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A Case Study of the Effects of a Constructivist Method of Instruction in General Chemistry Laboratory on Conceptual Change and Knowledge Construction among College Students

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INTRODUCTION

This paper deals with the qualitative aspects of a larger study of the effects of constructivist and traditional teaching methods on achievement, conceptual change, attitude and perception of college students in the general chemistry laboratory (Lewicki, 1993). Specifically, six case studies that relate to conceptual change and knowledge construction will be presented and discussed.

It is argued that laboratory experiences may be a worthwhile or essential aspect of science education, but the literature relating to research in this area does not always support these assumptions. While the laboratory may have value for nurturing positive student attitudes and for providing opportunities for students of all abilities to demonstrate skills and techniques (Bates, 1978), it appears that students may fare no better with a laboratory experience than without one in developing understanding of chemistry (Novak, 1984).

Several instructional models, such as inquiry-discovery, learning cycle, and cooperative learning, that could share features with laboratory experiences have been successful in attaining several important goals. These goals include: arousing and maintaining the interest of students; developing higher-level thinking skills; promoting the acquisition of process skills; and developing practical skills (Hofstein, 1988). Considering the value many science teachers place on the laboratory experience, it is appropriate to search for instructional strategies or modifications of existing ones which can promote these goals and to investigate their affect on student learning.

In considering teaching strategies and their impact, it is important to understand how students learn and the better way to teach them. Research directed to understanding student learning and teaching effectiveness has focused on students' pre-existing knowledge and conceptions and effective teaching strategies which take these into account and enable students to undergo conceptual change (Basili & Sanford, 1991). Much attention has also been paid to developing teaching strategies which enable students to construct representations of new experiences by relating them to past ones (Anderson, 1992).

An examination of a variety of learning theories and instructional-design models and to effective teaching methods enabled the investigator to identify components of a constructivist instructional method which could affect learning in the laboratory. The method was based on the assumption that students should experience what they learn in a direct way and be given time to think about their experiences and to discuss them with other students.

One of the components, conceptual integration, was based on meaningful learning theory (Ausubel, Novak & Hanseian, 1978) which suggests that the teacher needs to be concerned with the internal learning process and external events which can facilitate it. If concepts derive their meaning through connections or relationships with other concepts, then meaningful learning can occur if new knowledge is consciously linked to relevant concepts already possessed by the learner. Therefore, it is important that the teacher design activities which demonstrate how concepts are integrated and differentiated. In addition, using concepts that have wide explanatory power may result in better organization and integration of the subject matter (Cullen, 1983).

A second component, student-inquiry, was based on theory which suggests that knowledge can be acquired through discovery learning (Bruner, 1961). "Instruction in this domain consists mainly of having students use the processes of science...[which include] observing and measuring, classifying and organizing, measuring and charting, communicating, predicting and inferring, identifying and controlling variables and interpreting data" (McCormick & Yager, 1989, p.47). The teacher provides the materials and establishes situations for guided-inquiry to occur and encourages students to identify problems and actively explore solutions to them.

The third component, guidance to promote conceptual change, was based on conceptual change theory (Posner et al., 1982) which suggests that learning involves changing a person's pre-existing conceptions in addition to adding new conceptions. Learning involves an interaction between new and existing conceptions. According to Poser et al. (1982), students use their existing knowledge to determine if new concepts are intelligible, plausible and fruitful.

To facilitate the process, the teacher needs to play the role of antagonist by challenging students to defend their ideas. Students should critique evidence and theories in light of their own experiences in the laboratory. They should test hypotheses and modify their conceptions based on the results. In addition, there should be frequent attempts to show linkages between laboratory experiences and phenomena encountered outside the laboratory. In this way, concepts developed in the laboratory can be extended beyond the laboratory to open up new areas of inquiry.

The last component, <u>social interaction</u>, was based on research which points to the value of student collaboration (Johnson & Johnson, 1986). "There is increasing evidence that students who talk through material with peers learn it in a more effective way...and retention of information is enhanced in the cooperative setting...[because] students who work in cooperative relationships are more likely to have a conscious strategy for how they got to the answer" (Johnson & Johnson, 1986, p.3). Activities which require social interaction will stimulate learning and will enable students to appreciate the value of their actions and the actions of others.

A constructivist instructional method incorporating these four components was devised and tested by the investigator. The purpose of this study was to determine its effect on achievement, conceptual change, attitude and perception of college students enrolled in general chemistry laboratory. A conventional verification instructional method characterized by an inform-verify-practice sequence and students working independently was used for comparison. This paper will deal exclusively with the case study aspects of the study.

RESEARCH QUESTIONS

Among the research questions that served to guide the study, the following relate specifically to the qualitative aspects:

1. Does a college general chemistry laboratory course utilizing a constructivist method characterized by conceptual integration, episodes of student-inquiry, guidance to facilitate conceptual change, and social interaction promote conceptual change and knowlege construction?

2. Does a college general chemistry laboratory course utilizing a conventional method involving verification experiments promote conceptual change and knowlege construction?

METHOD

Sample

College students (N=68) enrolled in general chemistry laboratory in the spring of 1992 at a university in upstate New York were taught using the different teaching methods over a six week period. The two teaching methods were: (1) the verification method (control) and (2) the constructivist method (experimental). A convenience sample of six students from the larger sample (three from the control group and three from the experimental group) volunteered to participate in weekly half-hour interviews with the researcher. These students represented a range of abilities as evidenced by their performance on a variety of pre-cognitive and attitudinal measures. A total of thirty-four interviews were conducted with an average of five interviews per student. The interviews were audio-recorded with the student's knowledge and permission. The audio tapes were subsequently transcribed by the investigator.

Treatment

The verification method involved a sequence of six laboratory activities where students verified generalizations and concepts introduced by the textbook using highly structured procedures and fill-in-the-blank data tables. The textbook used was Chemical Principles in the Laboratory (Slowinski, Wolsey, & Masterton, 1989). The six acitvities were: Physical Properties and their relationships; mixtures and solubility; chemical properties; chemical reactions & chemical formula; mass relationships in chemical reactions; and chemical changes and energy.

The constructivist method involved a sequence of six laboratory activities involving the same content areas as in the verification method but were designed to promote knowledge construction and conceptual change through internal and external integration of concepts, open-ended, investigative activities, and social interaction. The student and teacher manuals used with this method were compiled by the investigator. Each activity consisted of four phases: (1) Demonstration: students observed an event and attempted to explain it using their pre-existing knowledge and understanding; (2) Guided inquiry: students discussed problems and possible solutions and interacted with concrete materials to acquire information about a chemical or physical system with minimum guidance from the teacher; (3) Concept Formation: students gathered together and were asked to look for relationships among variables, describe mathematical relationships, or look for general trends; (4) Application: students extended the basic concepts by solving problems which had relevance in the real world or with which they could identify. A variety of resources were used to construct the laboratory program (e.g., Journal of Chemical Education, Abraham & Pavelich, 1991) and the six activities were modifications of ones which were suited to the instructional model being tested. A sample activity may be found in the appendix. A pilot study was conducted with college students in the spring of 1991 to ensure the readability and comprehensibility of the student manual.

Instrumentation

A list of questions served as a basis to interview the six students to investigate how students' knowledge was changing from week to week and to determine if the instructional format was affecting this change differently.

Interview questions were modelled after ones used in a study that employed a naturalistic method to determine why inquiry-type laboratory experiences were successful in increasing enrollment in secondary school physics (Renner, Abraham & Birnie, 1985) and in a study that employed instructor-student interviews to determine the effectiveness of using concept mapping on conceptual understanding of chemistry (Felsine, 1987).

RESULTS

The data reported here were educed from the interviews with six students in the study . In general, students were questioned regarding how they perceived their knowledge and understanding were changing, the relationship between laboratory activities from week to week, and the chemical concepts learned in the laboratory and their relationships. Modifications of the interview-about-instances and the interview-about-events methods (Gilbert, Watts, & Osborne, 1985) were used to probe conceptual understanding. Although each session was structured using an interview guide, deviations from these were necessary to probe individual differences in the answers given and to probe individual conceptions relating to the laboratory activities.

The Individual Cases

The case studies of the three students in the experimental group will be presented first followed by the case studies of the three students in the control group. While data was collected that related to conceptual change, attitude and perception, only data relating to changes in the understanding of chemical concepts is presented. Direct quotes are off-set from the rest of the paragraph and are identified by a number corresponding to the week the interview was conducted during the six-week period. This permits an across-time comparison of remarks. The *pre- and post-Concept Test* referred to in the cases, was a pencil-and-paper test administered to all students in the study. It was used to assess students' conceptions prior to instruction and to determine the effectivenss of the instruction in helping students acquire scientific conceptions in the areas relating to the laboratory curriculum. A complete description and the test is provided elsewhere (Lewicki, 1993).

The Case of Laura

Laura was a senior enrolled in the Monday evening laboratory class which used the constructivist method. Her major was psychology. Laura had one year of high school chemistry, one year of high school biology and three years of mathematics through intermediate algebra. She was taking chemistry to fulfill a science requirement and had previously completed a required course in biology. She was not enrolled concurrently in any other science courses. Her last experience with chemistry was as a sophomore in high school, so it had been seven years from her last course.

Laura was interviewed on six occasions. She was a mature student who spoke clearly and purposefully in response to questions. She never missed an appointment and enjoyed talking about her experiences. She was always willing to answer questions and to elaborate on her answers without much prodding.

Understanding of chemical concepts

On several occasions Laura's understanding of chemical concepts and principles as they related to the laboratory activities was explored. Her score on the pre-*Concept Test* (0 out of 13) revealed that in spite of having completed one year of high school chemistry, Laura's understanding at the onset of the semester of several chemistry concepts related to laboratory was poor. Her post-*Concept Test* score (8 out of 13) was significantly better. This was also confirmed by the qualitative data. For example, her pretest score on items related to the concept of density revealed only a superficial understanding that mass divided by volume equals density. She felt the laboratory activity provided a greater depth of understanding.

> I understood that mass over volume equals density. Now its more...I understand more because I was able to see it being done. It has more of an influence on me now. It's not just a number, it's not just a formula, it's more understandable to me because I saw it...I saw it actually...Instead of having information...knowing the formula in back of my head...its something that's more...I don't have to think about it...I don't have to think "Oh what is that formula"...its something I really know now. (Week #1)

To probe the depth of this understanding, the researcher showed her an illustration of two vials of the same size, one filled with 10 grams of an unknown solid and the other filled with 10 grams of another unknown solid having identical physical characteristics except for volume.. The volumes of solids were noticeably different, but that was not pointed out to Laura. She was asked what she would have to do to determine if the two solids were identical or different.

> They must be different because there's more of one and therefore it's less dense; substance B. If they have the same weight and B has a larger volume, then it must be less dense. For them to be the same material, B would have to have a higher mass because there is more volume. The density is a proportion. If you have more volume, then you must have more mass. Twice the volume for example would have to have twice the mass, not the same mass. They must be different materials. (Week #2)

Her performance on post-*Concept Test* items related to density confirmed that she had increased her knowledge and understanding of density, but while discussing [in Week #6] a procedure for finding the volume of an irregular-shaped solid using mass and volume data of a regular-shaped sample of material of the same composition, Laura expressed a misconception related to volume. She insisted that the volume of water displaced by a solid dropped into the water would be the same whether the object dissolved or not.

> I: What if the object sinks, but it dissolves in the water. Would the object still displace water?
> L: You would still be able to see the increase even though it dissolved in the water.
> I: You mean the final volume would be equal to the original volume of the water plus the volume of the object you placed into it?
> L: Right.

Misconceptions of this nature do not necessarily surface during the laboratory activity and point to the need for frequent questioning and probing by the laboratory instructor to enable them to surface and be confronted. Several other misconceptions surfaced during the interviews which would not have been picked up by the pencil-and-paper tests. The following are some examples: "A compound could be two mixtures together."(Week #4); "A wet sponge is a good analogy for a hydrate. The sponge can be hydrated or dehydrated by getting all the water out." (Week #4); "When something dissolves in water a reaction occurs." (Week #5); "Solubility is a chemical property." (Week #6).

During another session (Week #5) Laura was shown an illustration of a sealed flask containing a solid substance before and after heating. The substance changed from a silver metal to a white powder after heating. She was asked to offer an explanation which would account for the change in appearance. Although she responded correctly to questions on the post-*Concept Test* which dealt with a similar situation, the dialogue which follows reveals more of a depth of understanding of the concepts and principles involved and points to the positive influence of the laboratory experience in promoting that understanding. However, in the end Laura was not able to tie together all of the relevant chemical facts to completely explain what had occurred. The episode points out the need for questioning which forces students to elaborate on their answers.

L: Well the substance combined with the oxygen and decomposed with the heating. It combined with the oxygen.
I: So you are speculating that the white powder is the product of the silver metal combining with oxygen?
L: Yes.
I: How would you prove that was the correct explanation?
L: You could weigh before and after and you see that it increased which means it must have combined with the oxygen.
I: How do you know it combined with oxygen?
L: Well it could have been nitrogen but it is primarily oxygen.
I: So every time something is heated, it always must combine with oxygen?
L: If there is air in the flask, it must be a substance from the air.
I: But aren't there lots of gases in air?
L: Yes.
I: Any way to prove it?
L: Possibly by the weight. You know how much, from the periodic table, oxygen weighs. You know how much weight it gained.
I: So the material gained weight during the change?
L: Yes.
I: From the increase in weight you can figure out that it is oxygen?

L: Well it depends on the metal. If you know what elements are in there.
I: You have to know what the metal is?
L: Yes.
I: If you knew what metal it is and from the weight increase, you can figure out that it combined with oxygen? How?
L: You can figure out from the ratio. For example, we had an activity where they gave you the molecular weight and you had to figure out how the elements combined and what the formula was.
I: How do you figure out just from the weight what the formula would be?
L: You couldn't know.
I: Is there any way to tell for sure what substance in the air combined with the metal?
L: Not that I can think of off hand.
I: What additional information would you need?
L: You'd have to be able to know the formula of the metal before heating, but also the...if you had...you'd have to do a test...to see exactly what the formula was...then do a test to find out after reaction what the formula would be.
I: Is there any other information that you would need to conclude that the silver metal combined with oxygen in the flask?
L: Any information?
I: Yes.
L: I don't know.
I: Is the problem an impossible one to figure out?
L: No, I just don't know.
I: Was there anything you did in the lab that was similar to this?
L: Yes. We took a piece of silver metal, heated it and [pause]
I: What did you do before you heated it?
L: We weighed it. After heating it, we weighed it again and saw that it increased in weight.
I: What were you able to figure out from that data?
L: That it combined with something.
I: How did you know it combined with oxygen?
L: We discussed it. People gave their idea of what they thought it would be and basically we concluded that it would combine with oxygen.
I: You mean that you were informed that it combined with oxygen.
L: Yes.
I: Was there anything that you did to prove it?
L: No. We were shown formulas on the board.
I: What do you mean by that?
L: We were shown formulas showing that it combined with oxygen.
I: Were there any other possibilities for combinations?
L: Well it could have been nitrogen.
I: Was there a difference in the way oxygen and nitrogen combine with the metal that might have given you a clue as to which it was?
L: We weren't told.
I: Well just in terms of what was written on the board?

L: It wasn't written out with nitrogen. We were just told it could have combined with nitrogen.
I: What information tells you the way two substances react together?
L: The formula. You have two formulas and then you see the product. You see what comes out. The statement is called the reaction. Basically what we were trying to find out was whether it increased or decreased in mass and what could be a possible reason for that.
(Week #5)

<u>The Case of Peter</u>

Peter was a non-matriculated post-baccalaureate degree student. He was enrolled in the Monday evening laboratory class which used the constructivist method. He completed a four-year degree in liberal arts at another four-year college and entered the university with the idea of completing basic science courses in preparation for graduate school or application to medical school. He was very concerned about doing well and placed great importance on grades. Besides completing one year in biology, Peter completed one year of high school chemistry, one year of physics and three years of mathematics through intermediate algebra.

Peter was interviewed on five occasions. He was quite talkative and did not hesitate to give lengthy answers to probing questions, albeit at times he tended to ramble and had difficulty concluding his remarks. Since he was an older student who already possessed a college degree, it appeared he had a strong desire to impress the interviewer with his answers. He was also very anxious prior to exams and apologized if his answers seemed unfocused during those times.

<u>Understanding of chemical concepts</u>

On several occasions Peter's understanding of chemical concepts and principles as they related to the laboratory activities was explored. His score on the pre-*Concept Test* (6 out of 13) revealed that he retained some knowledge and understanding from his prior experiences relevant to the laboratory activities. He scored well on most items related to density except when he claimed that two solids which have different masses must have different volumes. He failed to consider that their densities could be different.

Peter performed the laboratory activity which covered the topic of density. In an early session following that activity, Peter was asked to comment on the like or unlike composition of two 10-gram samples of solids contained in two identical-sized vials where the volumes of solids were noticeably different. His answer revealed that he had changed his conception.

> If the densities are the same then they are the same. Well you know you can see just by looking at it that there's more of one substance than the other...this tells you that their densities are different. Of course, one material is more dense than the other. You could tell just by looking at it. Their masses are constant. The volume of one is less than the volume of the other. The mass to volume ratio of one would be different than the other. (Week #2)

The conceptual change was confirmed by the post-*Concept Test* (score 10 out of 13) where he responded correctly to the item dealing with differences in the masses of two solids in spite of similarities in volume.

Following the laboratory activity on physical properties and mixture, he was asked how he would go about separating a mixture of two solids with similar physical characteristics. His suggestion demonstrated a sound understanding of the process and the concepts relevant to the process.

> You would have to know their solubility in water. You would have to know their solubility at different temperatures. Now by adding distilled water to the mixtures. Knowing the solubility...you have to try to keep one in the solution while precipitating the other out of the solution. Now you could heat or cool the solution to precipitate one of the solids. Then use filtration to remove the one solid which has precipitated out. The other one is dissolved. It remains in the solution. You would not recover all the solids because fractional crystallization is not one hundred percent efficient. (Week #3)

As in the previous case study, Peter was asked to offer an explanation for the change in appearance which occurred when a solid contained in a sealed flask was heated. The substance changed from a silver metal to a white powder after heating. He realized quickly the similarity between the illustration and his laboratory experience and used the latter as a focal point for his remarks. He also drew upon knowledge from his lecture course to reach his conclusions.

> P: Upon heating of this silver metal, the bonds in it were loosened and it mixed with the oxygen, we know that from the lab, this is magnesium by the way, and it reacted so as to create a powder. It loosened the bonds and when the oxygen and the magnesium combined with the product which was the white powder.
>
> I: How would the mass of the entire system compare with the mass of the system after heating?
>
> P: The whole system would weigh more after heating. [pauses to think] Actually I take that back. This is a closed system. It goes from one

to another...the law of conservation of mass...it is transformed from gaseous phase to solid phase.

I: How would the masses of the solid in the flask compare?

P: By the same reasoning it has to be the same.

I: What about the masses of gases inside the flask?

P: Again the same..uh...the mass of the gas...in the gaseous phase it would have to be less because some combined to form magnesium oxide.

I: But the mass of the solid remains the same?

P: Yes.

I: Why did you conclude it was magnesium?

P: Well it was based on what we did in the laboratory. To my limited knowledge, it is the only one that would do something like that.

I: Is the magnesium an element or a compound.

P: It's an element.

I: What about the white powder?

P: It's definitely a compound. It's made up of magnesium and oxygen.

I: Is it possible to figure out what the formula of that compound is?

P: Yes. You have to find...mass...you have to find molar masses. You have to find how many moles are in each one. You take...since they have to be in a fixed ratio...you divide them...how many moles of one, the least one, into that one, the one with the greater moles.

I: And what does that give you?

P: The empirical formula.

I: How do you calculate the number of moles of each?

P: You have to find its mass divided by...mass times...use factor label...its mass....one mole over...molecular weight.

I: What mass are you referring to?

P: Well assuming we know it's magnesium or oxygen...you take how ever many grams of magnesium...factor label...one molecular weight. Then do the same for the oxygen.

I: How would you get the weight of the oxygen?

P: You probably have to find the percentage of concentration of how much oxygen is actually...you can get it from atmospheric value...how much oxygen is in the atmosphere divided by the total possible elements in the atmosphere.

I: How would I obtain the mass of oxygen?

P: Well you could measure an empty flask with a stopper in it and...uh....

I: Nothing in the flask?

P: If you could possibly create a vacuum in it. Take the mass without anything in it, uncork it and let the gas in and take the mass of that. That would tell me how much air was in the flask.

I: How does that tell me how much oxygen is in the white powder?

P: The mass difference. The mass before subtracted from the mass afterwards.

I: You mean the two masses would be different?

P: Yes. This is greater. The total mass is the same, but the mass of the substance changes. The difference between the two masses is the

> mass of the oxygen. Once you have that you use the factor label method...divide by the molecular mass and calculate the moles.
> (Week #4)

The episode confirms a growth in depth of understanding which occurred when one compares Peter's responses to questions on the pre- and post-*Concept Test* which relate to the event. Initially Peter thought the mass of the metal would change "because part of the solid changed to a liquid or gas." On the posttest his reason demonstrated greater understanding: "By heating the metal, its bonds loosened enough to react with the 'air' in the container. Air was added to the hot metal, hence since air has mass, the metal's [mass] increases." Both qualitative measures confirm that conceptual change had occurred.

An analysis of the interview protocols did reveal some of Peter's misconceptions. For example: "Burning and heating are the same." (Week #3); "When things dissolve, a chemical reaction forms with a certain amount of heat." (Week #4); "When an object floats on water it displaces a volume of water equal to its own volume." (Week #5); "When a solid dissolves in water it displaces a volume of water equal to the volume it would displace if it didn't dissolve in the water." (Week #5). The last two misconceptions demonstrate the need for this type of assessment to probe a student's understanding. Peter correctly answered all items on the post-*Concept Test* which related to density. One might have concluded based on this measure that he understood the concepts. The dialogue revealed that there were still lingering misconceptions which needed changing.

The Case of Mark

Mark was a freshman who transferred to the university from a mid-western college. Concern for grades prompted this action and his intention was to do as well as he could in order to eventually apply to medical school. He was enrolled in the Monday evening laboratory class and used the constructivist method. His major was biology. Mark completed one year of high school biology, chemistry and physics and three years of mathematics through intermediate algebra.

Mark was interviewed on five occasions. He missed several appointments and had to be reminded often of scheduled sessions. Throughout the five interviews, Mark was cocky and infused humor into his remarks whenever he was a little unsure of what he was talking about. Frequently he would use excessive verbiage in order to impress the interviewer. For example, when asked what he thought the chemistry lab could be used for , he said, "It can be used to do experiments. Or in the hands of a professional chemist, chemicals could be used to put on a myriad, a cornacopia, a veritable, you know, a plethora of shows for interested students. The actual space could be used for other things, with the chemicals there. I mean besides chemistry experiments...my imagination is stunned right now."

Mark's previous experience with chemistry was in high school, but he thought the activities there were quite different from the activities he was engaged in at college.

> I don't recall that we did that much laboratory work in high school. If we did, the teacher did it as a demonstration and we observed...now there's more hands-on activity...also on the college level you expect to find a more advanced type of work being done...the experiments we conduct here are on a more advanced...a higher level than I did in high school. (Week #1)

In addition, he felt that his previous experiences with science courses did not accurately represent what really goes on in science.

> Usually in science courses you're told, this is the lab and in order to do this, you have to do this. You basically know right from the start where you are going to be and they tell you how you are going to get there. Then you do it, write a lab report, hand it in and wait till the next lab...it gets monotonous....Usually in scientific experiments, you're trying to find something new, so you don't know what the results are. That's what keeps scientists striving for new information. It keeps them going. If they knew where they were going, there would be no point to do it in the first place. (Week #1)

<u>Understanding chemical concepts</u>

By his own admission, Mark had trouble understanding some concepts in laboratory due in part to a failure to become more active during the class and his overdependence on his partner. This may have been the cause of a failure to undergo conceptual change especially with concepts related to density. On the pre-*Concept Test*, (score 3 out of 13) for example, when asked whether two solid metal balls of the same volume but different masses would displace the same volume of water if they sunk in the water, he wrote: "The ball with the greater mass will displace more water." For the same item on the post-*Concept Test* (score 5 out of 13) he indicated that the water level would rise higher with the heavier lead ball compared to the lighter aluminum ball because "lead has more density pushing upon the water." In the final interview which came close to the end of the semester, Mark revealed he retained the misconception regarding mass and volume.

Other misconceptions surfaced during the interviews in spite of laboratory activities which Mark completed which should have enabled him to change his conception and adapt a more orthodox one. The following are some other examples of misconceptions which he expressed: "Ethanol has a higher density than water because it had a greater push upon whatever was going to fall down into it" (Week #1); "A hydrate becomes an anhydrate when the water is burned off" (Week #3); "When something dissolves in water and the temperature drops, an exothermic process occurred because it gave off heat and therefore cooled" (Week #5); "The volume of water displaced by a solid which dissolves in the water would be the same volume if the solid didn't dissolve in the water" (Week #5); "The greater the density of a liquid, the more volume displaced by an object placed into the liquid" (Week #5).

He was confused with the concepts of compound and mixture and was not satisfied with his own understanding. With the right questions he was able to work out his confusion.

M: I always have difficulty between a mixture and a compound. I can't distinguish between the two.
I: Well give me an example of a mixture?
M: You mix two compounds together you get a mixture.
I: Can you mix two elements together to get a mixture?
M: You get a formula.
I: Can you have a mixture of elements?
M: Sure you can mix anything.
I: Well what's the difference between a mixture of elements and a compound of elements?
M: If they mix they become one thing, as a compound they are just two things connected.
I: When you mix the two things you can't separate them?
M: I guess so.
I: So when you mix sand and water, you cannot separate them?
M: You can separate them.
I: If sodium and chloride react to form sodium chloride, can you separate the sodium from the chlorine?
M: You could separate them but not as easily.
I: So what's the difference between a compound and mixture?
M: Well a compound you can put together and separate easily and mixture you can't. I'm sorry, the other way around.
I: Is the sand and water a mixture or a compound?
M: I'd say it was a compound. No I would say it was a mixture since you can mix them together and then separate them. The compound would be the sodium and chloride and the mixture would be the sand and water.
(Week #3)

In one episode, Mark recalled an instance where he underwent conceptual change. Mark was discussing the lab activity where a solid substance was weighed before and after heating. The substance changed from a silver metal to a white powder after heating. Initially he said, "When something is burned, oxygen would leave and the mass would be less." After completing the activity and discovering the mass increased after heating, he said, "I was surprised that I was wrong. I expected things to decrease in mass when they are burned." However, during a discussion of the event, Mark seemed to revert to his misconception when he said, "well we kept measuring and burning [the substance]...and [during burning] you're removing all...everything except [the substance]...whatever it was...you're removing off all the oxygen" (Week #3). Although he was convinced that the mass of a substance can increase after heating, his belief to the contrary was difficult to change. This was confirmed by the pre- and post-*Concept Test* . On the item related to this event, Mark stated that the mass would decrease because "the weight of the solid was converted into the weight of the [another solid] and some gas." On the posttest, he selected the same multiple-choice answer [Yes the mass changes] and stated as a reason, "most solids weights decrease after burning." He retained his prior conception in spite of a laboratory activity where he demonstrated that the mass of a solid can increase after burning.

In another interview, Mark was asked what properties one atom would have if the atom was removed from a solid which was malleable, an electrical conductor , and brown in color. Mark said that the atom would resemble the whole solid so it would have all three properties. When probed further, he eventually changed his conception when he realized that an atom could not be malleable. The episode points to the need for discussion to promote conceptual change.

> I: What is meant by malleability?
> M: The ability to be bent.
> I: So you mean an atom can be bent or flattened?
> M: Well...uh...I never really thought about that before. [pause] We were always told that each atom has the same or should have the same theoretical qualities that the whole does.
> I: Do you believe that?
> M: Well there's some food for thought here. I don't know if you could actually bend a single atom. You could bend a piece of metal.
> (Week #5)

When asked to discuss the dissolving process, initially Mark had some difficulty with the concept, but with probing questions he was able to work his way through to a clearer interpretation.

> I: Well take the example of salt. You take a cube of table salt, drop it in the water and it disappears. Where does it go?
> M: Into the water.
> I: Where into the water?
> M: Well it becomes sodium ions and chloride ions.
> I: Where do they go?
> M: They don't go anywhere. If you evaporate the water, they would reform.
> I: But you said they go in the water. You mean they go inside the molecules of water?
> M: No but they form a reaction with the water. They bond with the water.
> I: But if you have water molecules occupying the space in the beaker, then how can these other particles occupy that space as well?
> M: Well they bond with each other, but they are not in exactly the same place.

I: Is there room around the water molecules?
M: Of course. The water molecules can accept the sodium atoms and the chloride ions, they combine together.
(Week #5)

The Case of Denise

Denise was a sophomore enrolled in the Wednesday evening class which used the verification method. Her major was biology. She enjoyed biology courses, particularly anatomy, and took chemistry to fulfill a requirement. Denise completed one year of high school biology and chemistry and three years of mathematics. She was concurrently enrolled in general biology and often compared general chemistry with general biology claiming she always looked forward to the latter.

Denise was interviewed on only four occasions. She was involved in many extra curricular activities and often needed to be reminded of her scheduled interview appointments. In spite of these reminders she missed several appointments which had to be re-scheduled. Regrettably, she missed the final interview which could not be re-scheduled.

She was an average student who had difficulty articulating clearly what she was thinking. She often rambled when attempting to answer conceptual questions. When she became frustrated she would finish with statements like "well actually I don't know" or "I'm not sure."

Denise's last experience with chemistry was four years earlier and although there were some differences between the two courses she basically felt her college course was about the same as her high school course. She did highlight one significant difference when she said, "Actually there was more discussion in high school than now. You had the same teacher in class as you did for lab" (Week #2). Asked if that was beneficial she replied: "Yes, having the material taught in the classroom and in the lab by the same teacher was more helpful" (Week #2).

<u>Understanding chemical concepts</u>

Denise underwent some conceptual change as reflected in her pre- and posttest scores on the *Concept Test* (1 out of 13 and 6 out of 13, respectively). While she made feeble attempts to answer questions on the pretest, she left the majority of them blank. On the posttest, while not all of her answers were correct she did make attempts at answering them all. Her understanding of density changed little. For example, on the pretest she left blank or gave incorrect answers to questions relating to density. On the posttest, while she answered the questions, she revealed several misconceptions. Asked if a lead sphere would displace the same amount of liquid regardless of the liquid into which it was placed. She wrote: "Because the mass of water is less than carbon tetrachloride, the lead will tend to sink more in the water and float in the carbon tetrachloride. Therefore the level of carbon tetrachloride will rise more when the lead ball floats." When asked whether two spheres of the same volume but different mass will displace the same volume of water, she wrote: "Because the mass of aluminum is less than that of the lead ball, the aluminum ball will have more tendency to float therefore it will tend to raise the level of water." Her confusion with mass and volume also surfaced during the interviews.

> Well in almost every lab we had to weigh things. We had to weigh for the mass. [Long pause]. Well we needed the volume to do a reaction, we needed to measure volumes for a certain amount of a liquid into a reaction. Then we use a certain volume of a liquid, or an unknown, and we would weigh it, or no it would be given...the volume...and then we heat it or whatever, and see whatever happened in the reaction. And then we would weigh it. That would give us the mass. That's how they are related. (Week #3)

The relationship between mass and volume was summarized as follows: "Well the mass over volume is density...the greater the volume, the more the mass. That's about all I know." The results of the other assessments seem to confirm that her self-assessment was rather accurate.

One of the activities which Denise performed in the lab was to find the formula of an unknown compound. When asked to relate the concepts formula and compound, her answer lacked clarity.

> Well you had to decide...well they usually give you the compound...you then have to figure out the correct formula by doing certain reactions and finding out the percent of how is in each one. You get ratios, mole ratios, and you figure out the formula. (Week #3)

Denise did not feel the lab was effective in helping her to understand concepts.

> Well you had to do a lot of that in the lecture. So the lab work was...well we knew how to do all this already. At least I knew how to do all this before the lab. It would have been helpful to do this during the lecture. (Week #3)

One episode where Denise discussed the concepts hydrate, water, and formula revealed several points of confusion.

D: Well you know a compound or an element is a hydrate...a compound is a hydrate if it contains water. You know it's a hydrate if you can heat it and it lets go of water.
I: Is the compound a wet compound?
D: Not necessarily. The compound just contains molecules of water.
I: Can you see the water?
D: No. You usually can't. If you heat it, that's how you can tell whether it's a hydrate.
I: What happens when you heat it?
D: Water molecules form on the inside of the tube. If you put a liquid or a solid in a test tube, then heat it, and if water molecules form on the inside of the tube, it's considered a hydrate.
I: Now a wet sponge contains water, is a sponge a hydrate?
D: Yes I would assume so. Yes.
I: I can squeeze the sponge and the water comes out. Can I squeeze a hydrate to get out the water?
D: I'm not sure. But I think a sponge is still a hydrate.
I: How do you think these three concepts are related: **hydrate**, **water**, and **formula**.
D: A formula for a hydrate includes the water molecules. If you know its a hydrate then you know it has to have water in it.
I: Is there a ratio involved?
D: Yes. I'm not sure how you do that. I had trouble doing that in the lab. But there is a certain number of water molecules for every hydrate. (Week #3)

Denise was not sure about the difference between a compound and a mixture, "A compound is one or more elements...a mixture is when you take one or more elements and combine them" (Week #3). Asked if mixtures could be separated easily, she said: "Yes you can...like sugar and water...you could separate them using solubility...Some mixtures you can separate if they dissolve in water. Some can't be separated if they don't dissolve in water" (Week #3).

A question involving the temperature effects on solubility generated several misconceptions regarding the nature of matter and the solution process.

D: ...it seems more likely that more would dissolve if the temperature was greater.
I: Why do you think that is true?
D: Well when you heat you are breaking up molecules and so you are spreading them out and that gives a better chance to dissolve.
I: Does the volume of the liquid increase?
D: Uh...no...yes...when temperature increases, volume increases...as the molecules spread out more, there's more chance of solubility.

I: When the molecules spread apart what's between the molecules?
D: Just air. It's just the air molecules and the water molecules.
I: What happens when you add the solid?
D: I don't know...that's chemistry. I don't know when you heat...you don't necessarily heat the water before you add the solid.
I: But how does the solid go into the water if there's air between the water molecules?
D: If they are alike elements...like don't dissolve in water...I'm not sure...as far as I know different compounds can dissolve in a solution. When you heat the water, the molecules spread out and there's more air molecules. And the available space is where the solid molecules go. The solid disappears and you can't get it back, sometimes.
I: You can't get the solid back?
D: Some you can. If you dissolve them and let it sit, they will separate out. But some will dissolve and not come back.
(Week #3)

Lastly, Denise was presented with several events and asked to interpret or explain them based on here experiences in the laboratory with similar situations. Denise was often confused and visibly upset with her inability to use her knowledge in a clear and concise manner. Several additional misconceptions surfaced during the conversations. For example, she was shown an illustration of a sealed flask containing a solid substance before and after heating. The substance changed from a silver metal to a white powder after heating. She was asked to hypothesize as to what had occurred:

D: Well...the composition of the silver metal didn't change, just its state. Its still a silver metal...a compound...it's just in a different form.
I: Are the silver metal and the white powder the same substance?
D: Yes they are still the same compound.
I: Why is the appearance different?
D: Well the molecules could have broken down more.
I: Do you mean that the molecules that make up the silver metal broke apart?
D: Right.
I: Is there anything else that could explain what occurred?
D: Some of the air molecules could have escaped. Some of the air molecules surrounding the metal and that would give it more room to, when it's heated...for the molecules to separate.
I: Would the masses of the substances be the same?
D: Not necessarily. After heating it may gain or loose some of the molecules.
I: What would happen if the metal gained molecules? Where would the molecules come from?
D: I'm not sure.
I: Well what would cause a gain in mass?
D: I'm not sure.

I: Then perhaps it couldn't gain in mass? Did it lose mass?
D: It's possible. If it were to lose mass, some of the molecules could have evaporated during heating and that could decrease mass. I'm not sure why.
I: If it lost mass, where is the matter that it lost?
D: It is spread throughout the flask.
I: The how would the mass of the flask and contents before heating compare to the mass after heating?
D: After heating the mass would be less. Well no it would have to be the same. Because everything would still be in there.
I: What about the mass of the solid?
D: It would be less after heating.
I: Is there anything that you did in the lab that relates to this situation?
D: Well some of the labs we heating things and weighed them before and after. Actually one thing I heated weighed more after heating. I thought that was an error. But we don't talk about that, so I wouldn't know about it.
I: So when something is heated and it gains mass, that is an error?
D: I would think it should be.
I: Is mass always lost during heating?
D: Yes I would think so. Well that's not true. Some solids may turn to liquids and liquids would weigh more than solids.
I: If a solid changes to a liquid, the liquid would weigh more than the solid?
D: Yes.
I: So in the situation we are talking about, there is no possibility that the solid in the flask after heating could weigh more than the solid before heating?
D: I don't think so. It would have to be less mass.
I: Then why does the substance look different after heating?
D: I'm not sure, but if the molecules broke down, it would weigh less and it might give it a different appearance. I'm not sure.
I: Did you ever heat a substance in the lab that looked different after heating?
D: Yes. We did heat metals and they turned into powders, crystals. Also solids to liquids. They looked different.
(Week #4)

Denise was not able to relate the event to the laboratory activity which required her to determine the formula of a compound. The episode also confirmed her poor understanding as reflected on questions on the post-*Concept Test* related to a similar situation. When asked if the mass of the sealed container would change after reaction, she wrote: " Yes, because a substance changes its state. The mass changes and therefore the overall container and its content's mass changes." Asked why the mass of the substance in the container should change, she wrote: "When a substance changes state, its mass changes."

When discussing the concepts of solubility and temperature several misconceptions surfaced pointing to a lack of understanding of the solution process and the particulate theory of matter. She attempted to explain the effects of heating on dissolution but ultimately through up her hands in frustration.

The Case of Donna

Donna was a junior enrolled in the Thursday morning laboratory class which used the verification method. Her major was biology. Donna admitted that, although she was required to take chemistry, she had put it off to focus on her biology courses. Donna completed a year of high school biology and chemistry and three years of mathematics. She was concurrently enrolled in two biology courses.

Donna was interviewed on six occasions. She was always punctual and never had to be reminded of her scheduled appointments. Her sessions were generally longer compared to those of other students since she was very thorough with her answers. She was bright and articulate and answered questions carefully and precisely. She impressed the researcher as a student who was very concerned about accuracy, neatness, and thoroughness in order to ensure good grades. Donna's pre-and post-*Concept Test* scorses were 7 out of 13 and 11 out of 13, respectively.

Understanding chemical concepts

During interviews four, five and six, Donna was given the opportunity to demonstrate her understanding of concepts related to laboratory activities. In most instances she gave clear and concise answers to questions. This was expected considering her scores on the pretests reflecting a high level of prior knowledge. She also confessed to spending a lot of time studying.

First she was presented with pairs of concepts and asked to state a relationship between the two and then to relate the concepts to something she did in the laboratory. The following are remarks she made regarding the concepts compound and formula:

> They are related in that each compound has a particular formula to it...either an empirical or molecular formula. The object in the hydrate lab was that given a particular compound, find out the...I'm not sure whether they give you the empirical formula and then you find out the molecular formula or you find out both the empirical and then, by knowing the number of moles that you were given to find out the molecular formula. (Week #4)

She indicated that the concept of formula is subsumed by the concept of compound: "a formula is one aspect of a compound. There might be other things about the compound...basic characteristics or it's reaction with other compounds" (Week #4).

For the concepts mass and volume, she stated:

> Well in the first lab we observed the mass and the volume and we figured out density. Density equals mass over volume. Also, given the volume or the density we calculated the mass, or given the density and the mass we calculated the volume. We interpreted the formula in several different situations. (Week #4)

She related her understanding to the experience in the laboratory. When asked why she thought substances floated or sank in water, she responded: "It has to do with the density of the compound. In a given compound, if it's less than water it will float, if it's more dense than water it will sink. It has to do with the amount of particles or atoms in a given volume of the compound" (Week #4).

She related her understanding of the concept of hydrate to her laboratory experience.

> In the lab with the hydrate, you had an unknown hydrate...I think that was the lab where we took different hydrates and we put them in the those dishes...evaporating dishes...and we saw whether or not it gained water from the air or lost water to the air...to tell whether it was a hydrate...to tell whether it was efflorescence or...that other word...I forgot what it was called...Also we burned certain [compounds] to see whether or not they were...if they...if you took a [compound] and burned over a low flame and then it solidified more, it turned a different color and you added the water to it, stirred it and heated it under a low flame again and you got the original compound...that meant the hydration reaction was reversible. (Week #4)

Asked whether she was using knowledge gained from lecture or lab in discussing these concepts she said, "Well I'd say I'm using lecture and lab but more emphasis on lab" (Week #4).

During Week #5, Donna was shown an illustration of a sealed flask containing a solid substance before and after heating. The substance changed from a silver metal to a white powder after heating. She was asked to hypothesize as to what had occurred. Although there was some confusion with terminology, her responses revealed she had a good sense of what occurred.

However, she did not relate the situation to her laboratory experience involving finding the formula of a compound.

D: A chemical reaction is occurring with the silver metal and this is due towards the heating. Because you are not adding anything to the flask, it is closed and no air can come in or out. Perhaps by adding heat, you are breaking chemical bonds of the silver metal to produce a different compound which is the white powder.
I: Are the same atoms involved?
D: Yes.
I: What would cause a change in appearance?
D: The same atoms combine in different proportions...or perhaps they separate into...here you have atoms combined to make a compound and then you're breaking the bonds between the atoms so that you are having, either two separate compounds or just the atoms of one element and the atoms of the other elements.
I: Did the mass change during heating?
D: No I don't believe so.
I: Why not?
D: [long pause] I'm not quite sure but I think that the mass can't be created or destroyed. So that...well that might be energy...[laughs]...I think that since nothing could escape from the flask that the mass of flask one would have to equal the mass of flask two because nothing could escape.
I: There is air in the flask. Does that change your thinking at all?
D: If there is air in the flask, then perhaps the oxygen could possibly be burned or combined with the silver metal, so you're taking oxygen or carbon dioxide or any other element, hydrogen, carbon, or oxygen, found in the air of flask one and that combining with the silver metal to produce a different compound which is the white powder in flask two.
I: How would the masses compare under those circumstances?
D: The mass would still be the same because if you are using the air in flask one, those atoms would be combined in the compound of the white powder, so you are not gaining atoms or loosing atoms.
I: You mean the mass of the total system wouldn't change.
D: Right.
I: But what about the solid itself? Would the mass of the solid change?
D: The masses would probably be the same but the densities would be different.
I: What would have occurred to cause a difference in density?
D: The volumes would have either increased or decreased.
I: If the density decreased, what would have occurred?
D: If the density decreased..uh...the volume...has to increase.
I: So the mass of the system would remain the same and the mass of the solid would remain the same?
D: Not necessarily.
I: Could you explain that?

D: Because...uh...I don't know, I was thinking that perhaps the air in the flask...also has some mass to it, even though it might be very negligible...so...uh...the masses between the two, the mass of the white powder and the mass of the silver metal will differ, but the mass of the two systems would be the same.
I: How would the masses of the two solids differ?
D: It depends on what happens when you are burning it, if you are releasing atoms...
I: How would the masses compare then?
D: If you burned the silver metal, then, say for instance it was...a...uh...condensation reaction...you would be breaking bonds and water vapor would be produced...so that the silver metal would contain a higher mass the white powder.
I: Could the white powder weigh more than the silver metal?
D: Yes if you are taking the silver metal and you are combining it with another compound or atom in a dehydration reaction, then the white powder would contain more mass than the silver metal.
I: Where would the extra mass come from?
D: Okay...probably water vapor in the air...the silver metal combining with water vapor to produce the white powder.
I: Is the white powder a compound?
D: Probably.
I: Could the silver metal have been an element?
D: I think either one is possible. I'm not really sure.
(Week #5)

Donna was presented with other situations and in each case she was able to use her knowledge of chemistry to discuss them. She was clear and did not hesitate to elaborate if asked to do so. She related the concepts to laboratory activities when she thought it appropriate to do so and revealed no misconceptions.

While Donna was successful in laboratory and gained in knowledge and skill, she did not feel her overall experience was a positive one. She was asked to reflect on the laboratory experience and to summarize her feelings and beliefs about the course. She responded:

> Well as far I feel I'm not doing as well as I had hoped. I'm putting a lot of work into it. A lot of people tell me that the reason I'm not doing well is because I'm not cheating. I've seen a lot of cheating in the laboratory. People who do prelabs use their friend's prelabs from previous years. As far as quizzes are concerned, everyone is standing and taking the quiz. The TA is walking around. The books are sitting right here. You copy the answers from the books. I feel frustrated by that. The prelabs and quizzes are not a fair representation of what you are learning in the laboratory. I worked on a prelab and the TA never goes over the prelab. It is just assumed that you understand it. We never go over conclusions and draw deeper into the lab. I think that would be helpful....Initially I

> hated lab...I don't hate it now...I find some enjoyment in it...I find something interesting..uh...I think it could be made more interesting by correlating what your learning instead of just doing the laboratory. What is your goal, not to just get through with the procedure. To really find out something interesting. I don't know how that would be accomplished. (Week #6)

The Case of Jim

Jim was a junior enrolled in the Thursday morning general chemistry laboratory class which used the verification method. His major was physics. Jim had one year of high school chemistry, one year of high school physics and four years of mathematics through pre-calculus. At the time of this study he was concurrently enrolled in two advanced physics courses.

Jim was interviewed on five occasions. At first he was reluctant to participate in the interviews claiming he would have nothing of significance to say. He was quiet and thoughtful and paused often to reflect on what he had said and to consider carefully his answers to each question. He enjoyed the outdoors and found rock climbing especially challenging and enjoyable. He enjoyed science courses because he liked playing around with things, but found physics lab courses to be more time consuming and labor-intensive. He said, "We spend three hours in the [physics] lab plus another three hours writing the report [while] chemistry is not taking much out of me...It seems pretty straightforward" (Week #1).

Jim's last chemistry course was Regents chemistry in high school but it was too long ago for him to recall much details. Besides, he said, "It really didn't leave an impression on me" (Week #2).

Understanding of chemical concepts

Jim's performance on the pre-*Concept Test* (11 out of 13) revealed a good understanding of the concepts relating to the laboratory activities prior to actually doing the activities. His post-*Concept Test* score was 13 out of 13. During the course of the interviews, Jim demonstrated his knowledge and understanding of concepts related to the laboratory experience which confirmed his higher level of prior knowledge. He carefully considered the question or situation before responding and his remarks were always well qualified. Generally speaking, he seemed know what he was talking about.

On one occasion Jim was presented with a series of two concepts, each concept was written on a 3 X 5 index card. He was asked to think about the two concepts and to talk about how he thought they were related to each other and to relate the concepts to an activity in the lab. For the concepts solubility and temperature, he said:

> Okay we did a experiment where we had..we were separating two solutes from a solution. The solubility of each solute depended on the temperature...of the solution...so you heated them up...then dissolved this powder...which was a combination of two different things...then cooled it down until one of the solutes would come out of solution and crystallize...and the other would still stay in the solution. So that way we separated them. They had different temperatures when the solubility would decrease...and that helped to separate the mixture. (Week #3)

When describing the relationship between formula and compound, Jim described a compound as "a mixture of elements that would be written with a formula" (Week #3). Upon reflection, he corrected this when he said, "well not a mixture. A compound... its bonded elements in certain proportions...A mixture is not chemically bonded" (Week #3).

He recalled clearly his experience in lab when describing the relationship between mass and volume:

> Mass divided by volume is the density of the object. We did a lab where we found the...you can find volume if you knew density and mass...you find mass if you know volume and density...and you can find density if you know volume and mass. We were doing a...we were trying to find the volume of something...no that's not what we did. We were trying to find the density of a material. So we weighed it and found its mass and put it in a graduated cylinder with liquid water to find out its volume and divided the mass by the volume to find the density. (Week #3)

Jim was a little confused about the concept of hydrate. "A hydrate," he said, "is a salt that is mixed with water." When asked to relate this to his laboratory experience he said:

> We did an experiment where we were trying to find out if certain elements...certain compounds were hydrates. So we heated them up in a test tube to find out if they gave off water. Also the color would change of the hydrate. (Week #3)

The following is an example of a dialogue which reflects Jim's clear thinking about concepts and the processes of doing science. He was presented with the illustration which showed a sealed flask containing a silver metal before and after heating. He was asked to explain what might have occurred in the flask which would account for the change of the silver metal to a white powder:

J: Probably the metal was oxidized. I would assume.
I: What do you mean by oxidation?
J: The oxygen in the air chemically combining with the metal.
I: In there anything else that could have occurred to explain what is observed?
J: It could have melted and recrystallized also. It could have chemically combined with one of the other gases in the air.
I: For example?
J: Nitrogen or something else...carbon dioxide.
I: You now have stated four hypotheses. How would you have to prove that oxidation had occurred?
J: You could try the same experiment again but putting it in a container with just oxygen, putting it in a container with other gases or in a vacuum if you could. If it only occurred in an oxygen atmosphere, you conclude it was oxidation.
I: Let's say that oxidation did occur. How would the masses before and after of the system compare?
J: They would be equal.
I: How would the masses before and after of the substance compare?
J: The white powder would be heavier because it would have more atoms in it.
I: Would a definite amount of oxygen have combined with the silver metal?
J: Yes if it were completely oxidized.
I: How would you find out what that amount was?
J: You could figure out the pressure and quantity of gas...figure out how many moles of
atoms there were and then find out...uh...[long pause].
I: Measuring pressure difference would not be easy, is there something else you could do?
J: Weigh the metal before hand and then weigh the powder. Then you could figure out the difference in weight and the...using the...using the molecular weight of oxygen you could figure out how much oxygen molecules...atoms...were incorporated into the metal.
I: How would you convert from weight to atoms?
J: Use the atomic weight of oxygen. Take the weight difference, which would be the weight of oxygen and divide it by the molecular weight, which would tell you moles per gram. Then you have a quantity of atoms. (Week #4)

Although he did not relate this situation to his laboratory experience which involved the determination of the formula of a compound, Jim was drawing upon all of his knowledge and experience to explain what had occurred.

Analysis of interview protocols, summary of common features and comparison of experimental and control students.

Introduction

The interview protocols were analyzed to probe among other factors for differences and common features relating to the laboratory, the relationship of laboratory activities from week to week, and the chemical concepts learned in the laboratory and their relationships. The differences and common features were analyzed to provide a measure of within-group and between-group variations. Due to the sampling technique and the selection of students for interviews, the researcher was aware that the sample was to be regarded as highly selective within the total population and that the results must be interpreted with caution when generalizing to the whole group.

Distinguishable conclusions which emerge from the comparison of differences and common features will be substantiated by across-student examples at a given point during the six weeks of the study and/or by across-time examples for a given student. Due to the nature and quantity of data, thirty interviews transcribed on over 200 single-spaced typed pages, only a few justifications which substantiate each conclusion are presented. Additional justifications can be discovered by reading the complete set of transcriptions or by listening to the tapes of the students. The tapes and transcripts are available from the author upon request.

Relationship among laboratory activities.

It can be concluded that the internal integration of chemical concepts as reflected in the organization of the activities and the overt attempts to relate them to each other, enhanced conceptual understanding among students in the experimental group. The organization was viewed as an important aspect in the development of knowledge and skills. The following quotes across-students and across-time from interviews with the three students in the experimental group help support this conclusion.

> [Knowledge accumulates week to week from the lab activities.] That has been helpful. Everything's a build up, you keep applying concepts and building on them to do each lab. You are using that basic knowledge. I think it's all built up for the next experiment (Laura-Week #2).

> Each [activity] builds upon another. You are using basic concepts that are the same throughout. Finding densities and each one builds up. You have to know a little more after each one (Laura-Week #3).

> It's really an accumulation of all knowledge which you gained from the past labs...That has been helpful (Laura-Week #4).

> I think you are building on the basic concepts from less to more basic concepts (Laura-Week #5).

> [Speaking about three activities] well mixtures and physical properties are related, you're dealing with density and solubility...We dealt with hydrates...that's like the chemical version of the separation of physical properties. Whereas a mixture, is physically, you know you can physically separate them...So I see a relationship between the three (Peter-Week #3).

> I think they were put into a certain order because they build on each other There is a relationship among concepts, it's building up...The way we're doing it, the purpose is to build upon the lab before it...[The advantage is] there's a continual momentum, if you understand one week you can understand the next week...I'll say it works (Mark-Week #3).

The following quotes across-students from interviews with students from the control group show how an absence of relationship among activities resulted in a much different view. While there was a belief that laboratory techniques and skills thread their way through each activity, students felt the lab activities were conceptually unrelated. They believed that concepts developed in one activity were not necessarily used as a basis for developing concepts in another activity.

> More or less we've been doing a lot of reactions and just weighing. So basically it's been the same type of lab every week...I think each lab is good enough to understand what is going on. I don't think you need so much tie in. I mean in chemistry everything kind of grows anyway. So the way it is, it's set up okay (Denise-Week #1)

> In a way [the labs are related] because we started with the basic laboratory in lab one and basically dealt with just weighing things and then you had to take you knowledge from lab one and apply it to lab two and build on that (Donna-Week #2).

> As far as the concepts involved in the three labs...I don't see how they relate don't see the correlation. They were stand alone activities, except for procedures (Donna-Week #3).

> Well the first lab consisted of measuring the weight or the mass of the metal pieces. The goal was to familiarize yourself with the equipment. The second [experiment] you were trying to separate different chemicals

of the solution. There wasn't really very much correlation between the two (Jim-Week #1).

In summary, internal conceptual integration, part of the constructivist method, was viewed by students as an essential component which enhanced conceptual understanding and promoted the acquisition of skills and knowledge. Students using the verification method perceived there was some relationship among the skills and techniques used in the laboratory activities, but they did not express a belief that the activities were conceptually related.

Learning from the laboratory activities.

On the basis of pre- and posttest Concept Test scorses, the six students demonstrated a gain in the acquisition of concepts related to the content areas covered in the laboratory. Not all gains were the same. Comparing pre- and posttest scores on the *Concept Test* (maximum score=13), Laura showed the greatest improvement (8 points) and Mark showed the smallest (2 points). Jim also gained 2 points, but he scored very high on the pre-test (11). The average gain among the experimental students was 4.7 points, while the average gain among the control students was 3.7. Final laboratory course grades also varied among the six students: Laura (B); Peter (A-); Mark (B); Denise (B+); Donna (B); Jim (A-).

Evidence was presented in the case studies which confirmed the gains on the pencil-and-paper tests and highlighted the differences among the students. Students used the knowledge they were acquiring from week to week to discuss concepts and situations raised during the interviews, but the depth and breath of understanding varied considerably. The interview-about-instances and the interview-about-events techniques were helpful in probing a student's private knowledge and understanding and in exposing alternate conceptions. The data reveal that each student acquired a personal understanding of the chemical content area. Conclusions in the form of generalizations are difficult to make. For example, Jim's analysis of the reaction-in-a-closed-flask was probably the most sophisticated and well thought out among the students presented with that situation. Jim was in the control group. Would his analysis have been different if he was in the experimental group? One can only speculate that his understanding was based on a depth and breath of knowledge which developed over time regardless of the type of instruction he received. Although the analysis of case studies reveals a wide variance in conceptual understanding among the six students, it can be concluded that students in the experimental group which utilized a constructivist method believed the laboratory played on important role in the learning of chemistry. Conceptual integration, the exchange of ideas through social interaction, and the overall design of the activities (Demonstration, Guided Inquiry, Concept Formation, & Application) helped to instill that belief in students. The following quotes across-students from interviews with the students in the experimental group help to support this conclusion.

> The labs definitely helped me to understand different concepts. I likely working with a lab partner more than I liked working individually...The lab was important in teaching concepts...I felt that he labs were much more general than the lecture course, but I definitely understood general concepts better. It helped with the course (Laura-Week #6).

> Overall I think the experience was beneficial. In that, labs reinforced the concepts learned in the lecture. I found that by actually seeing the reaction..helped me to understand. The labs reinforce what we learned. The conduct of the lab was good...We started every lab with an explanation from the demonstration. From that you could work and figure out what was occurring. With the lab itself and discussing things with people from other labs, I found that other groups did labs individually as opposed to our section doing it as partners. I thought it gave you more time to think and see how things were working (Peter-Week #5).

> Well I would say it reinforced a lot of the chemistry...I learned some stuff too (Mark-Week #5).

Contrast the above statements with quotes across-students from interviews with students in the control group. Students expressed frustration with the method of instruction used in the lab. They also expressed how it could have been improved.

> I enjoy the lab but it is still not helping me with the course work. It's still not flowing at all (Denise-Week #3).

> The TA never goes over the prelab...It is assumed that you understand it. We never go over conclusions and draw deeper into the lab. I think that would be helpful. Initially I hated lab, I don't hate it now. I find some enjoyment in it. I find something interesting. I think it could be made more interesting by correlating what you're learning instead of just doing

> the laboratory. What is your goal, not just to get through with the procedure. To really find out something interesting. I don't know how that would be accomplished (Donna-Week #6).
>
> Well my first reaction is I don't want to get up early and go to lab, but once I'm there, I guess I enjoy it to a certain extent. I enjoy manipulating things. I guess it has helped get certain concepts clear in my head. Even if I already understood it. Just seeing it helps make it firm. Makes it believable. (The time was well invested], I believe so. I think there should have been more discussion between the class. Before and after the lab. Also it would have been helpful if the lab was correlated more with the lecture. Such that if we learned something in the lecture one week, maybe next week we would demonstrate the principles in the lab. Also it might help if the lab was a more problem solving oriented rather than here's how you do it, do it, and what do you get. I don't know if that would work with everyone because it is an introductory course, but if students could do it, they would be much better, helping them with work. I learned chemistry. Most of the concepts I knew already from high school (Jim-Week #5).

In summary, an analysis of the interview protocols revealed that one student's understanding of the subject matter is unique and different from other students. Each student acquired a personal understanding regardless of the instructional method. While it was expected that the constructivist method would result in greater depth and breath of knowledge and understanding, there is no overwhelming evidence from the sample of students interviewed to show that this occurred to any greater degree among the students in the experimental group. It can be concluded, however, that the constructivist method as it was operationalized through the laboratory activities fostered the belief among students that the laboratory is an important component for the learning of chemistry and did enhance the overall learning process. There was little evidence in the interviews of students in the control group that the verification method did the same.

DISCUSSION

Analysis of the interview protocols of a sub-group of students (n=6) supported the results of the pre- and post-treatment measures in the area of cognitive growth.

In the cognitive area, each student acquired a personal understanding of the chemistry content which was revealed by increased performance on the achievement measures and by verbal statements made during the six weeks.

Each reflected an increase in knowledge and understanding of chemistry. Differences among the verbal statements of students in the sample and differences among achievement scores of the entire population reflected differences in the depth and breath of understanding of the subject. The differences, however, could not be attributed to the benefits of one instructional method over the other.

By using a probing interview procedure, the investigator was able to assess the nature of college students' understanding of concepts introduced in the laboratory, their attitudes toward the conduct of the laboratory and toward laboratory work in general, and their perceptions of the value of doing laboratory work in the learning of chemistry.

As with this study, the effectiveness of the interview technique has been demonstrated in others. For example, it was used to probe students' understanding of science (e.g., Mitchell & Gunstone, 1984; Osborne & Cosgrove, 1983; Pines & Novak, 1978; Ross, 1989; Rowell, 1978; Roychoudhury, 1990; Stewart, 1982; Treagust, 1986; Yarrock, 1985), to track conceptual change (e.g., Hewson, 1980; Posner & Gertzog, 1982), and to determine changes in attitude or perception (e.g. Felsine, 1987; Gogolin & Swartz, 1992; Snively, 1986). The technique allows for flexibility in questioning and increases the level of understanding of the degree of learning which is occurring (White & Tisher, 1985).

The results of this study also point to the importance of gathering qualitative data along with quantitative data, since the latter may not be sufficient to fully describe the effects of instructional treatments on cognitive and affective outcomes. The combination of quantitative and qualitative methods has been used successfully in other studies (e.g., Baker, 1987; Cros et al.,1986; Howe, 1988; Mitchell & Gunstone, 1984).

As a result of the variation in representativeness of the sub-groups on the characteristics of cognitive ability caution was necessary in drawing inferences from the data and generalizing to the whole group.

CONCLUSIONS AND IMPLICATIONS FOR PRACTICE

Based on the analysis of the data, it may be concluded that:

1. College students enrolled in a general chemistry laboratory course demonstrate conceptual change learning using either a verification method or

a constructivist method over a six-week treatment period. It appears that a combination of factors (e.g., laboratory instruction, lecture instruction) are important in improving knowledge and understanding and in facilitating conceptual change.

2. Facilitating a constructivist teaching method in the laboratory depends on the skill and knowledge of the instructor and on the readiness and willingness of students to undergo cognitive struggle and to use metacognitive strategies to enhance meaningful learning.

While neither laboratory treatment was proven superior to the other over a six-week period, students taught under the constructivist method did perform as well as students taught under a conventional verification method. Therefore, the constructivist method should be considered a viable alternative to the teaching of general chemistry laboratory. The constructivist method provides opportunities for students to gather and talk about data, formulate alternate solutions to problems and work cooperatively to develop concepts. These opportunities may help to facilitate knowledge construction, allow students to link new information with existing knowledge, and increase meaningful learning. One should not expect dramatic and immediate effects. Benefits may accrue given a longer treatment period.

It should also be pointed out that, while the verification method did not provide formal instructional conditions which promote knowledge construction, the method did not prevent the process from occurring through informal means. Knowledge construction is an internal process which may also be supported in informal ways, such a discussions among students which take place inside or outside of class, group study prior to examinations, tutoring, attending recitation classes, or individuals reading and thinking about the subject matter. Perhaps a combination of these factors along with the instructional strategy, either constructivist or verification, enhances knowledge construction and promotes meaningful learning. In addition, knowledge construction and meaningful learning will be dependent on the interests, skills and efforts of the students. Students who think critically about the subject matter, struggle through problems by applying alternate strategies, and consciously link new knowledge to existing knowledge, may benefit from either instructional strategy. If students do not exhibit these skills, then teachers may want to consider approaches, such as a constructivist method or modifications to the verification method, which may help to develop them. Modifications might include: (1) providing opportunities before, during or at the end of laboratory activities for students to discuss data and conclusions; (2) masking portions of the written material so that students are not fully aware of all concepts which will verified in laboratory and giving them opportunities to identify them; (3) allowing students to work cooperatively to solve problems.

In universities where laboratory courses are frequently taught by graduate teaching assistants who may have limited teaching experience, it may be important to provide training and preparation for them. This could be done by having the teaching assistants work with an experienced teacher who would serve as their mentor. The mentor could work directly with each teaching assistant in the laboratory or could teach several laboratory and be video-recorded. During these sessions, the mentor could demonstrate effective techniques which encourage students to make their ideas explicit, demonstrate non-threatening ways of challenging students to defend their ideas while encouraging them to investigate alternatives, and enable them to test hypotheses. The mentor could also demonstrate ways of gathering students together and encouraging student interaction through discussion, persuasion and argumentation. Lastly, the mentor could demonstrate non-threatening ways of enabling students to challenge one another and reach consensus. The video-recordings could be viewed and discussed by the teaching assistants during pre-laboratory preparation sessions. The teaching assistants could also be video-recorded while they are teaching. These tapes could be viewed by the mentor and teaching assistants for analysis and critiquing. This formative evaluation procedure might enable teaching assistants to improve their teaching abilities and feel more comfortable in guiding knowledge construction and the conceptual change process. Without this teacher training the constructivist method probably would not be effective, but hope is held out that teacher training may make it an effective approach.

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