Usefulness of Concept Maps in College Chemistry Laboratories: Students' Perceptions and Effects on Achievement

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Abstract: The problem addressed by this study is that first-year college chemistry students learn little of the conceptual material associated with chemistry experiments they perform. The thesis of this research is that the construction of prelab and postlab concept maps help students understand the concepts involved in the experiments they perform. The study was conducted using 32 non–science majors enrolled in a first-year chemistry course. The experimental group constructed prelab and postlab concept maps, while the control group wrote essays explaining the conceptual chemistry of the four experiments used in this study. Both groups took 25-item achievement tests 1 week after each experiment. Prelab and postlab concept maps were scored and evaluated for significant differences. Five students were interviewed to investigate their perceptions regarding the usefulness of concept maps in chemistry laboratories. No significant differences were found between treatment groups with respect to students' conceptual understanding as determined by the multiple choice achievement tests. Students responded very positively toward the use of concepts maps in the laboratory. They felt strongly that constructing prelab and postlab concept maps helped them understand the conceptual chemistry of the experiments. © 1998 John Wiley & Sons, Inc. J Res Sci Teach 35: 1015–1029, 1998

Instructional science laboratories are widely regarded as a key component of science instruction. This is because most sciences, chemistry included, are activity-based explorations into the natural world (American Association of Advancement of Science, 1993; National Research Council, 1995). Both science majors and non–science majors find laboratory-based activities to be motivating and exciting.

Beginning in the 1970s, the quality and quantity of college-level laboratory instruction began to decline. Pickering (1993) suggested that the decline in interest in science as a career coincides with the decline of laboratory instruction. The high costs associated with this labor-intensive activity, the emergence of audiovisual and computerized experiments, safety concerns for hazardous materials, and legal ramifications all influenced the decline of college-level teaching laboratories (Pickering, 1988). Frequently, instructional laboratories are taught by graduate students (some with language problems) or instructors with little experience or desire to help

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students learn. Little effort is spent on developing new experiments that make connections to students' lives. These features can combine to produce boring, tedious, step-by-step procedures which often give students training only in mindless manipulations.

The nature of the college-level instructional chemistry laboratory is being changed by chemical educators who believe it is central to the understanding of chemistry. The instructors of college-level chemistry laboratories of the 1990s are beginning to ask students to engage in original scientific research rather than to conduct experiments that simply reconfirm well-known principles and laws. Other attributes of this new philosophy include conversion to microscale experiments which are safer and less costly owing to a reduction in quantities of chemicals used; incorporation of topics of current social interest such as the environment; use of modern instrumental techniques; and integration of concepts and techniques from several disciplines. This new philosophy toward college-level instructional chemistry laboratories is designed to encourage more students to become chemists, by asking them to engage in meaningful and interesting laboratory work as students.

The renaissance in the college-level instructional chemistry laboratory is also based on the notion that this type of teaching laboratory should lead to an understanding of concepts rather than the rote learning of facts and manipulative skills, and fact verification. The assumption that knowledge can be transferred intact from the mind of the teacher to the mind of the learner continues to be challenged by cognitive psychologists and by an increasing number of educators (Ausubel, Novak, & Hanesian, 1978). Cognitive psychology places emphasis on understanding how the mind works, on how learners learn, and on meaningful learning. The constructivist learning theory, with its roots in the learning theory of Ausubel et al., clearly states that every learner actively builds or constructs her or his own private understanding of the world. More simply, knowledge is constructed in the mind of the learner (Bodner, 1986). Addressing a learner's prior knowledge is one important ingredient in the constructivist learning theory (Pines & West, 1986). All learners bring existing ideas or preconceptions (and sometimes misconceptions) with them as they begin a learning task. For real understanding to occur, the teacher must actively involve the learner in a preliminary activity to elicit these preconceptions. Connections from this preexisting knowledge can then be made as learners continually build and test their knowledge. For true understanding to occur, learners' newly found knowledge must work for them, i.e., be fruitful, believable, and make sense (Posner, Strike, Hewson, & Gertzog, 1982). The constructivist learning model emphasizes the need for students to be actively engaged in their learning (von Glasersfeld, 1992). Students must ask questions of teachers and must be encouraged to test their own ideas. Teachers must seek out student ideas, promote cooperative group learning, and encourage students to challenge each other's ideas (Yager, 1991). Herron (1984) concluded that teachers should spend less time telling students and more time asking them what they think.

A technique called concept mapping was developed by Novak (1977, 1984) to help students make conceptual connections while doing laboratory work. Concept mapping is a form of two-dimensional diagramming which emphasizes the relationships between and among important concepts (Zeitz & Anderson-Inman, 1992). Students are actively involved because they construct the concept maps. By using a preinstruction concept map, a teacher is asking students to record their preconceptions and eliciting from them questions about the material to be learned. When the teacher uses a postinstruction/activity concept map, he can see the progress made by individual students in assimilating and accommodating new knowledge into their existing cognitive structures. Concept mapping is one instructional technique which allows the theoretical ideas of Piaget, Ausubel, and von Glasersfeld to be implemented by teachers. Chemistry and other science teachers continue to research the impact that student-constructed concept maps have on conceptual learning (Markham & Mintzes, 1994; Roletto, Regis, & Albertazzi, 1996;

Roth & Roychoudhury, 1993; Wilson, 1994). More research needs to be done to provide reliability and validity information on the effect of different concept-mapping techniques (Ruiz-Primo & Shavelson, 1995).

The thesis of this research was that the construction of a prelab concept map and the restructuring of this map during and after the laboratory period will help students understand the concepts involved in the experiments they perform. The construction of a prelab concept map is useful to students because they begin to focus on the important concepts of the experiment. Relationships between concepts become clearer to students as they restructure their maps while listening to the laboratory instructor present the introductory instruction. The postlab restructuring of concept maps gives students additional opportunities to be actively engaged with the construction of meaningful relationships between the important concepts involved in each experiment.

Purpose

Chemistry is widely perceived to be a difficult subject. The vast majority of students take chemistry as a required course for another discipline and are usually only motivated because they must obtain a passing grade in chemistry to continue in their chosen fields. Other factors which make chemistry difficult include its specialized language, mathematical nature, the amount of material needed to be learned (Johnstone, 1984), and its abstract conceptual nature (Carter & Brickhouse, 1989; Zoller, 1990). Lawson and Renner (1975) showed that a majority of science concepts at the high school and college levels are abstract. For example, chemistry requires students to deal mentally with a variety of objects which cannot be directly perceived, such as atoms, molecules, and ions (Ward & Herron, 1980).

Significant learning resulting from laboratory instruction has been a recurring problem for science teachers and students at all levels (Hofstein & Lunetta, 1982). In their review of the role of the laboratory in science teaching, Hofstein and Lunetta (1982, p. 212) concluded that "Researchers have not comprehensively examined the effects of laboratory instruction on student learning." Specifically, they recommended that further studies be conducted concerning the conceptual understanding students gain from laboratory instruction. One such study investigated students' understanding resulting from different technologies used to present acid/base concepts in a chemistry laboratory (Nakhleh & Krajcik, 1993, 1994).

The difficulties encountered by introductory college-level chemistry students is due in part to the abstract and quantitative nature of instructional material presented in both the lecture and laboratory. In addition, the concreteness of laboratory work, the objective nature of the process of science, and the necessity for reproducible results are all quite different from the conceptual understanding of the nature of matter.

Typically, first-year college students learn very little of the conceptual material associated with chemistry experiments which they perform in instructional laboratories. One reason for this failure is the absence or inadequacy of pre- and postlaboratory discussions and/or strategies which help students focus on the important conceptual material. For example, in a common laboratory report format, students are asked to explain in their own words the conceptual chemistry of the experiment in paragraph form, and they frequently respond by simply copying or paraphrasing the explanation given in their laboratory handout. Novak and Gowin (1984, p. 47–48) observed that:

> Often students enter into a laboratory, studio, or field setting wondering what they are supposed to do or see; and their confusion is so great that they may not get as far as asking what regularities in events or objects they are to observe, or what relationships between

> concepts are significant. As a result they proceed blindly to make records, manipulate apparatus, or make constructions with little purpose and little consequent enrichment of their understanding of the relationships they are observing and manipulating. Concept maps can be used to help students identify key concepts and relationships, which in turn will help them to interpret the events and objects they are observing.

In their final report, the American Chemical Society Chemical Education Task Force found that "applications of . . . discoveries about learning are occurring haphazardly" in college-level lecture and laboratory instruction (Yankwich, Eberhardt, Lavallee, & Schwartz, 1984, p. 845). At the 13th biennial conference on Chemical Education, very little evidence of pedagogical reform concerning the conceptual understanding that students gain from introductory college-level laboratory instruction was presented (Ross, 1994).

The problem addressed by this research was students' low-level conceptual understanding from introductory college-level chemistry laboratory instruction. This study investigated the use of student-constructed concept maps and the effects these maps have on students' conceptual understanding of the chemistry experiments they perform. Students' perceptions concerning the usefulness of concept maps in chemistry labs were also explored.

Methods

This study was conducted using students enrolled in Chemistry 170, during the Fall 1994 semester at a small private women's college in Connecticut. This four-credit course meets for three 50-min lectures and one 3-h lab per week This course is predominantly taken by nursing and nutrition students during their first year, and many of these students are of nontraditional age. The course content includes topics from inorganic chemistry (e.g., atomic structure and bonding, nomenclature, chemical reactions, acid-base chemistry) and organic chemistry (e.g., functional groups; nomenclature; structures; properties and reactions of alkanes, alkenes, alcohols, aldehydes, ketones, and carboxylic acids). Inorganic experiments (Eight-Solution Problem and Synthesis of Alum) were performed during the first half of the semester and coordinated with lecture, and organic experiments (Paper Chromatography of Food Dyes and Extraction of Caffeine from Tea) were performed during the second half of the semester and were not coordinated with lecture.

The quasi-experimental, nonequivalent control group design was employed using only the laboratory portion of Chemistry 170, Principles of Inorganic and Organic Chemistry. This researcher was the laboratory instructor for the entire semester for both control and experimental groups, while the lecturer was another full-time member of the Chemistry Department. Both groups took a 35-item multiple choice chemistry concepts pretest at the beginning of the semester, and scores from this exam were used to establish the equivalence of the two groups.

Subjects in the experimental group were introduced to the idea and construction of concept maps following the procedures of Novak and Gowin (1984). These students practiced constructing several small concept maps prior to the four experiments used for data collection. Several students in the experimental group used the computerized program Inspirations, version 4.0 (Inspiration Software, 1994) to construct their concept maps.

Subjects in both control and experimental groups received a handout and a List of Concepts sheet for each experiment 1 week prior to each experiment. A majority of the concepts on this list were taken directly from the laboratory handouts. For each experiment, the control group was asked to construct a list of objectives which included the concepts to be learned as a prelab assignment, while the experimental group constructed a prelab concept map. Both groups received 40–50 min of similar prelab instruction, performed the experiment, and turned in a written lab report 1 week after completing each experiment. The control group used the concepts on the List of Concepts sheet and wrote an essay explaining the chemical concepts involved in the experiment. This essay constituted the discussion portion of the lab report. The experimental group restructured their prelab concept maps briefly while in lab, and extensively as homework after completing each experiment. This postlab concept map constituted the discussion portion of their lab report. Both the essay and concept map were worth 25% of the lab report grade.

To protect against potential bias stemming from the researcher teaching both the experimental and control groups, two chemical educators viewed videotapes of the prelab instruction for both groups and judged the nature of the instruction. These judges had a list of the concepts presented in each experiment and made written notation that each was covered during each prelab instruction period. The judges were also asked to make written comments about the nature of the instruction by comparing the two groups.

One week after completing each experiment, at the beginning of the laboratory period, a 25-item achievement test was given to both groups. Four separate 25-item achievement tests were constructed by this researcher. Each test covered concepts involved in each laboratory experiment. Two equivalent forms (identical questions and different response order) of each test were constructed to avoid the possibility that students in the experimental group would benefit from talking with students in the control group. It is impossible and probably unnecessary to prevent students from different sessions from discussing labwork. The intent of alternate test forms was to discourage intentional cheating by sharing answer keys. The same two content experts who judged the nature of the instruction also made written records of the content validity of the achievement tests. The reliability of each test was determined using Cronbach's alpha.

Analyses of variance (ANOVAs) were used to test for significant differences between achievement test score means for the control group (students who wrote essays) and the experimental group (students who constructed concept maps). Paired sample *t* tests were used to test for significant differences between students' prelab and postlab concept map scores.

Qualitative methodologies were used to assess students' perceptions regarding the usefulness of concept mapping in relation to chemistry laboratories. Five students from the experimental group were interviewed and audio recorded with permission, and transcriptions were made. The subjects selected to be interviewed included two traditional-age students (18–23 years) and two non–traditional-age students (24 years & up), a student with average grades, and a student with above average grades in each age group. The fifth student had used the computer to construct many of her postlab concept maps. Sample interview questions are given below.

- How much time did you spend constructing the prelab and postlab concept maps?
- How did you use the List of Concepts sheet while constructing your concept maps?
- Comment on the feedback you received from me concerning your concept maps.
- Why was it hard to find appropriate linking words?
- Did the technique of concept mapping help you learn the concepts in each experiment?
- Is the technique of concept mapping useful to you? Explain.

The researcher kept a field notebook in which daily comments and observations were recorded with respect to the students in the control and experimental groups.

The credibility and, hence, trustworthiness of students' perceptions concerning the usefulness of concept mapping in instructional chemistry laboratories were enhanced by triangulating the researcher's field notebook, interview transcripts, and student-constructed concept maps

(Lincoln & Guba, 1985). In-depth, line-by-line analyses of interview transcriptions and comparisons of the three data sources yielded constructs of prelab concept maps, postlab concept maps, and the benefits of constructing concept maps.

Results

The results from the 35-item pretest were used to establish that the control and experimental group subjects were equivalent in their general knowledge of chemistry at the beginning of this study. The ANOVA indicated no significant differences on the pretest, $F = 0.251$; $p = .8752$ (Table 1). Cronbach's alpha reliability for the pretest (21 items) was .72. Fourteen of the original 35 items were eliminated owing to negative and low item correlations. With respect to their general knowledge of chemistry, the two groups were found to be equivalent.

Both content experts determined that all topics and concepts listed on the equivalence of instruction verification sheets were covered equally during both prelab instruction periods. Based on the comments and judgments made by two content experts, the nature of the instruction given to the both groups was equivalent. One sample comment was: "It was amazing how similar the presentations were between the two lab sections. The presentations were virtually identical."

Achievement Tests

With respect to their understanding of the concepts involved in each of the four experiments, no significant differences were found on three of the four achievement tests between students who wrote essays and those who constructed concept maps. The ANOVAs indicated that the control group did not score significantly higher than the experimental group on Achievement Tests 1, 2, and 4, $F = .309$, $p = .583$; $F = .009$, $p = .926$; $F = .055$, $p = .816$ (Table 2). The control group did score significantly higher than the experimental group on Achievement Test 3, $F = 1.092$; $p = .304$ (Table 2). Therefore, this research showed that students who construct concept maps do not score better on acheivement tests involving the chemical concepts of experiments they performed than students who write essays. For one of the four experiments, students who wrote essays scored significantly higher on the achievement test. Cronbach's alpha reliabilities for Achievements Tests 1, 2, 3, and 4, respectively, were .68 (15 items), .73 (17 items), .71 (15 items), and .74 (19 items). The number of deleted items for Tests 1, 2, 3, and 4, respectively were 10, 8, 10, and 6. The deleted items were eliminated owing to negative and low item correlations. The fact that these tests were not piloted before use is a limitation of this study.

Table 1
ANOVA results for pretest

Source of Variation	Sum of Squares	*df*	Mean Square	F	*p*
Between	0.0009	1	0.009	.0251	.8752
Within	1.0422	30	.0347		
Total	1.0431	31			

Table 2
ANOVA results for achievement Tests 1, 2, 3, and 4

Test	Source of Variation	Sum of Squares	*df*	Mean Square	F	*p*
1	Between	45.600	1	45.600	.309	.583
	Within	4430.275	30	147.676		
	Total	4475.875	31	144.383		
2	Between	1.4291	1	1.429	.009	.926
	Within	4882.071	30	162.736		
	Total	4883.500	31	157.532		
3	Between	208.384	1	208.384	1.092	.304
	Within	5725.616	30	190.854		
	Total	5934.000	31	191.419		
4	Between	12.706	1	12.706	.055	.816
	Within	6945.169	30	231.506		
	Total	6957.875	31	224.448		

Student-Constructed Concept Maps

Prelab and postlab concept maps were scored according to the procedures of Novak and Gowin (1984), in which 1 point is assigned for every valid and meaningful relationship between two concepts and 1 for every valid example, 5 points for every level of hierarchy, and 10 points for every valid and significant crosslink between one segment of the hierarchy and another. The prelab concept maps for all four experiments were scored first, followed by the postlab maps. This was purposefully done to avoid researcher bias that might occur had the prelab and postlab concept maps for every student been graded together. For a summary of prelab and postlab concept map scores, see Table 3. For sample student-constructed concept maps, see Figures 1 and 2.

For Experiment 1, the mean postlab concept map score was 33 and the mean prelab map score was 28, resulting in a two-tailed probability of .30, which statistically indicates no significant difference ($p < .01$). For Experiments 2, 3, and 4, respectively, the mean postlab/prelab concept maps scores were 39/26, and 34/18, and 38/22, resulting in two-tailed probabilities of .001, .001, and .000. Based on these results, statistically significant differences did occur between prelab and postlab concept map mean scores for Experiments 2, 3, and 4. Postlab concept maps for these three experiments showed more valid relationships (between concepts) and examples, a more intricate hierarchical structure with more branching, and occasional crosslinks between different branches of the hierarchy.

Students were not shown a criterion map constructed by the instructor. The significantly more complex concept maps are due to students' increased understanding resulting from the introductory instruction given at the beginning of the laboratory period, and the construction of prelab and postlab concept maps.

Students' Perceptions Regarding Concept Maps

Students' perceptions of the usefulness of concept maps were drawn from interview transcripts, the researcher's field notes, and student-constructed concept maps. Selected segments

Table 3
Prelab and postlab concept map scores

Student	Experiment 1		Experiment 2		Experiment 3		Experiment 4	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	61	74	17	57	13	52	33	68
2	27	22	20	23	13	†	14	†
3	25	25	18	41	14	27	16	31
4	41	42	40	59	24	52	49	61
5	13	37	14	35	14	34	†	38
6	27	34	15	28	15	31	18	32
7	29	29*	29	38	14	26	28	38
8	23	31	18	18*	21	16	18	28
9	23	29	17	30	13	28	†	31
10	23	30	†	†	19	17	15	36
11	†	29	22	44	17	28	†	38
12	24	22	18	36	12	19	15	20
13	26	33	55	55	30	54	30	46
14	29	26	45	53	29	36	18	33
15	26	31	33	34	16	56	15	29
Mean	28	33	26	39	18	34	22	38
SD	11	13	13	13	6	14	11	13

*Identical concept map; no changes.
†No concept map was turned in.

of interview transcripts will be used to illustrate and support assertions made concerning what students thought about concept mapping in chemistry laboratories.

The construction of a prelab concept map, with subsequent restructuring inlab and postlab, helps students understand the concepts of the experiments they perform. The construction of a prelab concept map provided the first opportunity for students to focus on the important concepts of the experiment, and required them to examine the relationships among concepts.

- It was good that they [list of concepts] were mixed up; it forced you to start to look for relationships.
- The concepts brought out important things in the experiment that I probably would not have noticed.
- If you did the prelab map, you are thinking about it as you go through the lab; as you are [teacher] explaining it, you are thinking about what words you could not link together.

During the introductory instruction for each experiment, students began to restructure their prelab concept maps. As the instructor used appropriate linking words to clarify relationships between concepts, students often made mental or written notes to themselves.

- I would write down ideas when you would speak at the beginning of the lab, and I would take them home with my results and redo my map.
- I would take my map, and I would write down little things on my map, because you would use words that we can use to link them together.
- The prelab instruction clarified questions I had on connections between concepts.

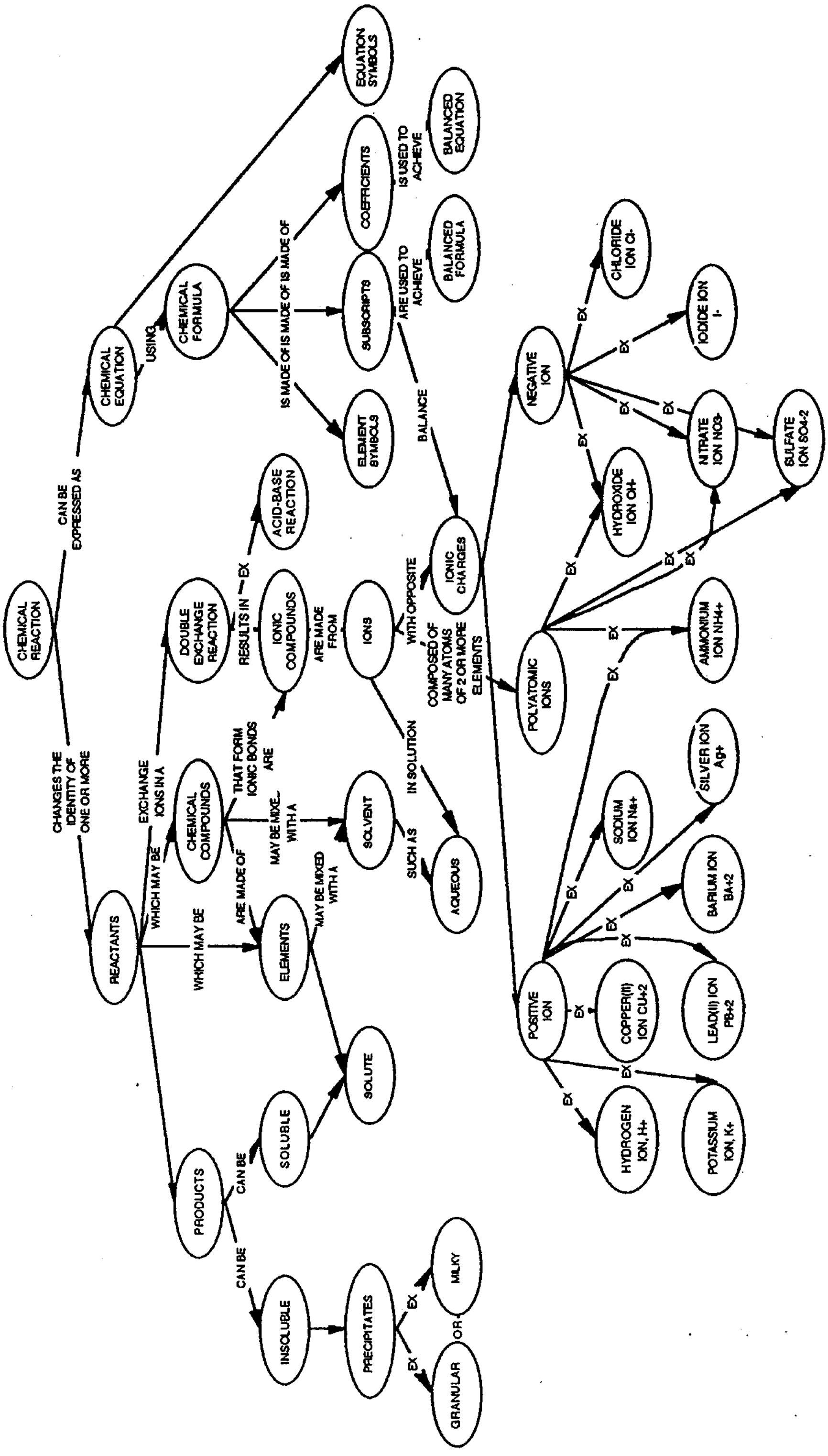

Figure 1. Student-constructed postlab concept map, Experiment 2.

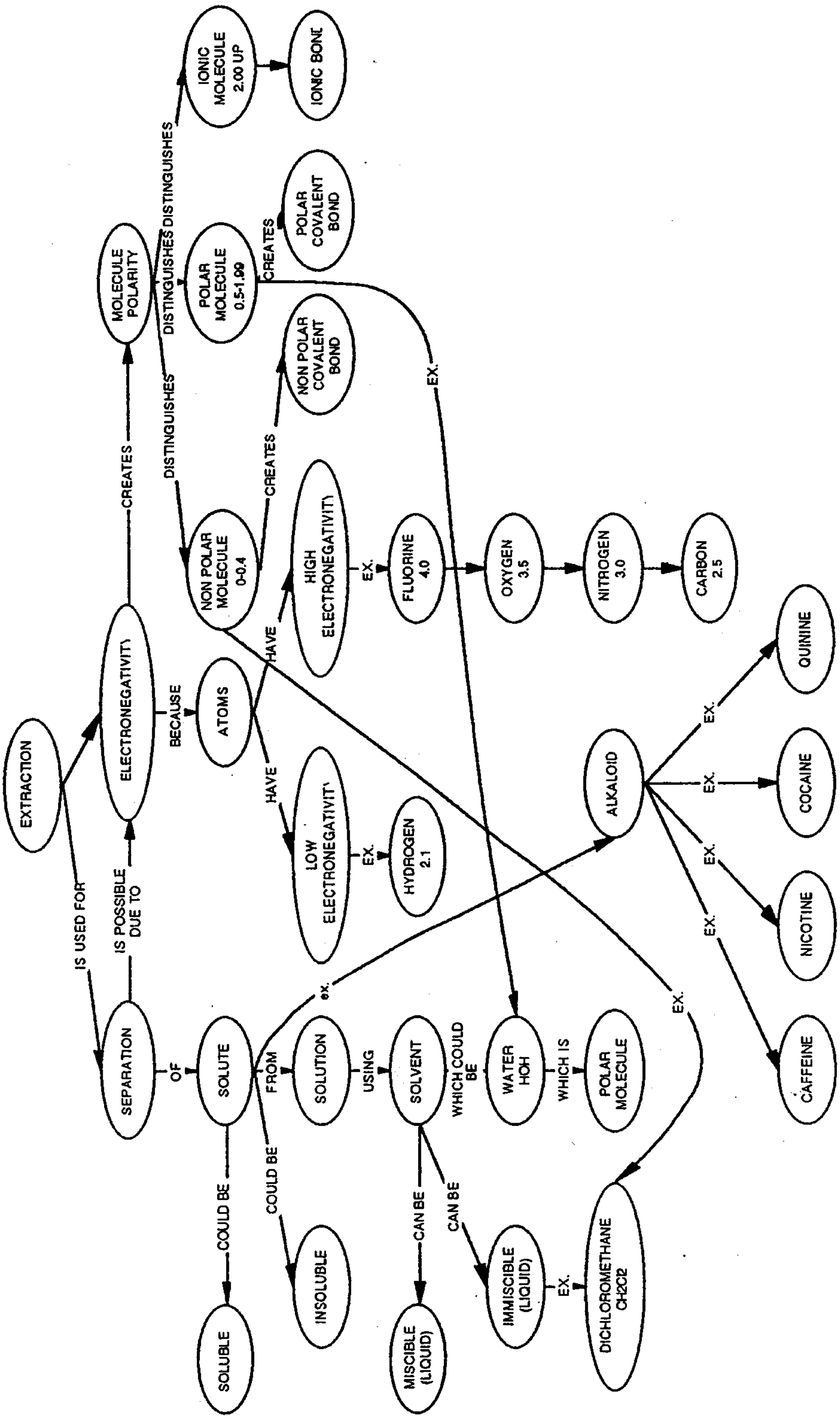

Figure 2. Student-constructed postlab concept map, Experiment 4.

Students felt that their active involvement in connecting concepts and the visual nature of the concept maps made it easier for them to understand and remember the concepts of the chemistry experiments they performed.

- When I learn a concept, I have a very fuzzy view to begin with, and then I kind of work at it and work at it, and read about it, and then the lightbulb goes on, and I think that concept maps helped to turn on those lightbulbs.
- . . . In the past, I might have read about the concepts, made some notes about the definitions, just as I did to get started here, but then the next step of bringing all the concepts together, I did not actively do something to make that happen.
- It helps me a lot to see stuff not in paragraph form, to see it as it relates to each other.
- When you are memorizing the definitions, you are not connecting them to each other; you are just basically memorizing them. And then you are not using them together when you go to do an experiment . . . you do not think about how they relate to each other. . . . With concept mapping, you know how they relate to each other.

Discussion

The results of this study indicate that learning did occur, and that there is no significant difference in the learning of conceptual chemistry as measured on achievement tests between students who write essays versus those who construct concept maps as part of their lab reports. The construction of prelab and postlab concept maps did help students understand the concepts in the experiments they performed.

A number of factors influenced the achievement test score results and need to be considered when assessing the importance of these findings. Although the reliabilities of the achievement tests used in this study were similar to those of tests used to evaluate other studies on concept mapping, they are still low (Pankratius, 1990; Stensvold & Wilson, 1990; Wallace & Mintzes, 1990). This fact, coupled with the small treatment groups, raises a question about the significance of these results. Instructional chemistry laboratories at the institution where this research was carried out can have a maximum of 20 students, and there are usually only two laboratory sections per course for any semester. Also, during a typical 3-h laboratory period, there is not enough time for students to take a 45-min test involving 40–50 items. Asking students to take this type of test at a different time would have been an unreasonable request, given the one credit awarded for laboratory work.

For future studies, it would be useful to have students construct prelab and postlab concept maps for every experiment performed and then take a longer, more reliable achievement test at the end of the semester which covers the conceptual content of all experiments. A control group similar to that used in this study would be used to test for significant differences. Since the technique of concept mapping is thought to promote meaningful long-term learning, this type of research design would then be assessing a longer-term retention of conceptual information than in this study.

The lack of significant differences between achievement test scores also raises the question of whether multiple choice tests are a suitable way to measure conceptual understanding. In general, a multiple choice item tests a student's understanding of a single concept, whereas a concept map requires students to focus more on the relationships between concepts. In future studies, control and experimental group students could be interviewed and asked to explain their understanding of the conceptual component of each experiment. This technique would allow the researcher not only to measure understanding of individual concepts, but also to evaluate a student's understanding of the relationships between concepts. The fact that control group students were not interviewed is a weakness of this study.

A second factor which could have influenced the achievement test results is the brief exposure to, and practice with, the technique of concept mapping prior to data collection. The first concept map used in this study (Experiment 1) was only the third map constructed by students in the experimental group. The lack of significant differences between prelab and postlab concept map scores for Experiment 1 seems to support this assumption (Table 3). Further support can be found in the researcher's field notebook for the collection of data during the first two experiments. These data show that some students were unclear about general map structure (hierarchy). Also, they were confused about what constituted concepts and examples. Since the students who participated in this study only received one credit for the laboratory component of this course, it was not fair to require additional time outside the normal laboratory hours to practice constructing concept maps.

A third factor is evident in the many low postlab concept map scores (Table 3), which may indicate that many students in the experimental group did not become actively involved with the concepts in the experiments. On 8 of 14 end-of-semester evaluations, students mentioned that too much work was required for the laboratory and the workload was not appropriate since they were receiving only one credit. These two statements demonstrate that about half the students in the experimental group were not willing to spend the time and energy necessary to produce well-structured concept maps.

Three of the four components in Novak's concept map scoring system were straightforward and easy to evaluate: valid relationships, valid examples, and crosslinks. Determining the levels of hierarchy on student-constructed concept maps was more challenging for the researcher. The lack of distinct levels of hierarchy may be due to the limited experience these students have with the construction of concept maps, or it may reflect real differences in conceptual understanding.

In a study of concept maps constructed by 15- to 16-year-old students from learner-generated concepts, Stuart (1985) investigated concept map scoring reliability. Stuart used a modified Novak scoring scheme consisting of six components: branching, general to specific, closed units, technical terminology, relationships, and hierarchy. That author found that the hierarchy component was strongly related to the relationships component, but that all other concept map component scores did not correlate significantly with each other and are therefore best treated and most reliable as separate measures. The reliability was lost when the component scores were combined together to produce a total score as suggested by Novak. Stuart asserted that using the components of her modified Novak concept map scoring scheme as independent measures is a more reliable method of assessing students' learning in a pretest/posttest fashion. Wallace and Mintzes (1990) also used five scoring categories, and another complex scoring system was proposed (Schreiber & Abegg, 1991). Future studies of the type conducted in this research should consider these other scoring systems, the issue of concept map scoring reliability, and the effects of teaching students how to construct concept maps (Ruiz-Primo & Shavelson, 1995).

With the exception of the first experiment, students constructed significantly more complex concept maps after they had listened to the introductory instruction and completed the experiment than before coming to lab having read only the experiment handout (Table 3). The characteristics of above average postlab concept maps include more valid relationships between concepts, a more general to specific hierarchical organization of concepts, more crosslinks and branches of the concept map, and more valid examples. The presence of these characteristics on postlab concept maps suggests a more complete understanding of the concepts of the experiment. Ruiz-Primo and Shavelson (1995) raised the question of whether concept maps provide a reasonable representation of a student's cognitive structure. Does a more intricate and complex concept map represent a more meaningful understanding on the part of the student, or has that student simply learned how to construct good concept maps? Once again, future research that included individual student interviews could assess this issue. The results of this study suggest that the assessment of meaningful understanding of conceptual material by laboratory students is a complex issue and may not be possible using only multiple choice tests and concept maps.

All of the students interviewed felt that the construction of prelab and postlab concept maps helped them more fully understand the conceptual chemistry of the experiments they performed. A weakness of this study was that the interviewer was also the students' instructor, and therefore perhaps students were reluctant to voice negative opinions during the interviews. Based on many low prelab and postlab concept map scores, it appears that many students lacked the motivation necessary to construct meaningful concept maps. Interview data and course evaluations indicated that the time involved for the one credit earned may have limited students' motivation to construct more complex concept maps. A future study could award students two credits for their laboratory work. Perhaps this would increase motivation and, coupled with positive student perceptions of the technique of concept mapping, could result in much greater conceptual understanding by students in chemistry laboratories.

Appendix

Sample Questions from Achievement Test 4 (Asterisk Indicates Correct Answer)

1. Which of the following statements is *true* for caffeine?
   a. Caffeine is soluble in water.
   b. Caffeine is soluble in dichloromethane.
   c. Caffeine is less soluble in hot water than in cold water.
   d. (a), (b), and (c).
   *e. (a) and (b).
2. Which statement is *not* true for caffeine?
   a. Caffeine is a nitrogen-containing ring compound.
   *b. Caffeine is a central system depressant.
   c. Caffeine is a member of the alkaloid family.
   d. None of the above.
9. Which of the following statements is true?
   a. Caffeine is more soluble in water than dichloromethane.
   b. Caffeine is insoluble in water.
   *c. Caffeine is more soluble in dichloromethane than water.
   d. Caffeine is equally soluble in water and dichloromethane.
10. Solvents that are miscible:
   a. Have large differences in molecular polarity.
   b. Do not readily mix together.
   c. Have identical boiling points.
   *d. Have small differences in molecular polarity.
11. Electronegativity is a property of:
   a. molecules
   *b. atoms
   c. solvents
   d. chemical bonds
13. Which of the following statements is true?
   a. The density of water is more than the density of dichloromethane.
   b. The density of water equals the density of dichloromethane.

c. The density of dichloromethane is less than the density of water.
*d. None of the above.

14. Which of the following would *decrease* the *percent yield* of caffeine?
a. Use fewer tea bags.
b. Extract the tea bags with boiling water for 10, not 7, min.
*c. Extract the tea bags for 5, not 7, min.
d. None of the above.

19. How many bonding electrons are involved in a polar covalent bond?
a. 1.
b. 3.
c. 4.
*d. 2.

References

American Association of Advancement of Science. (1993). *Benchmarks.* New York: Oxford University Press.

Ausubel, D.P., Novak, J.D., & Hanesian, H. (1978). *Educational psychology: A cognitive view,* 2nd ed. New York: Holt, Rinehart, & Winston.

Bodner, G.M. (1986). Constructivism: A theory of knowledge. *Journal of Chemical Education, 63,* 873–878.

Carter, C.S., & Brickhouse, N.W. (1989). What makes chemistry difficult. *Journal of Chemical Education, 66,* 223–225.

Herron, J.D. (1984). Using research in chemical education to improve my teaching. *Journal of Chemical Education, 61,* 850–854.

Hofstein, A., & Lunetta, V.N. (1982). The role of the laboratory in science teaching: Neglected aspects of research. *Reviews of Educational Research, 52,* 201–217.

Inspirations, v. 4.1. [Computer software]. (1994). Portland, OR: Inspiration Software.

Johnstone, A.H. (1984). New stars for the teacher to steer by. *Journal of Chemical Education, 61,* 847–849.

Lawson, A.E., & Renner, J.W. (1975). Relationship of science subject matter and developmental levels of learners. *Journal of Research in Science Teaching, 12,* 397–398.

Lincoln, Y.S., & Guba, E.G. (1985). *Naturalistic inquiry.* Newbury Park, CA: Sage.

Markham, K.M., Mintzes, J.J., & Jones, M.G. (1994). The concept map as a research and evaluation tool: further evidence of validity. *Journal of Research in Science Teaching, 31,* 91–101.

Nakhleh, M.B., & Krajcik, J.S. (1993). A protocol analysis of the influence of technology on students' actions, verbal commentary, and thought processes during the performance of acid-base titrations. *Journal of Research in Science Teaching, 30,* 1149–1168.

Nakhleh, M.B., & Krajcik, J.S. (1994). Influence of levels of information as presented by different technologies on students' understanding of acid, base, and pH concepts. *Journal of Research in Science Teaching, 31,* 1077–1096.

National Research Council. (1995). *National Science Education Standards.* Washington, DC: National Academy Press.

Novak, J.D. (1977). An alternative to piagetian psychology for science and mathematics education. *Science Education, 61,* 453–477.

Novak, J.D., & Gowin, D.B. (1984). *Learning how to learn.* New York: Cambridge University Press.

Pankratius, W.J. (1990). Building an organized knowledge-base: Concept mapping and achievement in secondary school physics. *Journal of Research in Science Teaching, 27,* 315–333.

Pickering, M. (1988). Report on the NEACT conference: The chemistry lab and its future. *Journal of Chemical Education, 65,* 449–450.

Pickering, M. (1993). The teaching laboratory through history. *Journal of Chemical Education, 70,* 699–700.

Pines, A.L., & West, L.H.T. (1986). Conceptual understanding and science learning: an interpretation of research within a sources-of-knowledge framework. *Science Education, 70,* 583–604.

Posner, G.J., Strike, K.A., Hewson, P.W., & Gertzog, W.A. (1982). Accommodation of a scientific conception: toward a theory of conceptual change. *Science Education, 66,* 211–227.

Roletto, E., Regis, A., & Albertazzi, P.G. (1996). Concept maps in chemistry education. *Journal of Chemical Education, 73,* 1084–1088.

Ross, L.R. (1994). Chemistry curriculum reform focuses on content, technology and pedagogy. *Chemical & Engineering News, August 29,* 35–38.

Roth, W.-M. & Roychoudhury, A. (1993). The concept map as a tool for the collaborative construction of knowledge: A microanalysis of high school physics students. *Journal of Research in Science Teaching, 30,* 503–534.

Ruiz-Primo, M.A.. & Shavelson, R.J. (1995, April 19). Concept maps as potential alternative assessments in science. Paper presented at the American Educational Research Association annual meeting, San Francisco, CA.

Schreiber, D.A., & Abegg, G.L. (1991, April 7–10). Scoring student-generated concept maps in introductory college chemistry. Paper presented at the annual meeting of the National Association for the Research in Science Teaching, Lake Geneva, WI. (ERIC Document Reproduction Service No. ED 347 055)

Stensvold, M.S., & Wilson, J.T. (1990). The interaction of verbal ability with concept mapping in learning from a chemistry laboratory activity. *Science Education, 74,* 473–480.

Stuart, H.A. (1985). Should concept maps be scored numerically? *European Journal of Science Education, 7,* 73–81.

von Glasersfeld, E. (1992). Questions and answers about radical constructivism. In *The practice of constructivism in science and mathematics education.* Washington, DC: American Association for the Advancement of Science Press.

Wallace, J.D., & Mintzes, J.J. (1990). The concept map as a research tool: exploring conceptual change in biology. *Journal of Research in Science Teaching, 27,* 1033–1052.

Ward, C.R., & Herron, J.D. (1980). Helping students understand formal chemical concepts. *Journal of Research in Science Teaching, 17,* 387–400.

Wilson, J.M. (1994). Network representations of knowledge about chemical equilibrium: Variation with achievement. *Journal of Research in Science Teaching, 31,* 1133–1147.

Yager, R.E. (1991). The constructivist learning model. *Science Teacher, 58,* 52–57.

Yankwich, P.E., Eberhardt, W.H., Lavallee, D.K., & Schwartz, A.T. (1984). Recommendations of the American Chemical Society Chemical Education Task Force. *Journal of Chemical Education, 61,* 845–847.

Zeitz, L.E., & Anderson-Inman, L. (1992, April 24). The effects of computer-based formative concept mapping on learning in high school science. Paper presented at the annual conference of the American Educational Research Association, San Francisco, CA.

Zoller, U. (1990). Student's misunderstandings and misconceptions in college freshmen chemistry (general and organic). *Journal of Research in Science Teaching, 27,* 1053–1065.