent in the interactions between Peter and Tom when Tom peer-tutored and helped Peter to write his draft text notes. Similarly, much negotiation of meaning also occurred during the restructuring of the concept map representations of their data structures in weeks 3 through 6.

The students' commitment to sharing and advancing the knowledge of the collective also changed during the course of the study. An analysis of their discourse in the first 2 1/2 weeks indicated that most of their discourse seemed to be focused on finding and sharing "facts." This was reflected in the research records each of the students wrote during this period. When answering the questions, "What did you do in this session?", "What did you find out?", and "What do you need to do?", the students' reflections seemed to indicate that their discourse during these sessions mainly was about ways of getting more information about Mars and/or of sharing the information they had found. There was little evidence of what Bereiter (1994) refers to as the collective pursuit of understanding. However, by weeks 5 and 6, the focus of their discourse had changed to the pursuit of meaning and the production of knowledge-objects that could be discussed, tested, compared, modified, and so on. The quality of the students' discourse (e.g., when they linked the information about size and gravity or when they linked the information about time and setting) indicated that they had indeed become a knowledge-building community that viewed the project as an opportunity to deepen the group's understanding of the topic being investigated. This viewpoint was reflected in the research record forms written by the students during weeks 5 and 6. We considered that the Keys88 software facilitated these changes by (a) encouraging the construction of higher-order representations and integrations of knowledge, and (b) enabling the students to see their work in terms of its contributions to the advancement of the group's knowledge. THE

CONSTRUCTION OF KNOWLEDGE Based on the analysis of changes that occurred to (a) the complexity of the students' data structures; (b) the quality, amount, and levels of integration of the students' corpus of knowledge about Mars; and (c) the quality of the students' discourse, we feel justified in claiming that engaging the three elementary students in a collaborative science project in which they generated a format-free database was a very effective way to facilitate the construction of knowledge.

The apparent success of this endeavor can probably be attributed to four factors. First, the format-free database provided the children with cognitive scaffolds to aid the process of collective knowledge construction. For example, the structure of the format-free database with its text screens linked by keywords contained within the text notes compelled the students continuously to re-organize, re-integrate, and make meaning out of all of the information they had collected. Second, the flexible and easy-to-operate nature of the format-free database software's data entry and interrogation procedures enabled the students to continuously modify the database as they became more expert-like in their understanding of the information about Mars. The extensive research on expert/novice differences informs us that experts organize their knowledge differently than do novices (Ericsson & Smith, 1991). Reasonably, then, novices may be expected to reorganize their knowledge-base, from time to time, as they become more expert-like in their understanding. The format-free database software allowed the students to reorganize easily the external database so that it accurately reflected the nature and quality of their current knowledge-base. Third, the collaborative development of the format-free database provided a context which supported the establishment and maintenance of a knowledge-building community and thus made the major focus, not the completion of the project, but the deepening of the collective understanding of the group. Fourth, throughout the project, the students received much cognitive scaffolding, support, and encouragement from their teacher. This, too, undoubtedly contributed much to the apparent success of the endeavor.

CONCLUSIONS The present study found that the construction of knowledge by the group of elementary school students was enhanced by providing them with the opportunity to work collaboratively in a small group to generate a format-free computer database. As the students grappled with adding keywords, headings, and/or more information while developing their database, the cognitive scaffolding provided by the Keys88 format-free database software both informed and guided their development and modification of concept maps and thus enabled the students to generate increasingly more complex and rich (in terms of structure, number of heading nodes, quality and quantity of information within nodes, and keyword links between nodes) data structures. Thus, by the end of the study, the students were able to transform the information they had collected from books and other media into a corpus of highly integrated, highly structured, in-depth knowledge about Mars.

The present study also found that having students work collaboratively in a group to generate a format-free computer database was a very effective way for establishing a "knowledge-building community" (Bereiter, 1994) within an elementary school classroom.

During the study, the students developed behaviours such as shared goal-setting, sharing of information, negotiation of meaning, dedication to the task, and learned to value each other's individual and group effort. Also, their primary focus by the end of this study was on the production of knowledge objects (e.g., ideas or interpretations) that could be discussed, tested, compared, modified, and so forth rather than on the compilation of "facts" about Mars. The processes and the products of the students' endeavors thus were fully consistent with those of a knowledge-building community. These findings have a number of important implications for the teaching of science in elementary schools and for future research into the applications of information technology in science education.

IMPLICATIONS FOR TEACHING SCIENCE Most current science project work occurring in elementary school classrooms can be characterised as the simple, routine compilation and presentation of information that students have copied from books, other media materials, teacher's blackboard notes, or comments made by the teacher. Most science project work thus is viewed by students as being something to be completed rather than as an opportunity to deepen the group's understanding of the topic being investigated. However, according to Cohen (1994) and Scardamalia and Bereiter (1989), little significant construction of knowledge or knowledge-building will occur within small groups unless the students view a group learning task as an activity to deepen the group's understanding of the topic being investigated. Therefore, it is hardly surprising that little significant construction of knowledge occurs in most elementary school science projects.

This study found that having a small group of elementary school students collaboratively generate a format-free database from the information they had collected and organised was a very effective way to facilitate the construction of knowledge during a science project. This implies that science project work which involves the application of format-free database software (such as Keys88 and Hypercard) could be of immense benefit to elementary school students especially if the aims of these projects are to facilitate the construction of knowledge and the establishment and maintenance of knowledge-building communities. Also, the findings imply that students can respond effectively to the challenges presented in a project of this kind and therefore that they are capable of processing, using similar techniques, information collected during library assignments, field trips, visits to the museum, and so on.

IMPLICATIONS FOR RESEARCH Although this study showed that having small groups of elementary school students collaboratively generate format-free computer-based databases facilitates the construction of knowledge and the development of knowledge-building communities, a number of important questions concerning the use of format-free databases in science project work need to be investigated.

One such question is whether the students' levels of learning and motivation were mainly attributable to the computerised database construction or to the group investigation strategies introduced to the students in this study. Work conducted by Sharon and Shactar (1988) involving cooperative learning classrooms produced results similar to those of this study thus indicating that the latter may have been the major reason for the high levels of knowledge construction displayed by our group of students. A comparative study between one group of students using group investigation strategies and paper and pencil (i.e., no format-free computer database) and another group of students using group investigation strategies and format-free computer database software thus should be considered in the future.

Two of the students in the present study were of average or above average ability. The third student (Peter) had limited reading, writing, and researching skills. Still, he possessed quite good analytic skills which he used effectively during the course of this study. However, one of the groups of students most in need of developing the ability to collectively construct knowledge in elementary schools is the group with below-average intellectual abilities (Reiss, 1993). Therefore, another question that should be investigated in future research is whether the collaborative generation of format-free computer databases would be effective in facilitating the construction of knowledge and/or the establishment of knowledge-building communities with groups of students of below average intellectual abilities. Another question that should be investigated is whether multimedia format-free databases, involving not just text notes and keyword-links but also graphics, animation, and iconic links, would be more effective in facilitating the construction of knowledge and the establishment and maintenance of knowledge-building communities than would format-free databases that are based on software such as Keys88, which only enable the production of textnote and keyword-link databases.

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