The influence of teachers' epistemologies on the development of students' higher-level thinking skills using a computerised scientific database

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abstract

The purpose of this session is to discuss the results of a study which investigated students' development of higher-level thinking skills in a computerised learning environment which was designed to facilitate an inquiry-based approach to learning. The session will focus on the social interactions and the influence of teachers' epistemologies on the development of students' higher-level thinking skills. In the class where the teacher implemented a constructivist-oriented approach to teaching that emphasised both the personal and social construction of students' knowledge, most students developed higher-level thinking skills. The results of this study suggest that it is not the computer

itself which facilitates inquiry learning; the facilitative role of the teacher is essential for students to be able to utilise the computer as a tool of scientific inquiry.

introduction

Inquiry-based science teaching, which was introduced more than twenty years ago, has been largely disappointing. Research has found that inquiry-based curricula have failed to promote higher-level cognitive outcomes (Shymansky & Kyle, 1992; Tobin & Gallagher, 1987; Weiss, 1987). Nevertheless, the call for this form of teaching continues to be made. According to Project 2061, for example, the teaching of science should be consistent with the spirit and character of scientific inquiry:

[Which] suggests such approaches as starting with questions about

phenomena rather than with answers to be learned; engaging students actively in the use of hypotheses, the collection and use of evidence, and the design of investigations and processes; and placing a premium on students' curiosity and creativity. (American Association for the Advancement of Science, 1989, p. 5)

Why has science education been unable to assist students to develop important inquiry-related higher-level thinking skills? A likely explanation that has arisen from recent research on teacher cognition (Tobin, 1990) is the role of teachers' personal epistemologies. The research suggests that the failure of inquiry curricula is linked to the prevalence of the 'transmissionist' epistemology of the traditional classroom learning environment. This epistemology underpins pedagogies which emphasise the learning of scientific facts and formulae, rather than the investigation of problems, and which focus largely on the individual student, rather than the social aspects of inquiry. The traditional science classroom environment provides, therefore, an inaccurate representation of how scientific understanding is generated (Burbules & Linn, 1991).

Two recent developments that are attracting increasing attention amongst science educators offer the prospect of overcoming this problem. The first is the emergence of 'constructivist' epistemology as a key referent for research on teacher change (Hand, Lovejoy & Balaam, 1991; Tobin, 1990) and curriculum innovation (Cobb, 1989; Cobb, Wood, & Yackel, in press; Driver, 1990; Driver & Bell, 1986). The second is the introduction of the personal computer into school science classrooms and the increasing availability of 'problem solving software'.

Although several research studies support the use of computers to promote higher-level cognitive learning (Horak, 1991; Krajcik, Simmons, and Lunetta, 1988; Parker, 1986; Ryba & Anderson, 1990), very few have investigated the influence of teachers' epistemologies on students' development of higher-level thinking skills in computerized learning environments. The question arises, therefore, of the extent to which teachers' epistemologies influence students' interactions with computer-based learning programs that are designed to develop higher-level thinking skills.

This research problem was addressed in the study reported in this paper. The study investigated the mediating role of teachers' epistemologies in high school computerized classes in which students worked with a scientific database, the Birds of Antartcica, that had been compiled by scientists during an expedition to Antarctica. The database was designed to provide opportunities for students to engage in scientific inquiry and to develop understanding of the natural environment in the field of scientific research. The paper discusses the major outcomes of this doctoral study and provides insights into the constraints and opportunities that are likely to arise when computers are introduced into high school science classes.

Research Design

The study was designed initially in relation to the well-established inquiry skills framework in science education which is described by Schwab (1963) and Tamir (1989). The initial research question of the study asked how students develop scientific inquiry skills in a computerized learning environment. This research question was addressed by designing a study in which a computerised scientific database was introduced into seven Grade 11 classes. For a period of two 10-week school terms, twice a week, students were engaged in scientific investigation

using the database on personal computers.

The Database

The Birds of Antarctica database was designed originally to enable students to develop scientific inquiry skills, in particular:

. . . to make hypotheses and then examine the evidence to test their validity. In this way they can experience a practical example of the nature of scientific research.
     (National Information Technology Committee, 1984, p. 4).

When interacting with the database, students were exposed to 'real life' scientific information based on data gathered by scientists on a voyage to Antarctica in 1982. The database comprises observations of sea birds, together with meteorological information, time, dates, and the ship's positions and activities. This information creates an artificial laboratory in which students may conduct investigations in the endeavour of inquiry-based learning.

Curriculum Materials

During the five-month study, the students interacted individually with personal computers, as well as with other students and the teacher during class discussions. The student-computer interaction was mediated by a specially-designed Student Booklet (Maor, 1993) which provided a series of carefully structured and graded worksheets that were designed to guide students towards the attainment of higher-level thinking skills.

The Student Booklet provided instructional directions for students to interact individually with the computerized database. The Student Booklet freed the teachers from a primary instructional role, and provided opportunities for them to monitor closely students' progress and to intervene with subsidiary instruction when it seemed necessary to do so.

Data Collection

Two high school computing classes were selected for an interpretive study (Erickson, 1986) in which the researcher adopted a participant-observer role. During whole-class discussions, the researcher observed the students and teachers, recorded fieldnotes, and audio-recorded the discourse. When students interacted individually with the computerized database, the researcher moved around the classroom and posed questions, interviewed students, listened to them 'thinking aloud' as they interacted with the computers and curriculum materials, and responded to students' comments and questions. At the end of class sessions, the researcher held informal discussions with the teachers about issues that arose during the lessons, and about teaching plans for the next class session.

Constructivism: An Interpretive Framework

A constructivist theoretical framework was adopted in order to investigate the relationship between teachers' epistemologies, their classroom roles, and students' learning activities. The framework comprised two key aspects of constructivist theory. The perspective of personal constructivism, provided an interpretive research focus on students' individual constructions of higher-level thinking skills as they interacted with the computerized database. Additionally, a social constructivist perspective on the teaching-learning process, provided an interpretive focus on students' negotiation of meaning, especially during whole-class discussions.

Personal Constructivism

Constructivism has emerged as a radical alternative to the transmissionist epistemology of traditional science teaching that conceives of knowledge as being 'out there' in the world and available for transfer to the learner (Tobin, Briscoe & Holman, 1990). From the latter perspective, knowledge "can be accumulated bit by bit, subject by subject, . . . and corresponds to the world as it is. . . . This knowledge is therefore independent of the subjective constructions of the learner" (Pope & Gilbert, 1983, p. 194). The transmissionist epistemology gives rise to a pedagogy that conceives of the student as a passive recipient of knowledge, rather than as an active participant in the construction of his/her knowledge.

By contrast, a personal constructivist perspective regards knowledge as being constructed by learners who give meaning to new data in terms of their prior knowledge and personal experiences. This perspective emphasises a cognitively active approach to learning in which students construct knowledge which is true for them, and incorporate it within their views of the world (Pope & Gilbert, 1983).

The main pedagogical implication of a personal constructivist perspective is that the active learner's construction of his/her own understanding can be facilitated by teachers who provide stimulating and motivational experiences that challenge students' extant conceptions and involve them actively in the teaching-learning process. This pedagogy "emphasizes that learners need to be actively involved, to reflect on their learning and make inferences, and to experience cognitive conflict" (Fosnot, 1989, p. 3).

Social Constructivism

Recently, science educators have realised that personal constructivism fails to acknowledge the importance of the social aspects of learning:

Strictly personal constructions, like that produced by the young Einstein when he imagined the effects of pursuing after a beam of light, do undoubtedly also occur. But social constructions are both far more common, and also based on a different thought system.

(Solomon, 1987, p. 66).

Constructivist-oriented science educators such as Cobern (in press), Miller (1989), Solomon (1987), Sutton (1989), Tobin (1990), and Wheatley (1991) have added a key focus on teachers' and students' social construction of scientific knowledge.

From a social constructivist perspective, learning is regarded as a social activity in which learners are engaged in constructing meaning through discussions and negotiations among peers, students, and teachers (Edwards & Mercer, 1987). At the same time, students' individual construction of meaning occurs when their ideas are compared, explored, and reinforced in a social setting, with each student having the opportunity to reorganise his or her ideas through talk and listening (Driver, 1990; Solomon 1987). Through social interactions, students become aware of others' ideas, seek reconfirmation of their own ideas, and reinforce or reject their personal constructions.

Discussions between teacher and students in the science classroom are regarded as valuable if they prompt the learner to ask himself/herself questions like: Are the solutions of others viable? Are they equally as viable as my solutions? What are the reasons for differences in my explanations and those of others? Answers to these questions can result in cognitive conflict which can be resolved by the group and lead to consensual understanding. However, the main reason for class discussion is to negotiate meaning so that the learner has the opportunity to express his/her ideas and explore the ideas of others. Tobin et al. (1990) describes this process as that of "comparing personal meanings to those embedded within the theories of peers" (p. 32):

. . . assignment of language to understandings and processes such as explaining, clarifying, elaborating, justifying, evaluating, analysing, synthesizing, questioning, and restructuring. These processes occur as individuals reflect on what they have learned and as they interact with teachers and peers. Students should become conscious about what they do and do not understand, develop strategies to ask peers or the teacher when they need additional information or clarification, and accept responsibility for learning with understanding.
(Tobin, Briscoe & Holman, 1990, p. 411)

Interpretive Research Questions

Together, personal and social constructivism served as an interpretive framework for extensive data collection and analysis activities, especially in relation to the more detailed research question that emerged as the study progressed (Gallagher & Tobin, 1991):

- What is the role of the teacher's epistemology in providing opportunities for students to develop higher-level thinking skills?
- How does classroom interaction enable students to develop higher-level thinking skills?

These emergent research questions reflect the complexity of the learning processes in the two classrooms observed in this study. To help answer these questions, further data were collected. Selected students 'thinking aloud' was audio-recorded while they interacted with the computerized database, interviews which investigated teachers' epistemologies were conducted, and further observations of the nature of the teacher-governed classroom discourse were recorded.

Results

The main results of the study, which are expressed in the form of interpretive 'assertions' and constitute emergent theory (Erickson, 1986), were inferred from a synthesis of the qualitative and quantitative data (Maor, 1993). This paper is concerned with the first of the four assertions:

In computerised classroom learning environments that are designed to facilitate students' scientific inquiry, teacher epistemology mediates student-computer interactions; a constructivist pedagogy provides enhanced opportunities for the development of students' higher-level thinking skills.

The paper discusses evidence that warrants this assertion. The evidence was obtained from two high school classes that were taught separately by teachers Ken and Sam. The paper discusses the two teachers' contrasting attitudes and epistemologies, and the different opportunities and constraints that they created as they mediated their students' interactions with the computerised database.

At the commencement of the study, Sam and Ken agreed that their main classroom roles would be to facilitate and guide students in using the database in order to develop scientific inquiry skills. Both teachers undertook extensive training aimed at familiarising them with the potential of the database to facilitate students' higher-level thinking. Nevertheless, classroom observations and interviews indicated that Sam and Ken mediated students' use of the database in very different ways.

Constraints of a Transmissionist Epistemology

Throughout the study, Ken's transmissionist epistemology underpinned a pedagogy that was characterised generally by:

- his unilateral control of the classroom learning environment
- his low expectations of students' abilities
- his didactic classroom discourse
- students generating narrow questions and conducting simple investigations (see Figure 1)

Transmissionist Epistemology
(Constraints) Constructivist Epistemology
(Opportunities)

- control • shared control

- low expectations
  - high expectations

- didactic discourse • student-student negotiation

- narrow questions and simple investigations • creative questions and complex investigations

Figure 1 Teachers' Epistemologies in Two Selected Classes
Teacher Control

Most of the time, Ken was authoritarian in his attitude to his students and in his teaching style. It was clear from the first lesson that he believed that he should 'transfer the knowledge' to the students, as expressed in an interview: " . . . You have to tell these students, otherwise they will not do it" (Field notes 11.6.90).

Ken preferred to read to the class the instructions in the Student Booklet. He directed students to follow the instructions and not to "miss out any questions" (Field notes 25.5.90). This attitude of 'cover the curriculum' or 'transfer knowledge' illustrates Ken's general transmissionist epistemology. He preferred a structured, step-by-step teaching approach which enabled him to monitor closely each lesson, thereby giving students very little independence to investigate the database. The following comment serves to document the nature of his general attitude and didactic pedagogy:

Use the Tab key, type in sp and follow instructions from the Booklet and you will get your Output Option . . . and then press F5.
(Field notes 10.8.90)

Another example of Ken's strong control of students' interactions with the database was documented when he gave students explanations of the variables of the database. He proceeded slowly and read all the details from the screen while the students were sitting passively and observing. This lesson wholly comprised the teacher's presentation, and the students did not have opportunities to interact individually with the database.

Generally, Ken adopted the role of lecturer and did not support self-initiation by students. For most of the time, he instructed students in what to do, and adopted a 'lock-step' approach from the beginning of the program as the next quotation from his classroom discourse illustrates: "We walk together through the database now". . . (Field notes 28.5.90). On most occasions, Ken dominated classroom discussions and, consequently, students had few opportunities to interact independently with the database or

initiate their own investigations (Field notes 15.6.90). For example, a lesson transcript shows that students gave only short answers to teacher-posed questions, and that Ken drew the conclusions to his own questions.

Based on these observations, Ken's epistemology can be described as 'largely transmissionist'. Only in a single lesson did he adopt a more constructivist approach when he described the structure of the database to the students. In this episode, he used the physical analogy of a card index file to illustrate the database structure to the students. The following quotation illustrates how he used the card catalogue as a physical visual analogy, that was familiar to the students, to demonstrate the structure of the database to the class:

I like to get students to think about a card file system where they can see concrete cards with all the information written on them. . . . It is only when you approach these students in physical terms that they have a good chance of understanding and applying concrete ideas to the software which is quite abstract. (Interview 1.6.90)

Subsequent to Ken's demonstration, many of the students seemed to construct viable understandings of the database and were able to overcome some of the constraints which they were experiencing. Ken based his strategy on students' prior knowledge to overcome some misunderstandings and to make learning more meaningful.

Teacher's Low Expectations

When Ken was asked whether he intended to give the students more responsibility for their own learning, he responded:

It depends upon the amount of success which they are getting and whether the students find it easy to produce what the Booklet requires. But if it's too difficult for them, they will not see it as a challenge and they will just give up. (Interview 28.5.90)

Ongoing observations showed that students in this class were expected to follow a strict teacher-directed routine before beginning each computer session. In this routine, students were not allowed independently to pick up their Student Booklet, but were required to wait for the booklets to be distributed by one of the students and, only then, to begin work all at the same time. Classroom observations also revealed that students developed a dependency on either the teacher or researcher, and did not continue to the next worksheet unless directed to do so by the teacher.

Although Ken had been familiarised with the potential of the database to cater to individual students' learning needs, he largely failed to encourage students to explore the database independently, although he acknowledged that the more able students were capable of working independently.

Teacher's Didactic Classroom Discourse

In Ken's class, discussions that focused on making sense of the database were limited in scope. Although Ken allowed students to interact with the database, most of the time he imposed on the whole class his conclusions about the Student Booklet activities. Ken's largely transmissionist epistemology limited students' opportunities to negotiate with each other and make sense of their experiences in a social context.

Although Ken's whole-class discussions were aimed at resolving problems that he had detected while monitoring students' interactions with the database, they resulted usually in teacher-centred discourse. For example, on one occasion he drew the globe of the Earth on the white board in order to explain the concepts of latitude and longitude. He referred to a question in the Student Booklet, and the following discussion took place about birds called Petrels:

Teacher: Where do you find the Snow Petrel?
Student: 62 °E. (Teacher writes on the board.)
Teacher: Where do you find the White Chinned Petrel?
Student: 82 °E, 120 °E. (Teacher writes on the board.)
Teacher: And the Antarctic Petrel?
Student: 62 °E. (Teacher writes on the board.)
Teacher: What is the preferred ice condition of the Snow Petrel?

(Field notes 17.8.90)

During this instructional event, Ken continued to ask 'informative type' questions and to acknowledge correct answers. After the students had answered all of his questions, he stated that "we can deduce a couple of things", and continued to conclude and summarise the investigation (Field notes 17.8.90). He did not allow students to be engaged in discussions in order to arrive at consensual understanding, and restricted their verbal interactions. At other times when discussions occurred, interactions took place mostly between Ken and small group of students, rather than amongst students themselves.

Student-student interactions in Ken's class were not as frequent or meaningful as those in Sam's class. Ken's students were provided with only limited opportunities to negotiate meaning and reflect on other students' ideas. These discussions were not stimulating or motivational experiences to the extent that would be expected from a social constructivist perspective on teaching and learning.

Narrow Questions & Simple Investigations

Ken provided very few opportunities for students to develop creative questions. Throughout the study, most students in Ken's class generated narrow questions which required little more than simple investigations on the database. Their repertoire of questions was limited to the examples provided in the Student Booklet. Consequently, their understanding of the opportunities existing in the database was limited to what appeared 'on the screen', and they did not demonstrate the requisite creative thinking for using the database 'to its limit'.

The following examples illustrate the narrow factual type of student-generated question which focused their database investigations on only a single variable:

- How many observations were made when the wind speed was 10 knots? (Natalie's booklet, p. 32)
- How many bird species were around when the air temperature was 3 °C? (Gen's booklet, p. 37)
- What were the average ice conditions? (Geoff's booklet, p. 26)
- What wind speed do Snow Petrel prefer? (Gen's booklet, p. 37)

Entries in students' booklets revealed very little change in the type of student-generated question during the program. For example, extracts from Tara's Booklet illustrate that she did not progress beyond the generation of factual questions:

- How many South Polar Skua were seen when the air temperature was 5°C? (Tara's booklet, p. 37)
- When did [the voyage] start? (Tara's booklet, p. 46)
- What is the most preferred wind speed? (Tara's booklet, p. 52)

Although Ken's students had generated a variety of questions towards the end of the program, the questions continued to be of a narrow factual type. For example, at the beginning of the program, Adam asked the single-variable question: "What was the average sea temperature over the test [time]?" (Field notes 15.6.90). However, when his manipulation of the database improved, he asked questions which incorporated three variables: "How often was [the Wandering Albatross] travelling in the same direction as the ship with wind speed 4 [moderate breeze]?" (Field notes 17.8.90). These more complex questions, which were generated by a small minority of students, are evidence of a transition towards the development of higher-level thinking skills. Nevertheless, when compared with the creative questions generated by students in Sam's class, the three-variable questions elicited largely factual information from relatively strightforward investigations of the database.

Because of his largely transmissionist epistemology, which underpinned a very teacher-centred classroom learning environment, Ken provided few opportunities for his students to initiate or control their learning, negotiate meaning with their peers, generate creative questions, or conduct complex investigations. Only a few students demonstrated the ability to make a transition towards developing higher-level thinking skills.

Opportunities of a Constructivist Epistemology

By contrast, a generally different style of teaching occurred in Sam's class where his constructivist epistemology underpinned a pedagogy that was characterised by:

- his willingness to share with students control of the learning environment
- his high expectations of students' learning abilities
- his initiation of student-student negotiation
- his encouragement of student-initiated negotiation
- students generating creative questions and conducting complex investigations (see Figure 1)

Student Control

In the first lesson, Sam allowed the students to experience independently the database after his brief verbal introduction. Most of the students tried immediately to interact with the database and, at the same time, tried to read the instructions in the Student Booklet (Field notes 21.5.90).

In the second lesson, however, Sam conducted a largely whole-class discussion of the database language. In an interview after that lesson (25.5.90), Sam expressed his concern that, by stopping students' 'trialing' in order to focus on the database language, he might have been holding back some of the "brighter kids" by not letting them explore by themselves:

I felt that I was holding students back. I wanted them to have a better start to the program as you [the researcher] expected from me.

(Interview 25.5.90)

Sam exhibited more of a transmissionist approach to teaching on this occasion because he felt that this approach was expected by the researcher. However, after clarifying the issue with the researcher, he restated his goal:

I will break the flow of work by posing questions, and promote class discussions and verbal interactions in the classroom as the need arises.

(Interview 25.5.90)

Unlike students in the other class, Sam's students developed the habit of picking up their computer disks and booklets when entering the class, and immediately started their work at the computers.

Teacher's High Expectations

Very early in the study, Sam expressed confidence in students' ability to develop higher-level thinking skills:

As these kids become better at using the database, they'll be able to develop the other type of thought [inquiry skills].

(Interview 11.6.90)

This illustrates an aspect of Sam's constructivist perspective which harboured high expectations of all students.

Teacher-Initiated Negotiations

Early in the study, when students in Sam's class experienced problems, either with the database language or in visualising the structure of the database, Sam initiated an interactive form of whole-class discussion that encouraged students to respond to each other's problems and ideas. Students left their computers and gathered either in the centre of the room, or by one of the computer screens, in order to discuss the problem. In these discussions, students helped one another to solve a variety of problems, including retrieving information, using the technical language of the computer, and using the Help Screen (Field notes 8.6.90).

As the study continued, Sam involved the students in more complex arguments. At times, this type of social interaction created conflicts, especially when different student designs for investigating the same question resulted in different learning outcomes. For example, during a whole-class discussion students attempted to resolve a conflict about which one of a number of answers to a problem was the 'right' answer. After much teacher-guided debate, they concluded that the method of investigation influenced the result and that, therefore, there was more than one 'right' answer to the problem (Field notes 5.9.90). This example illustrates how a teacher-guided, whole-class discussion resulted in a negotiated settlement that was acceptable to all students. The teacher exposed students to conflict situations and enabled them to elaborate their ideas through negotiation with each other. This example illustrates the social constructivist epistemology which Sam tried to promote in his class.

By contract, when a similar problem occurred in Ken's class, Ken did not initiate a whole-class discussion and the matter went unresolved with students remaining puzzled about the nature of the 'right' answer.

Another example of Sam's initiation of whole-class negotiation in order to enable students to resolve a problem occurred when a student asked a question about the relationship between ice condition and the latitude and longitude of the ship's position. Rather than answering the question himself, Sam broke the student's question into two parts and asked the class to respond. First, he invited an explanation of the relationship between ice condition and latitude. A student, Koie, replied:

> Latitude and ice condition . . . latitude increases . . . ice condition increases. (Transcript 5.9.90).

Next, Sam asked the class to explain the relationship between ice condition and longitude. However, the class seemed to be unsure about how to answer. Then, Sam asked two students, Shaun and Jim, to conduct an investigation on their computer and to display the results using either the Display Option or a Scattergraph, Barchart or Histogram. The class gathered around the two computers while Shaun and Jim conducted the investigation by using the Scattergraph option. They printed the graphs and distributed copies among the students. Sam asked the students to think about the relationship between the variables. As a result, the following whole-class conversation took place:

Simon: Latitude increases and we get more ice.
Teacher: As latitude increases, we get more ice. Do you agree with that Jim, Natalie? Anyone disagree? Right, have a look at a longitude graph. What do you find?
Geoff: As longitude increases, the ice decreases.
Teacher: Why?
Shaun: Because you are looking at a range of latitude and not all of them, and a range of longitude . . . ?
Teacher: Why is the longitude. . .
Shaun: Because Antarctica is not a circle.
Geoff: I don't understand.
Shaun: See for yourself! It's covered the latitude from there [points on screen], and all the way around from there, and all the way around to there [points on screen]. The ice is different around.
Teacher: Ok. . . but does that affect what happens? What is the most important factor which determines whether or not we're going to find ice? (Fieldnotes, 5.9.90)

Although Sam was not sure about the answer, he challenged the students with this last question (Interview 7.9.90). This question spawned a very stimulating and controversial discussion about the possible answer and, more so, about the database itself and its limitations as a research tool:

Edward: Sea temperature.
Teacher: Think about it. On our trip, what is the most important factor which will determine when and where we find ice?
Geoff: Longitude, no latitude, yeah.
Teacher: We're on a boat.
Geoff: Latitude.
Edward: Sea temperature.
Natalie: Air temperature.
Shaun: [to the teacher] Are you looking for one single answer? You can't see it on the screen.
[At this point students were shouting different answers and arguing among themselves.]
Teacher: How about how close we are to Antarctica?
Geoff: That is latitude. We're just saying that. That's what latitude is. But, more important, it's looking at specific

coordinates.
Shaun: That's right, that's what I mean. It's looking at its longitude with respect to its latitude. . . because you can see [refers to the screen] that, if you turned them around, they're just about the same.

Teacher: Why do we have greater ice in a change in longitude? [Sam emphasises with his voice the importance of the issue.]
Shaun: Because you are looking at coordinates and not longitude.
Natalie: . . .[L]ongitude, and you're down there at that latitude . . . closer to Antarctica.
Teacher: Exactly.
Shaun: That's what I meant by coordinates . . .
Simon: Coordinates of the location of the boat.
          (Field notes 5.9.90)

As a result of this controversial discussion, Sam referred to the database and asked students' opinions about whether it provided enough information to answer the question. Edward argued that the database gave a lot of information but that: "You just can't make any decision on it." Shaun added that "that's definitely a misleading question. It's ambiguous." The argument continued for the rest of the lesson while students tried to decide whether the question was misleading, the information in the database was not sufficient, or, as Edward summarised in frustration:

All the way through this database it asks you to think, it asks you to apply your knowledge and say "why is this happening?" . . . It's a paradox now, because the Scattergraph didn't show it [the direct relationship between the ice and longitude].   (Field notes 5.9.90)

These excerpts from class discussions illustrate how students were able to negotiate the meaning of an ambiguous question with the teacher, but, in this case, were not able readily to reach a conclusion or consensus. This pattern of behaviour falls within the framework of constructivism in that the teacher and students were engaged in inquiry-based sense-making while they were trying to explain and justify their arguments.

Student-Initiated Negotiation

In addition to initiating whole-class discussions, Sam actively encouraged students to become involved in student-initiated discussion and negotiation at the whole-class level. For example, in response to a student-intitiated question about the use of a Venn diagram to solve a problem, Sam chose to deflect the question to the class:

Can anyone answer that? It's not one of my strong points.
(Field notes 20.6.90)

As the study progressed, students in Sam's class became accustomed to initiating class discussions when the need arose. Five examples are discussed briefly. First, when students were asked to plot the path of the ship, most students in both classes used the Scattergraph Option and managed to display the path of the vessel on their screens.
In relation to this activity, a student in Ken's class (where a transmissionist epistemology prevailed) posed a question about the direction of the ship which could not be determined from the Scattergraph. This question created an opportunity for a class discussion. Although students suggested methods for finding the path of the ship, ultimately the class accepted Ken's recommended method and his (less than optimal) design for the investigation. In this way, Ken limited students opportunities to engage in their own investigations.

By contrast, in Sam's class, students took control of the class discussion which centred around this question. After a long debate about the direction of the ship, the students presented alternative methods for finding the direction of the ship and, subsequently, adopted a student's suggestion. In this class, students became comfortable with whole-class discussions to the extent that student-initiated discussion and negotiation became a routine and integral part of the learning process.

Observational notes illustrate several cases where one of Sam's students assumed the role of the teacher by facilitating class discussion and encouraging other students to participate. In an episode reported earlier, a student named Shaun used the white board to explain the way in which he used a Venn diagram to design his investigation. While he was explaining his strategy, he asked students for their opinions about his design and involved them in a debate about the use of three variables (Field notes & Transcript 20.6.90).

On another occasion, students in this class challenged each other to provide reasons for their hypotheses. Jim and Shaun assumed the teacher's role in leading the class discussion by criticising students' hypotheses that were not supported by adequate data. Consequently, Shaun and Jim stimulated argument about the need to provide additional support for a hypothesis through different investigations. On this occasion, Sam chose to adopt a passive role, and allowed the students to lead the discussion (Field notes 18.6.90). Based on his constructivist epistemology, Sam acted as a facilitator for the negotiation of meaning in class discussions.

A fourth example of a student-initiated discussion occurred when Shaun posed questions about which was the tamest bird of the 26 species (Field notes 15.6.90), and what was the migration period of some species (Field notes 15.6.90). He explained the investigations that he had designed and asked classmates to respond. Jim, another student in the class, responded to Shaun's inquiry and encouraged other students to conduct an investigation in order to answer Shaun's question. The focus of this discussion, which was on students' explanations and justifications, signifies a classroom environment based on the principles of personal and social constructivism.

Finally, Edward, another student in Sam's class, generated a highly creative question and initiated a discussion about why the Antarctic Skua was observed by scientists to be in isolation from other birds. After reading in the library, he presented the class with new information which, consequently, generated an intriguing discussion about the limitations of the database in regard to information that was not included by the scientists on this voyage (i.e., pictures of the birds).

The examples mentioned above illustrate that students in Sam's class became very involved in class discussion when they generated their own questions and sought to negotiate with other students.

Creative Questions and Complex Investigations

Students in Sam's class benefitted from his constructivist pedagogy to the extent that they had more opportunity to generate creative questions and to undertake complex investigations with the database and other resources, especially in the later stages of the study. For example, Edward generated the following creative questions about a species of bird, the South Polar Skua, that he had captured his imagination:

Basically I set myself a task to explore the living conditions of the South Polar Skua, and I was sort of trying to work out things like how did it interact with other bird life forms, and draw conclusions from that as to its general capacity for living in the Antarctic and how it actually lived there. (Interview 17.8.90)

Edward retrieved the information for his investigation from the database and drew relevant conclusions about the bird species:

One thing I did find was that most of the other birds, when they were observed, were with other species. But with this bird it was alone. I mean it only appeared in ones or twos. Why does this happen when all the other birds interacted with each other? So the conclusion I drew from that was that possibly it was a bird of prey, a hunter. It preyed on other birds.
(Field notes 15.8.90)

Subsequently, Edward offered a range of hypotheses as to why the South Polar Skua was observed by scientists to be in isolation from other birds:

[M]aybe they prey on other birds, maybe they're smaller than other birds and they get preyed on when the other birds are around, or perhaps the conditions in which they hunt and the way they hunt are different from any other bird, and having any other birds around would lessen its chances of being able to find prey. Or maybe it's just the fight for food.
(Transcript 15.8.90)

On the basis of his finding that this bird species was observed to be alone, and on the assumption that the species was either a predator or was preyed on by other birds, Edward made further studies of the species by using the school library as his main resource:

I went to the library to find out whether my hypothesis . . . my conclusions were correct. . . . Indeed, it is a scavenger, it is a hunter, . . . It eats birds and small mammals, and it hunts eggs, especially from the Adelie Penguin. (Interview 17.8.90)

Edward concluded his lengthy and fruitful investigation by presenting the final conclusions to his peers. In a later interview, when Edward was asked to reflect on this particular experience in relation to the database, he responded:

When I'm given information [from the database], I'm not just saying that's the information. . . . I'm sort of thinking "but why is that so?" . . . Now, I can actually draw my own conclusions from the information that I'm presented with. (Interview 17.8.90)

This example illustrates the complex type of investigation that is possible in a classroom learning environment that is shaped by a constructivist epistemology. The student was able to exploit the opportunity to generate creative questions and conduct a relatively complex scientific investigation that involved reflecting on his own learning.

Sam's higher-expectations of his students and his facilitative instructional role provided richer learning opportunities that enabled a majority of students in his class to generate creative questions and conduct complex investigations. Student- -generated questions stimulated students to conduct series of follow-up investigations. Their questions were not confined to the content of the database, but were extended to related areas. Sam encouraged students to base their questions on their prior knowledge, reflect on their ideas, and reshape their ideas by means of negotiation with their peers.

Conclusion

This study has highlighted the influential role of teachers' epistemologies in facilitating students' development of higher-level thinking skills. The personal epistemologies and pedagogies of two teachers were examined, and their mediation of students' interactions with a scientific database was investigated.

In Ken's class, a largely transmissionist approach to teaching and learning resulted in fewer opportunities for students to be involved in discussion and negotiation of their database activities. Generally, the discussions in this classroom were initiated and controlled by the teacher, were mostly didactic and 'led' students to pre-determined conclusions, and embodied the teacher's low expectations of students' ability to work independently with the database. Students generated mostly narrow, factual type questions and conducted relatively simple investigations with the database. Only a few students in this class demonstrated the ability to make a transition towards developing higher-level thinking skills.

In Sam's class, however, a largely constructivist approach to teaching and learning provided more opportunities for students to be involved in class discussion and negotiation and to generate creative research questions for which they designed and conducted their own complex scientific investigations. Sam frequently challenged the students with questions that spawned stimulating and controversial discussions about the database and its limitations as a research tool. In this class, discussion between teacher and students was an integral part of the program, and students constantly negotiated meanings and argued their ideas in the whole-class forum. By verbalizing and reflecting on their own thinking, students became aware that they were performing an active role in their own learning processes. It was evident that the teacher's constructivist-oriented personal epistemology was reflected in the teaching-learning processes which enabled the majority of students to develop higher-level thinking skills.

It was evident that social interaction in the classroom was a major contributor to the development of students' higher-level thinking skills. Bell (1991) characterises higher-level thinking skills as students involvement in asking creative questions, asking reflective questions about their learning, debating wrong answers, clarifying confusion, reflecting on their own views, considering new ideas, testing out their conflicting ideas, and negotiating meaning in group discussions. In this study, evidence was obtained of many of these characteristics of higher-level thinking skills. The evidence was most apparent in the classroom learning environment that was shaped by a constructivist epistemology.

Results of this study indicate that the use of computers in inquiry-based science classrooms offers the potential to facilitate higher-level learning amongst students. However, in a computerized classroom environment, the teacher's epistemology plays a critical role in mediating students' learning. This study illustrates that teachers who retain a transmissionist epistemology while adopting seemingly inquiry-based teaching approaches might fail to develop a pedagogical focus on the promotion of students' higher-level thinking skills. By contrast, it seems likely that teachers who adopt constructivist pedagogies which promote both the personal and social processes of knowledge construction might enable students to exploit better the potential of computerized databases for developing the higher-level thinking skills associated with the generation of scientific understandings.

There is a common belief amongst educators that computers are a tool of inquiry learning, but this study suggests strongly that substantial changes in teaching practice are required for this to occur. The computer, in itself, does not necessarily facilitate inquiry learning; it is the teacher and the students who grasp the tool to facilitate collaborative inquiry. Further research is needed to investigate the conditions that are required to promote constructivist approaches to teaching and learning in computerized learning environments in order to facilitate students' development of higher-level thinking skills.

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