An Exploration of the Concept Map as an Interview Tool to Facilitate the Externalization of Students’ Understandings about Global Atmospheric Change

James A. Rye, Peter A. Rubba

1Department of Curriculum and Instruction, West Virginia University, Morgantown, West Virginia 26506
2Department of Curriculum and Instruction, Pennsylvania State University, State College, Pennsylvania 16802

Received 8 May 1996; revised 13 June 1997; accepted 28 October 1997

Abstract: The primary purpose of this study was to investigate the effectiveness of two different types of interviews—one that did (POSTICM) and one that did not (POSTI) embed a concept-mapping process—to elicit students’ postinstructional understandings about chlorofluorocarbons and their role in global atmospheric change (GAC). A chief criterion measure was accordance, the degree to which students held the ideal postinstructional understanding set forth in a teacher-expert concept map. After GAC instruction that included concept-mapping activities, 34 eighth-grade science students were assigned randomly to groups and completed either POSTICM or POSTI. These students and their teacher also completed relatedness ratings of central concepts from the teacher-expert map. The Knowledge Network Organizing Tool™ was used to transform relatedness ratings to Pathfinder networks and compare nets to yield a student to teacher similarity index (Pathfinder index). Regression analysis revealed that type of interview did not predict accordance. However, most POSTICM students perceived the concept-mapping interview component to be helpful and affect positively their answers to the interview questions. The Pathfinder index did predict \( p = .003 \) accordance—the Pathfinder index was a reliable confirmatory measure of the degree to which students held the ideal postinstructional understanding. J Res Sci Teach 35: 521–546, 1998.

Over the past decade, the concept map has emerged as a versatile and promising tool in the area of science education, especially in research that seeks to investigate students’ conceptual understandings (Good, Novak, & Wandersee, 1990; Markham, Mintzes, & Jones, 1994; Wandersee, Mintzes, & Novak, 1994). The concept map finds support in semantic network and schema theories (Jonassen & Marra, 1994), Quillan’s (1968) model of active structural networks and spread of activation theory (Benjafield, 1992; Reichgelt, 1990), and Ausubel’s theory of meaningful learning (Ausubel, Novak, & Hanesian, 1978; Novak, 1992). The latter also is known as assimilation or subsumption theory, and underlies hierarchically framed concept maps.
Concept mapping was developed as a strategy to probe knowledge structures of learners (Driver, 1989). Its use in representing and assessing students’ conceptual understandings, alternatively termed structural knowledge (Jonassen, Beissner, & Yacci, 1993) or cognitive structure (Acton, Johnson, & Goldsmith, 1994; Geeslin & Shavelson, 1975), was pioneered by Novak and colleagues (Horton, McConney, Gallo, Woods, Senn, & Hamelin, 1993; Novak, 1990; Novak & Musonda, 1991). Novak and Gowin (1984) recommended three uses of concept maps in concert with interviews to evaluate students’ understandings: (a) to inform the development of interview questions, (b) to explicate post hoc student understanding data captured by the interview transcripts, and (c) to assess student understandings as captured in the transcripts. Wandersee et al. (1994) cited Novak and Gowin as “see[ing] concept maps constructed from taped interviews as an excellent way to multiply the power of two tools [concept maps and interviews]” (p. 200). These interview-related applications of concept maps have been applied by several researchers (e.g., Auld, 1990; Brody, 1991; Heinze-Fry, 1987; Novak & Musonda, 1991; White & Gunstone, 1992) and are reviewed elsewhere (Rye, 1995).

Central to the research conducted by this study is the supposition that concept mapping, when employed as an integral component of a concept interview (White & Gunstone, 1992), will facilitate the externalization of students’ understandings. In discussing the dimension of availability of knowledge, White (1985) posited that individuals who are equally knowledgeable may differ in their facility to recall relevant elements of that knowledge and that “the source of such a difference is an absorbing realm for research . . . if explained, may lead to dramatic improvements in human performance” (p. 56). Accordingly, interview-based research that seeks to investigate students’ understandings must recognize a central concern, that being the researcher’s ability to externalize those understandings. The researcher’s ability to elicit knowledge is identified widely as a problem area (Cohen, 1991; Firlej & Hellens, 1991; LaFrance, 1992; Pidgeon, Turner, & Blockley, 1991; Swaffield, 1990). In his discussion of methodological difficulties surrounding the interview, Shuell (1985) remarked that “students often are not able to articulate what they know” (p. 123). Pidgeon et al. (1991) quoted Polanyi, who contended that “we know more than we can say” is a significant social science concern.

The concept map is a graphic metacognitive tool (Johnson & Thomas, 1992; Novak, 1985; Wandersee, 1990; West, Farmer, & Wolf, 1991), which provides an external representation of structural knowledge—a visual image—in the form of a two-dimensional semantic network (Jonassen, 1996). As such, the concept map potentially extends working memory and encourages critical thinking; it may trigger recognition, thereby lowering the threshold of availability and increasing recall of knowledge held in long-term memory (Ausubel et al., 1978). Metacognition (Flavell, 1985) includes “strategic actions of the reasoner” (Eylon & Linn, 1988, p. 280) such as questioning, self-checking, and generating alternatives. The concept map, as a “mind-tool” (Jonassen, 1996), may facilitate such strategic actions in the interview setting. For example, it may cause students to reflect more so on what they know and say, thereby stimulating spread of activation and leading to further recall and elaboration (Gagne, 1985; Johnson & Thomas, 1992; Wandersee et al., 1994).

A literature review failed to disclose research on the concept map as an interview tool to enhance students’ recall and elicitation of knowledge, relative to the interview questions posed. Wandersee and colleagues (James Wandersee, personal communication, November 24, 1993) reported their development of a “coconstruction of concept map” technique that is deployed in the interview setting. Gordon and colleagues (Gordon & Gill, 1989; Gordon, Schmierer, & Gill, 1993) described an interview-based process termed concept graph analysis to “extract” knowledge from experts. In this study, the investigators adapted concept graph analysis to design a teacher-expert concept map, which became a referent for analyzing student interview transcripts.
In concept graph analysis, question probes are employed with an evolving conceptual graph structure that facilitates elicitation and verification of the expert’s understandings. The conceptual graph structure becomes the “expert” representation of knowledge. Gordon et al. (1993) reported that the use of interview question probes in concert with conceptual graph structures provides a “sensitive means of measuring student knowledge structures” (p. 479). McCagg and Dansereau (1991) provided a brief review of research that has used expert-generated knowledge maps.

A teacher-expert concept map also was used in this study to identify concepts for Pathfinder analysis (Schvaneveldt, 1990). Pathfinder networks are two-dimensional link-weighted graphic representations of structural knowledge (Jonassen et al., 1993) derived through application of the Pathfinder scaling algorithm (Goldsmith, Johnson, & Acton, 1991) to the relatedness ratings of concept pairs. They may be compared to yield an index of configurational similarity (Goldsmith et al., 1991) or “closeness” (Acton et al., 1994) of each student’s to the teacher’s net. This configurational similarity index (Pathfinder index) is believed to be an excellent measure of students’ structural knowledge (Jonassen, 1993).

The Pathfinder network is a relatively new tool in educational research (Goldsmith et al., 1991). However, Geeslin & Shavelson (1975) introduced over 2 decades ago the idea of closeness in describing a similarity matrix constructed from concept relatedness data. In addition, semantic proximity data (central to Pathfinder analysis) was employed by Shavelson and colleagues (Geeslin & Shavelson, 1975; Shavelson, 1974) to generate via multidimensional scaling graphic representations of students’ understandings. Pathfinder networks differ from graphic representations derived from multidimensional scaling in that the former explicate local concept relationships whereas the latter capture global relationships (Acton et al., 1994). According to Acton et al., “the literature suggests that Pathfinder networks capture the structure of conceptual (rather than perceptual) domains better than multidimensional scaling” (p. 305). Jonassen et al. (1993) concurred, contending that the Pathfinder network “better represents local or pairwise comparisons between concepts in a knowledge domain” (p. 74).

This study explored new ground by using an expert concept map to inform Pathfinder analysis and in examining the predictive validity of the Pathfinder index for student performance in the interview setting. A review of the literature revealed no studies that apply in concert these tools to data analysis in the manner described here. Wilson (1994) did employ the Pathfinder algorithm in an investigation of the differences in concept maps of high and low achievers in high school chemistry. The similarity index of the Pathfinder networks of the two groups—high and low achievers—was low (.38). The Pathfinder network of the high achiever’s group had the more broad inclusive concepts located centrally and the more concrete concepts located on the periphery, whereas the net of the lower achiever’s group placed less inclusive concepts centrally.

Background

This study emerged from research that was part of a National Science Foundation–sponsored Teacher Enhancement Project for middle-level science teachers (Rubba, Wiesenmayer, Rye, & Ditty, 1996). During the early stages of the project, teams of teacher-participants developed Science–Technology–Society (STS) “investigation and action” units (Rubba & Wiesenmayer, 1985) on global warming. Each unit contained lessons that presented STS foundations and a general awareness of STS issues prior to lessons that honed in on investigating and taking action on global warming. As part of formative evaluation of these units, project staff conducted semistructured interviews (Merriam, 1988) with students to elicit their postinstructional
understandings about global warming. Analysis of the interview transcripts incorporated the concept map tool as an expert referent derived from document analysis (Jonassen et al., 1993; Rye, Rubba, & Wiesenmayer, 1994). In addition, the concept map tool was employed during a small number of the interviews: The student was asked to concept map what he or she believed to be important parts of his or her verbal response to certain interview questions. At the close of the interviews, the interviewer solicited the students’ perceptions of this process as a means to help them answer these interview questions. The students’ responses, such as “They [concept maps] give you ideas to the answers to the questions,” suggested the merits of the concept map, as process and evolving product, to facilitate the externalization of students’ knowledge in the interview setting. Transcript excerpts from two other of these students follow, which speak to the supposition that the concept map may facilitate metacognition, and elaboration and explanation by students of their understanding:

Guy: It [concept mapping parts of my answer] made it clearer so that I could understand what I thought about. . . . When I think about things I just think about things one at a time. This put it all together and I can think about it more clearly.

Janelle: As I was writing the things and I could see them there, it made me think that there are also more things that made, you know . . . just seeing them helped me think of more things.

The experience gained through and the findings (Rye, Rubba, & Wiesenmayer, 1997) from the endeavors described above informed many aspects of the study set forth here, including: (a) the development of interview protocols, (b) techniques for data collection and analysis that incorporated the concept map tool, and (c) the choice of chlorofluorocarbons (CFCs) as a subset of the domain—global atmospheric change (GAC)—in which to investigate students’ conceptual understandings. Many of the students who had completed the STS-global warming instruction gave evidence of holding alternative conceptions that involved CFCs—over one half believed that ozone layer depletion was a major cause of global warming (Rye et al., 1997). The STS unit2 (Rubba et al., 1995) that guided the instruction in this study had been revised to help students restructure such alternative conceptions and to target other GAC issues. Thus, instruction from the revised unit became known as “STS-GAC.” In addition, the unit revisions included an increased emphasis on the concept map. Several of the lessons incorporated concept maps/mapping, and a self-instructional appendix on the what, why, and how of concept mapping was included for science teachers.

The individual who served as the teacher-subject and reference expert in this study was a veteran science teacher and an exemplary participant in the teacher enhancement project referred to above. She had considerable interest in the concept map as a science education tool.

Purpose

The primary purpose of this study was to investigate the effectiveness of two different types of postinstruction concept interviews—one that did or one that did not embed a concept-mapping process—as a means of eliciting students’ postinstruction understandings about the nature of, source of, and problems caused by CFCs. Several dependent variables of conceptual understanding were defined (White & Gunstone, 1992). Chief among these was the criterion measure of accordance (ACCORD), which represented the extent to which the student explicated during the interview the concepts and concept relationships that comprised the ideal postinstructional understanding. This ideal understanding was based on the instruction provided by the classroom
teacher and was set forth in a teacher-expert concept map. An important research question was whether an interview that embeds concept mapping (compared to one that does not) increases significantly ($p < .05$) the externalization of ACCORD.

Two other criterion measures (White & Gunstone, 1992) of students’ conceptual understanding examined in this study were as follows: (a) external relatedness (EXTERN), as defined by all other GAC concepts set forth in concept maps that were placed at the beginning of each investigation lesson in the STS-GAC unit, and valid concept relationships between the teacher-expert and these other GAC concepts; and (b) interrelatedness (INTER), as defined by the mean number of relationships per concept (Stensvold & Wilson, 1990), where concepts were teacher-expert and other GAC concepts (as described above), and relationships were those that comprised accordance and external relatedness of understanding. Corresponding research questions addressed type of interview as a predictor of EXTERN and INTER.

A secondary purpose of this study concerned the addition of the independent variable, Pathfinder index, to two-parameter regression models that included the predictor type of interview. Research questions posed were (a) whether the Pathfinder index improves significantly ($p < .05$) the prediction of ACCORD and (b) whether there is a statistically significant ($p < .05$) interaction between the Pathfinder index and type of interview as it regards the prediction of ACCORD. This study also sought an answer for the question of the students’ perceptions of the processes instituted in the interviews as means to “tell what I know.”

Methodology

Subjects and Research Design

This study was conducted in a junior high school located in a semiurban area of the northeastern United States. Subjects were an eighth-grade physical science teacher and student volunteers from four sections of her physical science course. Prior to the study, the teacher introduced her students to the concept map tool and provided instruction from the STS-GAC “foundation and awareness” level lessons and on other course content. This period spanned 3 months and did not include any instruction on CFCs. Subsequently, student volunteers were recruited for the study (parents provided informed consent). A total of 38 student volunteers—approximately two third female—completed an initial (preinstruction) interview, which was conducted chiefly for the purposes of removing the novelty to students of the interview setting. None of the preinstruction interviews embedded concept mapping. However, they did pose questions to elicit students preinstructional conceptions of CFCs, which are presented elsewhere (Rye, 1995).

The STS-GAC instruction from the investigation level lessons followed the preinstruction interviews and spanned a 5-week time period. Students had the opportunity to learn science content that underlay global warming and ozone layer depletion, and as such included instruction on CFCs. The teacher used concept maps to convey certain GAC content and assigned several concept-mapping exercises to the students. However, students were not assigned to develop concept maps in which CFCs were the focus or most superordinate concept.

Following the investigation level instruction, the students who were present for at least 75% of this instruction and had completed the preinstruction interview were randomly assigned to two different type of interview groups. Each of these groups consisted of 18 students. Seventeen of the students assigned to each group completed a second concept interview: a postinstruction interview that embedded a concept-mapping process (POSTICM) or one that did not
embed that process (POSTI). Independent two-sample $t$ tests verified that these two groups did not differ significantly ($p < .05$) on the scaled scores from the Grade 7 take of the California Achievement Test verbal component ($t = -.228, df = 31, p = .821$) or component total ($t = .406, df = 31, p = .688$) (CTB McGraw-Hill, 1986). Also, the teacher certified that all students who completed either type of interview were competent in concept mapping.

After the completion of the STS-GAC investigation instruction, interviews also were conducted with the teacher to develop the teacher-expert concept map. In addition, after the postinstruction interviews were completed, the classroom teacher completed a classroom activity in which students rated the relatedness of concepts central to an understanding of CFCs and supplied the investigators with the ratings data (used later for Pathfinder analysis).

**Data Collection**

All data were collected by the first author. The tools used to collect data were: (a) the investigator as interviewer (Erlandson, Harris, Skipper, & Allen, 1993); (b) standardized open-ended interview protocols (Patton, 1990); and (c) for the POSTICM and teacher interviews, the concept map and construction materials (e.g., a ceramic dry-erase board and blank sticky notes).

**Investigator.** The investigator’s experience with interview-based research targeting students’ conceptual understanding of global warming was set forth previously. The investigator also possessed a sophisticated understanding of GAC relative to the science content that comprised the STS-GAC instruction. Novak and Musonda (1991) pointed to the importance of such in their interview and concept map-based research of students’ understandings in science: “We found that it was essential for interviewers to have a sound grasp of the science concepts involved in the interview. . . . ” (p. 124). This also is critical to the interviewer’s issuance of declarations of complexity (Dana, Dana, Kelsay, Thomas, & Tippins, 1992) during the interview as well as to carry out data analysis of the emergent interview transcripts.

**Postinstruction Student Interviews.** The POSTI and POSTICM were conducted in a private setting in the junior high school during normal school hours, and were tape recorded, transcribed, and verified against the tape. The interviews began approximately 1.5 weeks after the completion of the investigation instruction and were conducted over 8 sequential school days. The POSTI ranged in length from 18 to 39 min and the POSTICM from 28 to 50 min. Approximately equal numbers of POSTI and POSTICM were conducted on each day. The interview protocols conformed to specifications set forth by recognized authorities (Novak & Gowin, 1984; Osborne & Freyberg, 1985; White & Gunstone, 1992), e.g., the interview questions were open-ended, nonleading, and sequenced from somewhat broad to more specific. In addition, a separate study (Rye, 1995) was conducted to pilot-test these protocols and resulted in minimal changes.

The POSTI and POSTICM each were designed to include the following components: (a) a verbal explanation by the interviewer of the purpose and processes involved in the interview, including that questions would be posed about CFCs; (b) up to 6 min of quiet time (Heinze-Fry & Novak, 1990) for students to think about CFCs and jot down thoughts and ideas that they believed were important, for future reference while answering the upcoming interview questions; (c) questions to elicit the students’ conceptual understandings about CFCs (Table 1); (d) the provision by the interviewer of reflective/verification statements (Dana et al., 1992; Spradely, 1979)
in response to the students’ answer to each question (Table 1); and (e) questions to elicit the students’ views on the interview as a means to “tell what I know” (Table 2).

The POSTI and POSTICM differed in that the POSTICM embedded a concept-mapping process that: (a) involved the student in constructing a concept map which set forth what the student believed were important parts of his or her verbal responses to the interview questions, (b) included dialogue between the interviewer and student relevant to the concept-mapping process, and (c) explicated an evolving visual—the student’s concept map—for the student to view and reflect upon as the interview progressed. The concept-mapping interview component [see Rye (1995) for a detailed account] included few “task constraints” and did not restrict the

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Questions to elicit students’ conceptual understandings about CFCs in all interviews</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. In your thinking, what are CFCs?</td>
<td></td>
</tr>
<tr>
<td>2. Where do CFCs come from?</td>
<td></td>
</tr>
<tr>
<td>3. What, if any, problem is caused by CFCs?</td>
<td></td>
</tr>
<tr>
<td>a. How do CFCs cause (problem cited by student)?</td>
<td></td>
</tr>
<tr>
<td>b. I believe (problem cited by student) is a problem because:</td>
<td></td>
</tr>
<tr>
<td>4. Now, is there anything else you remember or would like to tell me about CFCs?</td>
<td></td>
</tr>
<tr>
<td>5. What else, if anything, would you like to tell me about any problems caused by CFCs?</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Questions in postinstruction concept interviews to elicit students’ views on the interview as a means to “tell what I know”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Questions posed to all students</td>
<td></td>
</tr>
<tr>
<td>1. What are your views and opinions about this interview as a way to help you think and talk about CFCs?</td>
<td></td>
</tr>
<tr>
<td>2. I am interested in things you found helpful in the interview as well as things you believe should be changed or added to make the interview more helpful.</td>
<td></td>
</tr>
<tr>
<td>a. What, if anything, do you believe was helpful?</td>
<td></td>
</tr>
<tr>
<td>b. For what reason or reasons was (______) helpful?</td>
<td></td>
</tr>
<tr>
<td>c. What, if anything, do you believe needs to be changed or added?</td>
<td></td>
</tr>
<tr>
<td>d. For what reason or reasons should I change or add (____________________)?</td>
<td></td>
</tr>
<tr>
<td>Additional questions posed to students undergoing POSTICM</td>
<td></td>
</tr>
<tr>
<td>3. What, if any, (other) comments do you have about the concept mapping that you did as a part of this interview?</td>
<td></td>
</tr>
<tr>
<td>4. Imagine that you went through this same interview, but without doing the concept mapping:</td>
<td></td>
</tr>
<tr>
<td>a. Do you believe your answers to the questions about CFCs would have been the same as those you gave me today, or would your answers have been different?</td>
<td></td>
</tr>
<tr>
<td>b. Please tell me your reasons for saying this.</td>
<td></td>
</tr>
<tr>
<td>c. If student responds “different” to (a), ask: In what ways would your answers have been different if we had not done the concept mapping?</td>
<td></td>
</tr>
<tr>
<td>5. In what ways, if at all, did you make use of the concept map during the interview?</td>
<td></td>
</tr>
<tr>
<td>6. How, if at all, did the concept map influence your thinking to the interview questions about CFCs?</td>
<td></td>
</tr>
<tr>
<td>7. In your opinion, was drawing and having the map helpful or not helpful to you in telling me what you know about CFCs?</td>
<td></td>
</tr>
<tr>
<td>a. If student says “helpful,” ask: For what reason or reasons was having the map helpful?</td>
<td></td>
</tr>
<tr>
<td>b. If student says “not helpful,” ask: What, if any, ideas do you have that would make drawing/having the map helpful?</td>
<td></td>
</tr>
</tbody>
</table>
“task content structure” to “hierarchical” (Ruiz-Primo & Shavelson, 1996, p. 578). At the close of orienting the student to this process, the interviewer said:

Since this interview is about CFCs, I will write this concept down on a blank sticky note and I would like you to use it in your concept map. You can use it when you start your map or you can map it in later. This is the only term that I will ask you to use: You will decide all of the other concepts that go in your map.

The interviewer then placed the sticky note of CFCs on the side of the dry-erase board, asked the first interview question (“What are CFCs”) (Table 1), and proceeded as follows:

1. The interviewer issued a reflective statement to the student’s initial verbal response. If the student came forth with additional responses, the interviewer provided corresponding reflective statements. Then, the interviewer asked the student: “What are a couple of terms in what you just said, that you consider to be most important?”
2. After the student verbalized the term(s), the interviewer printed them on separate sticky notes and placed them beside the sticky note “CFCs.”
3. The interviewer asked the student to start constructing the concept map by selecting two of the “stickies” (i.e., terms) and mapping in the connection, while thinking about his or her past response to “What are CFCs?”
4. The interviewer reminded the student not to be concerned with neatness and that he or she could change the map at any time.
5. The interviewer posed the question again, which was followed by any further response(s) from the student and additional mapping as desired by the student.
6. The above process (Steps 1–5) was repeated through Question 3b (Table 1). The interviewer encouraged the student to examine the evolving map while thinking about how to respond to each initial and subsequent interview question.
7. After the student had no more to say in response to Questions 3–3b, the student was allowed to make any final changes deemed necessary to the map, and the concept-mapping component of the interview came to a close.

**Postinstruction Teacher Interviews.** Two postinstruction teacher interviews (summarized below) that adapted conceptual graph analysis (Gordon et al., 1993) were conducted to set forth the teacher-expert concept map. The POSTICM protocol was used as a guide for the first of these two teacher interviews, which resulted in a draft of the expert map. This map explicated what the teacher believed to be the ideal postinstructional understanding that her students should hold, relative to the interview questions (Table 1). The teacher reflected on the draft expert map over a 1-week period and during a second interview modified and verified the map to yield the final version set forth as Figure 1. The map subsequently was employed as a referent to construct templates of concepts and concept relationships, which were applied in the analysis of students’ responses to the questions in Table 1. In addition, the teacher identified eight concepts in the verified map that she deemed most central to the understanding set forth by the map. These eight concepts, which formed the basis of the concept relatedness ratings for generating Pathfinder networks, were as follows: global warming, greenhouse gas, ultraviolet light, depletion, manmade, ozone layer, coolants, and CFCs.

**Relatedness Ratings of Concepts.** The concept-rating activity was a paper and pencil exercise that required rating the relatedness (1–9 Likert-type scale, where 1 = none or very weak and 9 = very strong) of all possible pairings of the eight concepts deemed most central by the
teacher. The algorithm \([n(n - 1)/2]\) for computing the maximum number of concept pairs from some number \(n\) of individual concepts (Acton et al., 1994) resulted in 28 concept pairs. The investigator derived the concept rating activity and instructions based on procedures set forth by others (Acton et al., 1994; Jonassen, 1993; Schvaneveldt, 1990) for producing Pathfinder networks and determining the similarity (Pathfinder index) of student to expert Pathfinder networks. Specifically, an ordered list of the 28 concept pairs was derived by (a) generating a random sequence of the eight central concepts, and (b) entering this random sequence of concepts into the Knowledge Network Organizing Tool (KNOT™; Interlink, Inc., Las Cruces, NM) computer program, which in turn generated the ordered list of the 28 concept pairs. Students were told to: (a) take no more than 15–20 s to make a decision about the relatedness of any concept pair, and (b) circle “5” on the rating scale if they had no idea of the degree of relatedness of a given concept pair. The activity and instructions were verified by the teacher as something that students readily could understand.

All of the teacher’s physical science students were engaged in this rating task, with the idea that later the ratings would be used by the teacher in a debate-type classroom activity. Making this task a part of the science course potentially increased the reliability of the results of the ratings. Of the 34 students who participated in the postinstruction interviews, 33 completed this task. The investigator also administered the task to the teacher. The student and teacher data subsequently were used for Pathfinder analysis.

Data Analysis

The POSTI and POSTICM data were assessed against referent templates to determine the degree to which each student achieved the criterion measures of understanding: ACCORD, EXTERN, and INTER. The templates were derived from the expert map (Figure 1) prior to the analysis of any of the postinstruction interview data and are described in the sections below.

The content of each POSTI and POSTICM transcript through student responses to interview Question 5 (Table 1) was unitized via a case analysis process (Patton, 1990) to determine the presence of the concepts and relationships that comprised the measures of ACCORD and EXTERN, and these concepts and relationships were marked on the data analysis templates. The analysis of concept relationships as a measure of student understanding from interview transcripts has been described as “concept propositional analysis” (Novak & Gowin, 1984; Posner & Gertzog, 1982) and referred to by others as the use of “expert-derived” or “critical” propositions (Lomask, Baron, & Grieg, 1993; Wallace & Mintzes, 1990). The sums of these concepts and relationships marked on the templates were used to derive quantities for the extent to which the criterion measures of ACCORD and EXTERN were present. The measure of INTER—a ratio of the concept relationships to the concepts explicated—was derived from the concepts and relationships marked on the ACCORD and EXTERN templates. Specifically, the total number of teacher-expert relationships plus relationships between teachers-expert and externally related GAC concepts explicated by the student was divided by the total number of teacher-expert plus externally related GAC concepts explicated by the student. This quotient constituted the ratio INTER.

After the investigator completed the analysis of student transcript data against all of the templates, he conferenced with a colleague—the second author of this article, who also was very familiar with the STS-GAC unit—on a small number of problems that arose during analysis. This colleague helped the investigator to establish procedure to resolve such problems, and the investigator applied such procedure in a second examination of the data.

Regression analyses (Judd & McClelland, 1989) of data, performed by MYSTAT™ (SYSTAT), were used to answer the research questions about (a) type of interview prediciting
Figure 1. Teacher-expert concept map.
CONCEPT MAP

DEPLETION contributes to TROPOSPHERE, which travels from...

OZONE LAYER in the stratosphere thins the penetrates UV LIGHT, which penetrates through the atmosphere, causing damage to humans (such as cataracts) and plants.

GLOBAL TEMPERATURE/GLOBAL WARMING leads to an increase by acting as a greenhouse gas, which absorbs infrared energy and emits some towards the Earth, perceived as heat.

CONSEQUENCES include:
- Icing/melting
- Rising
- Changes:
  - Severe: causing heat stress and altering species
  - Patterns: altering weather
- Production: altering food

Sea level rises, causing damage to the ice caps.
each of ACCORD, EXTERN, and INTER; and (b) Pathfinder index improving the prediction of ACCORD, or interacting with type of interview in predicting ACCORD. Frequency and inductive analyses (Patton, 1990) were employed to analyze student transcripts to determine their perceptions of the interview to “tell what I know” (Table 2). The frequency analysis was similar to a classical content analysis; inductive analysis followed a grounded theory approach, where transcript data were unitized, coded and labeled (Pidgeon et al., 1991).

**ACCORD Templates.** One template for ACCORD listed the 40 concepts from the teacher-expert map and the second template listed the 45 concept relationships from the map. The teacher-expert relationships included propositions explicitly illustrated on the expert map (e.g., CFCs are used in coolants), explicitly illustrated crosslinks (e.g., CFC substitutes may also be greenhouse gas), and propositions that were implicit in the understanding set forth by the expert map. Implicit propositions were instances of two concepts in a progressively differentiated subsection of the expert concept map hierarchy that were not directly linked, yet could be related in a valid and relevant manner through linking words that existed in that same segment of the concept hierarchy. Examples of implicit propositions were “CFCs are used in air conditioners,” and “global warming alters species.” The use of such implicit propositions in data analysis allows for the counting of valid and relevant (to the expert map) understandings that may be omitted by basing the assessment only on explicit propositions (Rye et al., 1994). The investigator’s decision as to what constituted the realm of implicit propositions was influenced by (a) his immersion in the knowledge engineering process with the teacher to produce the expert concept map, and (b) his in-depth knowledge of the STS-GAC unit of instruction in this study. A fair cross-validation for the determination of implicit relationships would require other investigators to be equally immersed and knowledgeable.

Concepts and relationships explicated by the student that were very similar in meaning to those on the templates were counted as semantic equivalents. Such semantic equivalency included relationships that were asymmetric equivalents; e.g., “Humans make CFCs” is the asymmetric equivalent of “CFCs are human-made.” The taking into account of implicit propositions, similar semantic meanings, and asymmetrically worded relationships for assessment purposes is congruent with the constructivist paradigm that guided this study—it recognizes that knowledge is individually constructed and idiosyncratic, and that expert concept maps should not be “straightjackets” (Lomask et al., 1993, p. 5) for assessment.

**EXTERN Templates.** The STS-GAC unit investigation lessons each contained a concept map which set forth important understandings. There were 141 different concepts in these investigation lesson concept maps. Practically all of the concepts in the teacher-expert map (i.e., the ACCORD concepts) also were in these lesson concept maps. This total of 141 concepts was reduced to 87 by eliminating those teacher-expert concepts. These 87 concepts were the externally related GAC concepts and comprised the concepts template for EXTERN. A second template was derived for recording all valid relationships between EXTERN and ACCORD concepts.

**Pathfinder Analysis.** The relatedness ratings of the 28 concept pairs completed by each student and the teacher were entered by the investigator into KNOT™. KNOT™ transformed these ratings, using the Pathfinder scaling algorithm, into a Pathfinder network for each student and the teacher (Figures 2–4). The nodes in these Pathfinder networks are the eight concepts deemed
Figure 2. Teacher-expert Pathfinder network.

Figure 3. Pathfinder network of the student with the highest Pathfinder index.

Figure 4. Pathfinder network of the student with the lowest Pathfinder index.
by the teacher to be those most central in the understanding set forth in the teacher-expert concept map. These concepts are arranged spatially according to the relatedness ratings of the concepts comprising the concept pairs. Two nodes are linked if the Pathfinder algorithm determines that this link explicates the minimum path length between the two nodes.

KNOT™ subsequently was employed to compare each student’s net to the teacher’s, to generate the Pathfinder index for each student. The Pathfinder index is a quantitative measure ranging from 0 (nets have no similarity) to 1 (nets are identical).

Findings and Discussion

**Criterion Measures of Conceptual Understanding**

Table 3 sets forth descriptive statistics on the degree to which students who completed each type of postinSTRUCTION concept interview (POSTI or POSTICM) explicated the criterion variable measures of understanding: ACCORD, which is the sum of teacher-expert concepts (ACCORDC) and relationships (ACCORDR); EXTERN, which is the sum of externally related GAC concepts (EXTERNC) and relationships (EXTERNR); and INTER, which is the ratio of teacher-expert plus externally related relationships to teacher-expert plus externally related concepts [i.e., (ACCORDR + EXTERNR) / (ACCORDC + EXTERNC)].

Bivariate regression analysis failed to reveal type of interview as a statistically significant predictor of any of the criterion measures of understanding. Parameter estimates (b), probabilities (p), and proportional reduction in error ($R^2$) in predicting each criterion measure were as follows: for ACCORD, $b = -3.059$, $p = .467$, $R^2 = .017$; for EXTERN, $b = -1.294$, $p = .542$, $R^2 = .012$; and for INTER, $b = .024$, $p = .669$, $R^2 = .006$.

**Pathfinder Index in Predicting Accordance**

The multiple regression models employed to determine if the Pathfinder index improved significantly ($p < .05$) the prediction of ACCORD or interacted with type of interview in pre-

---

**Table 3**

Descriptive statistics for results of POSTI and POSTICM on criterion variable measures of conceptual understanding

<table>
<thead>
<tr>
<th>Criterion Variable</th>
<th>POSTI ($n = 17$)</th>
<th>POSTICM ($n = 17$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
<td>$M^a$</td>
</tr>
<tr>
<td><strong>Accordance</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACCORDC</td>
<td>6–26</td>
<td>18.89</td>
</tr>
<tr>
<td>ACCORDR</td>
<td>1–24</td>
<td>14.89</td>
</tr>
<tr>
<td>ACCORD</td>
<td>7–49</td>
<td>33.77</td>
</tr>
<tr>
<td><strong>External relatedness</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EXTERNC</td>
<td>1–17</td>
<td>4.06</td>
</tr>
<tr>
<td>EXTERNR</td>
<td>1–12</td>
<td>3.65</td>
</tr>
<tr>
<td>EXTERN</td>
<td>2–29</td>
<td>7.71</td>
</tr>
<tr>
<td><strong>Interrelatedness</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>INTER</td>
<td>0.29–1.04</td>
<td>0.79</td>
</tr>
</tbody>
</table>

*a*Group means were not significantly ($p < .05$) different for any of the criterion variable measures of understanding.
dicting ACCORD were built upon the two-parameter model used to investigate type of interview as a predictor of ACCORD. Descriptive statistics on the Pathfinder index for students completing each type of interview were as follows: for POSTI, mean ($M$) = .454 (range of .250–.786), standard deviation ($SD$) = .130; and for POSTICM, $M$ = .444 (range of .158–.733), $SD$ = .125. Results of the independent $t$ test ($t$ = .226, $p$ = .823) revealed that the group means did not differ significantly, which provided further verification of random assignment to group.

Figures 2–4 illustrate, respectively, the Pathfinder networks of the teacher and the students with the highest (.786) and the lowest (.158) Pathfinder index. A visual inspection of the teacher-expert Pathfinder network and Figure 3 suggests that a high degree of similarity existed between the cognitive structures (relative to the concepts shown) of the teacher and the student with the highest Pathfinder index. These two nets had 11 links in common and the location of most of the concept nodes was very similar. Each net located CFCs most centrally and interlinked it most extensively with neighboring concept nodes.

Considerable dissimilarity appeared to exist in the cognitive structure between the teacher and the student who had the lowest Pathfinder index (Figure 4), with only three links common to both nets. This student’s net also had fewer total links than either of the nets set forth in Figures 2 and 3. As such, this student’s cognitive structure relative to the concepts shown appeared to be less interrelated than that of the teacher or other students. In addition, unlike the nets in Figures 2 and 3, this student’s net interlinked to the greatest degree and located most centrally the concept node manmade, with CFCs occupying a space on the periphery.

The results from multiple regression analysis revealed that Pathfinder index improved significantly ($b$ = 42.286, $p$ = .003, $R^2$ = .266) the prediction of the ACCORD. However, the predictor that examined for an interaction (Type of Interview $\times$ Pathfinder Index) was not a worthwhile ($b$ = 7.004, $p$ = .821, $R^2$ = .002) addition to the model. The investigators became interested in whether Pathfinder index also would improve significantly ($p < .05$) the prediction of students’ California Achievement Test scores. Post hoc multiple regression analyses showed that the Pathfinder index did improve significantly the prediction of the verbal ($p$ = .001) and total component ($p$ = .003) scores. These post hoc findings, coupled with the fact that the Pathfinder index was a strong predictor of ACCORD, lend additional support to the utility of Pathfinder network structural representations of knowledge, and most specifically the validity of the Pathfinder index as measures of school learning (Jonassen et al., 1993).

Goldsmith et al. (1991) contended that “the validity of the structural approach [assessment] is better evaluated if the concepts used to derive the structure are only a sample of the set of concepts on which performance is assessed” (p. 94). Ideally, this sample would be relatively small in number but highly representative of the instruction provided. Keeping the sample of concepts to a minimum seems especially important in the case of working with younger learners, where time on task is more of an issue. For example, Pathfinder networks based on the relatedness of one half (20) of the concepts in the teacher-expert map would have required students to rate 190 concept pairs! In this study, the Pathfinder index was derived from student ratings of a critical subset of only eight concepts, and correlated strongly ($r$ = .515, $p$ = .003) to ACCORD. Goldsmith et al. took this correlation as the measure of predictive validity of the structural assessment. Therefore, a relatively high level of predictive validity was established for the Pathfinder index from the ratings of just eight concepts (i.e., 28 concept pairs). Perhaps the construction and verification by the teacher of the expert concept map facilitated the subsequent selection of those concepts that truly were most central to the domain (CFCs and their role in GAC), and accordingly, for which the concept relatedness ratings would ultimately yield a Pathfinder index with substantial predictive power.
Students’ Perceptions of Interview

The findings set forth below generally are limited to POSTICM students’ views of concept mapping as a tool to help “tell what I know.” The findings of all students’ perceptions about the interview are presented elsewhere (Rye, 1997). However, important to the conclusions of this study was the value that all students ascribed to quiet time for thinking and jotting down thoughts about CFCs prior to considering the interview questions. Quiet time was the interview component perceived as helpful by the most (82%) POSTI students (n = 17), and by almost 60% of POSTICM students (n = 17). Students supported this perception with a variety of reasons, including “[It] sort of refreshed my memory,” and “It made me recall the information so I could use it in the interview.” A couple of students gave evidence that the notes jotted during quiet time were of assistance beyond their face value, e.g., “I could see what I had down there, then I could also picture what some of my other papers [were] on CFCs before.”

Prior to reporting POSTICM students’ perceptions of the concept map as an interview component, some attention is given to the maps that emerged from these interviews.

Maps Emergent from POSTICM. The 17 concept maps prepared by the students during their POSTICM varied somewhat in structure and even more so in the number of concepts and concept relationships. The mean number of concepts per map was about 10, with a range of 3–17. The number of concept relationships ranged from 2 to 18, with a mean of 9. Few of the concept relationships in any map were explicated as crosslinks (Novak & Gowin, 1984).

Figures 5–7 are concept maps prepared by three students during the POSTICM and were selected to illustrate the variety of maps in terms of framework, branching or progressive differentiation, and crosslinking or integrative reconciliation (Novak, 1992). Figure 5 illustrates one of the least complex of all concept maps produced by the students. It is hierarchically framed (as were about one half of the maps), but basically linear. Figure 6 illustrates one of the more complex of all maps and represents the extreme in terms of articulating clearly the levels in the concept hierarchy. The map illustrated in Figure 7 is a hybrid (West et al., 1991) of web and hierarchical structures. It explicates the extreme in terms of crosslinks, but clearly all of these crosslinks are not indicative of integrative reconciliation. Also, unlike most of the maps, CFCs was not the focus or superordinate concept.

POSTICM Students’ Perceptions of Mapping. The first interview question (Table 2) to elicit students’ perceptions was worded to avoid cueing students about specific interview components. In response, over 40% of the students stated that the concept map was helpful in some way. One of these students spoke to the graphic organizer (Wandersee, 1990) feature of a concept map: “And it was good to do a concept map, too, because it kind of helped you sort your thoughts out . . . so you can kind of see what you are thinking.” This student suggested that the map was employed metacognitively—as a “strategic action of the reasoner” (Eylon & Linn, 1988)—to help organize thoughts. Another student inferred that the concept map played a role in spread of activation (Gagne, 1985), leading to further recall of knowledge: “[W]hen I would see this one thing, it would lead to another thing that I would, maybe, didn’t think about before.”

Questions 2a–d attempted to focus students’ attention on what they believed was helpful or was in need of change in regard to specific interview components. Students’ responses here were pooled with responses to the first question, which revealed that more students (76%) reported
concept mapping to be more helpful than any other interview component. Reasons provided by the students suggested further the utility of the concept map in fostering metacognition and triggering recall of what they had learned about CFCs. For example, Roberta spoke to the metacognitive nature of the concept map as she identified it as an image to help her monitor and check on the completeness of her recall:

Roberta: Well then, I mean when you look at the map and then you can always find something you missed. If you go over it a second time, then you are usually able to think through your memory and make sure you did not miss anything.

Another student also talked about the map as an image to facilitate recall: “[J]ust looking at it and seeing all the words helped me to think of the other terms.”

The remainder of the interview questions for the POSTICM students honed in on the concept map, to elicit further comments on this interview component and ascertain if and how the concept map might have affected the students’ answers to the interview questions. Sixty-five percent of the students said they believed their answers to the interview questions would have been different had the concept mapping not been a component of the interview. Some of these students inferred that the visual nature of the map was an asset to them while thinking about the interview questions. Mollie put it this way: “[I] could look at what I had said and so I could remember what I didn’t say and . . . so I wouldn’t leave anything out.” Another student provided

---

**Figure 5.** One of the least complex concept maps emergent from POSTICM.
Figure 6. One of the most complex concept maps emergent from POSTICM.

Figure 7. Hybrid-type concept map emergent from POSTICM.
evidence of her metacognitive knowledge in referring to the visual nature of the map: “It’s easier for me to look at something and explain it than to just think off the top of my head.” Other of these students gave evidence that the visual nature of the map triggered in them the spreading activation process, e.g.: “Um, I’d look at one piece of paper [sticky note]—it’d make me think of something else.” Some students, such as Lucille, referred to the value of the concept connections in the map:

Lucille: Well, whenever we made the concept map, it kind of let me think about what, what I could, like, connect things from. And that kind of helped me remember what to answer the questions—if I had forgotten some things.

Most of the students who believed that the concept mapping did not change their answers to the interview questions perceived the mapping as just restating what they had verbalized, or that the notes they had taken during quiet time had the same influence as did the concept mapping on their answers. One student suggested that the interviewer could consider giving the students a word list to use in constructing the map. Another student (Jack) wanted to have a fill in the blank concept map and suggested the following as a modified procedure for the interview:

Jack: Well, I think like you should have—find out what we are doing in science and have, like, maybe a review thing to help you remember everything. Like, make a review concept map where you fill in the blanks, instead of just making up your own from scratch.

Jack’s suggestion paralleled some of instructional activities he engaged in to build competence in concept mapping and study material from the STS-GAC unit. This was revealed by the post-instruction interviews with his teacher, as the teacher responded to the query: “Now, if you would please tell me, for the concept mapping . . . how you developed their competence.”

And then I started giving them—at the end of the [science] unit—I would give them a concept map with boxes with connectors in place, some terms in place, and then a list of terms at the bottom that they needed to put in the appropriate box to show that they understood the connection. . . . Then we graduated from that to some with just the boxes filled in and they did the connectors. And then ultimately to just, “Here is a list of terms that you should be able to connect.”

The teacher also described the extent to which she had used concept mapping in the GAC unit:

I took a number of the ones that were in the teaching materials and whited out boxes and after we had gone over a lesson, gave it to them and said, “This is a summary of the lesson and you go back and fill in the boxes.” . . . So, I felt for the kids that had difficulty taking notes, as many eighth graders do, that that was their backup. That that became their security blanket.

The excerpt that follows from the interview with Carley suggests that students did hone in on these maps in studying about CFCs and their role in GAC.

Interviewer: Was there anything—be real frank with me—was there anything that was helpful? That is, helped you remember, think, and talk about CFCs?
Carley: The concept map helps. . . . Um, like, at nighttime when we’re studying this, I’d go home and I’d study it. And it was a lot easier than to have to read, you know, the chapters in the books and stuff.

Carley’s comment suggests further that she valued the concept map as a study aid. It is likely this value also was held by various other of her classmates. Evidence for this comes from comments made by her teacher during the postinstruction teacher interviews:

And today, we started a new chapter on simple machines, and that was the first thing they said. Because I said, “Get out paper. We are going to take some notes.” They said: “We going to do a concept map?” [Laughter] And I said, “Not right now. . . . “

The teacher responded further that the students seemed to enjoy and understand the mapping.

Further evidence that the students valued concept mapping came from a post hoc inspection of the students’ notes that they jotted during the quiet time: Four (24%) of the POSTICM and three (18%) of the POSTI students chose to sketch a concept map as opposed to just writing notes. The interviewer did not state that a concept map could be used for recording thoughts during this quiet time. Rather, he emphasized that it was most important to make these notes “useful to you.” Figure 8 illustrates the most detail concept map notes prepared during quiet time by any of these seven students—a student who had been assigned to POSTI.

The investigator also engaged in conversations with the teacher after data analysis, to verify further his contention that the students valued concept mapping. Here, the teacher revealed that over one half of the students who participated in the study went on to develop their own concept maps for subsequent units of study in science class. Further, the teacher reported that

![Figure 8. Concept map notes drawn during quiet time by POSTI students.](image-url)
these students often chose to use such maps as opposed to materials developed by the text publisher to study from for science unit examinations.

Conclusions and Recommendations

In this exploratory study, an interview that embedded a concept-mapping process (compared to an interview that excluded this process) did not effect statistically significant changes in the externalization of students’ conceptual understandings about CFCs. This finding was unanticipated given the potential impact on cognition of the concept map tool. Furthermore, this finding was surprising given that the majority of students completing the POSTICM reported that the concept-mapping interview component was helpful and inferred that such had a positive impact on their responses to the interview questions about CFCs.

One explanation for these findings may be the quiet time that preceded the interview questions, which was perceived as helpful by the majority of POSTI and POSTICM students. The quiet time appeared to facilitate a state of mental readiness and the notes then jotted appeared helpful in responding to the interview questions. As such, the quiet time interview component may have enhanced the externalization of all students’ understandings to the degree that the concept-mapping component did not elicit further knowledge in the POSTICM group.

Another reason that the POSTICM did not effect statistically significant increases in the externalization of students’ understandings may be found in the type of concept-mapping activities that were included in the STS-GAC investigation instruction. The researchers had not constrained the teacher’s use of concept mapping, except for the directive not to engage students in constructing maps in which CFCs were the focus concept. The student and teacher interviews revealed that the type of concept maps comprising instruction included expert or instructor-prepared. Poststudy conversation with the teacher verified that about two thirds of the concept maps that students dealt with were of this type, where students filled in missing concepts and connectors in partially completed concept maps as a means to build competence in concept mapping and to summarize information from class sessions. McCagg and Dansereau (1991) reported that use of instructor-prepared maps can deprive students “of understanding that they might have gained from generating their own maps” (p. 318). Schmid and Telaro (1990) suggested that instructor-prepared maps can result in rote memorization, already too common in schools: “Junior high school students have become adapted to primarily rote-mode learning and it is not easy to move them to meaningful learning strategies” (Novak, 1990, p. 41).

Accordingly, some of the students in this study may have come to view concept maps as being somewhat static—more as finite entities than as a tool for elaborating their knowledge. The student in this study who achieved the highest of all students on the criterion measures of accordace and interrelatedness of understanding gave explicit evidence of that, in telling the investigator how to improve the concept mapping component of the interview: “[M]ake a review concept map where you fill in the blanks, instead of just making up your own from scratch.” The teacher reported that about one third of the concept maps in the investigation instruction were those that students constructed on their own from a list of concepts, always with the opportunity to “add their own” concepts. The latter was considered by Novak and Gowin (1984) as a meaningful learning context. It is possible that the findings of this study might have been different if students had been involved in constructing more of their own concept maps.

Yet another explanation for the finding that the POSTICM did not effect statistically significant gains in the elicitation of students’ understandings might be found in the inherent comp-
plexity of global environmental change problems (Mackenzie & Mackenzie, 1995) and the difficulty that middle-level students, in transition from being concrete to formal-level thinkers (Eylon & Linn, 1988; Wandersee et al., 1994), may have in comprehending the phenomena that underlay such problems. For example, CFCs have dual mechanisms of action in GAC and their greenhouse effect requires an understanding of abstract concepts about the electromagnetic spectrum, such as the absorption and reemission of electromagnetic energy and the inverse proportionality that underlies electromagnetic wavelength and energy. Complicating this are the tenacious alternative conceptions about the ozone hole causing global warming that students appear to bring to or formulate during GAC instruction (Boyes & Stannisstreet, 1993; Dorough, Rubba, & Rye, 1995; Rye, 1995). In this study as well as that reported by Rye et al. (1997), few students labeled the concept “infrared energy” or described the role of such relative to how CFCs potentially contribute to global warming. Less than 40% of all students in this study connected CFCs to global warming. Of those who did, most (29% in each interview group) explained that CFCs caused global warming by destroying the ozone layer. Indeed, current scientific thinking is to the contrary: Ozone layer depletion provides negative feedback to global warming (Houghton, Filho, Callander, Harris, Kattenberg, & Maskell, 1996).

Despite the fact that type of interview was not a predictor of any of the criterion measures of conceptual understandings, the interview component perceived as helpful by the most POSTICM students was concept mapping. The reasons students provided as to why the concept mapping was helpful indicated that they used the map metacognitively and that it triggered the spread of activation process. The majority of POSTICM students also inferred that the mapping had a positive impact on their responses to the interview questions. The investigators conclude that many of the students—POSTICM and POSTI—had come to value concept mapping. Further evidence for this was provided in the postinstructional interviews with the teacher and by the fact that over 20% of all students decided to draw a concept map to record their thoughts during the quiet time period.

The investigators recommend that future research should examine the effectiveness of the POSTICM protocol with students who have limited exposure to concept maps of the instructor-prepared variety in the domain under study. Ideal conditions in such a study might also include the following: (a) Students would have considerable previous experience in developing their own concept maps; (b) concept mapping competence would be verified through a task developed and assessed by the investigator; and (c) quiet time would be examined as an independent variable, i.e., a four-group design would be employed to allow for the examination of any separate impacts of type of interview and quiet time on the externalization of students’ conceptual understandings.

The Pathfinder index was a worthwhile addition to the regression model for predicting accordance (ACCORD). The Pathfinder index had predictive validity for performance in the interview on the measure of ACCORD and proved to be a reliable confirmatory measure of the degree to which students held an ideal postinstructional understanding. The predictive validity of the Pathfinder index for ACCORD is quite high, given that only eight concepts formed the basis of the relatedness ratings. The investigators infer that the knowledge-engineering process of constructing an expert concept map with the teacher facilitated the selection of concepts for Pathfinder analysis that were associated with substantial predictive power.

Research that incorporates pre- to postinstruction comparisons of domain knowledge, as elicited through both concept interviews and Pathfinder analysis, would make a contribution to the literature base that shows students’ knowledge structures become more like their instructor’s or experts as they develop expertise (Goldsmith & Davenport, 1990; Ruiz-Primo & Shavelson, 1996). Complementary to this would be research that attempts to replicate or expand the find-
nings of this study, where an expert concept map is used to identify domain-specific concepts for concept relatedness ratings, and these ratings are transformed into the Pathfinder index and regressed on performance measures to determine predictive validity. In addition, research that examines the concept links in Pathfinder networks and concept maps, derived from a common set of concepts (e.g., a central subset from a teacher-expert concept map), might help to answer the question set forth by Goldsmith et al. (1991) about Pathfinder networks: “How meaningful is the presence or absence of a specific direct link between two concepts?” (p. 95). They call for considerable research that analytically examines concept relationships among specific subclusters of concept networks and deficits in knowledge.

This research was supported in part by National Science Foundation Grant TEP-9150232 and a grant from the Pennsylvania State University College of Education Alumni Society. Any opinions, findings, and conclusions or recommendations expressed in this article are those of the authors and do not necessarily reflect the views of the National Science Foundation or the Pennsylvania State University College of Education Alumni Society. An earlier version of the manuscript was presented at the 1996 annual meeting of the National Association for Research in Science Teaching, St. Louis, MO, 31 March–3 April.

Notes

1 Fictitious names have been assigned in this article to all students for whom transcript excerpts have been included.

2 The current version of this STS unit, Global atmospheric change: Enhanced greenhouse effect, ozone layer depletion, and ground level ozone pollution, is on the World Wide Web at http://www.ed.psu.edu/dept/ci/sts/gac-main.html.

References


per presented at the National Association for Research in Science Teaching Annual Meeting, San Francisco, CA.


Rye, J. (1995). *An investigation of the concept map as an interview tool to facilitate exte-


