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Author: Lewicki, Daniel

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The Effects of a Constructivist Method of Instruction in General Chemistry Laboratory on College Students' Achievement and Conceptual Change

Daniel Lewicki
Sage JCA/The Sage Colleges, United States

INTRODUCTION

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 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 & Hanesian, 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, social interaction, 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 by the investigator. The purpose of this study was to determine the effect of this method of instruction on declarative and procedural knowledge and conceptual change of college students enrolled in general chemistry laboratory.[1] A conventional verification instructional method characterized by an inform-verify-practice sequence and students working independently was used for comparison.

RESEARCH QUESTIONS

The following research questions helped to guide the study:

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 improve declarative and procedural knowledge, promote conceptual change, and enhance overall achievement?
2. Does a college general chemistry laboratory course utilizing a conventional method involving verification experiments improve declarative and procedural knowledge, promote conceptual change, and enhance overall achievement?
3. Is there a relationship between level of cognitive development and declarative and procedural knowledge achievement and conceptual change?
4. Is the constructivist method or verification method equally as effective for students at different levels of cognitive development?
5. Is there a relationship between prior knowledge and achievement/conceptual change depending on the instructional method?

[1] This paper is based on a larger study which investigated the effects of the instructional methods on achievement, conceptual change, attitude and perception. In that study, quantitative and qualitative data were collected. Only quantitative data relevant to achievement and conceptual are reported here.

METHOD

Sample and Treatment

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 and compared on declarative and procedural knowledge achievement, and conceptual change. The two teaching methods were: (1) the verification method and (2) the constructivist method.

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 constructivist method involved a sequence of six laboratory activities 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 written 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.

The students voluntarily participated in the study. Thirty-three students, eighteen in one class and fifteen in another, comprised the control group which used the verification method. Thirty-five students, eighteen in one class and seventeen in another, comprised the experimental group which used the constructivist method. The laboratory classes were taught by two graduate teaching assistants. Each teaching assistant taught one control class and one experimental class. All students were concurrently enrolled in the same general chemistry lecture course taught by a full-time faculty member at the university. The lecture textbook was General Chemistry (Chang, 1991). The investigator did not do any direct teaching but served as a mentor for the teaching assistants during the six weeks.

Instrumentation

Students were administered a modified form of a *New York Regents High School Examination in Chemistry* to assess prior knowledge, the *Test of Logical Thinking* (Tobin & Capie, 1980) to assess cognitive development, and two investigator-generated tests (i.e., a *Laboratory Test* and *Concept Test*,) prior to the start of the laboratory program. Two weeks following the completion of six laboratory activities, the students received the posttest versions of the *Laboratory Test*, and the *Concept Test*,. The pretest and posttest versions of each instrument were identical.

The *Laboratory Test* was used to measure student achievement of chemical laboratory concepts and principles relating to measurement, physical and chemical properties, mass relationships during reactions, and energy changes during reactions. The test consisted of 34 multiple-choice items to assess declarative and procedural knowledge: knowledge and comprehension (12 items); application, analysis and synthesis (22 items). Students were scored on the basis of the total items correctly answered. Several sources were used to generate the items (Chang, 1991; Cull, McDonnell, & Meyer, 1967; Hudzik, 1988; Malone, 1989; Wiseman, 1981). Sample questions are shown in Figures 1 and 2.

Alpha reliability coefficients were determined for the *Laboratory Test*. The coefficient on the pretest was 0.64; the coefficient on the posttest was 0.67. Content validity was established by two college chemistry professors who reviewed the process used in developing the test and the test itself. They were asked to judge how well the items represented the intended content areas.

The *Concept Test* was used to assess students' conceptions prior to instruction and to determine the effectiveness of the instruction in helping students acquire scientific conceptions in the areas of measurement, physical and chemical properties, mass relationships during reactions, and energy changes during reactions. It contained items which assessed the extent to which students identified with statements which represented alternative conceptions as identified in the literature or with an accepted scientific conception. There were 13 items: 9 two-tier items, modelled after an instrument used by Peterson, Treagust and Garnett (1986), of which the first tier required a multiple-choice response and the second required a reason for the selection, and 4 items requiring students to answer a question and state a reason for the answer. Items were selected from ones used in previous studies relating to student conceptions (Ben-Zvi, Eylon, & Silberstein, 1986; Cachapuz & Martins, 1987; Gennaro, 1981; Glassman, 1967; Fensham, 1984; Mitchell & Gunstone, 1984; Novick & Menis, 1976). Some items were modified to suit the content of the laboratory program.

The items on the *Concept Test* were scored as follows: the multiple-choice part was marked correct or incorrect based on the student's choice and, the reason was marked (1) blank or "I don't know," (2) incorrect or unrelated concept, (3) partially correct concept, or (4) correct concept. This approach was similar to one used by Hewson and Hewson (1983). One point was awarded for a correct choice and 1 point was awarded for a partially correct or correct reason. The maximum possible score was 26. Samples from the *Concept Test* are shown in Figure 3.

The alpha reliability coefficients were determined for the *Concept Test*, pretest and posttest scores. The coefficient on the pretest was 0.49; the coefficient on the posttest was 0.46. Content validity was established by two college chemistry professors and one college science education professor. The latter was familiar with the misconceptions literature and was able to judge how well the items represented student alternative conceptions.

An investigator-generated *Laboratory Survey,* a treatment-monitoring instrument, was used to obtain descriptive information regarding the method and materials used in the classes. It was administered to students following the completion of the six activities.

________The *Laboratory Survey* contained 20 items and was modelled after the Laboratory Program Variables Inventory (LPVI) developed by Abraham (1982). Similar to the LPVI, the *Laboratory Survey* was used by students to describe characteristics of the teaching methods, activities, and procedures used in the chemistry laboratory. The 20 items represented aspects of student-student, student-teacher, and student-material interactions that students might or might not be exposed to during the laboratory activity depending on the teaching method (constructivist or verification). Students were asked to read each statement and characterize the variable using a four-point scale ranging from rarely occurs to very often occurs. The majority of items were scored 1 to 4 so that a higher score reflected a characteristic of the constructivist method. For some items the scoring was reversed so that the higher score reflected a decreased occurrence of the activity. Items were also included which represented characteristics of both methods. These alterations were designed to decrease the possibility of a response set. Samples from the *Laboratory Survey* are shown in Figure 4 .

_______The alpha reliability coefficient for the *Laboratory Survey* was 0.80. Content validity was established by two college education professors who were familiar with the two treatments used in the study.

RESULTS & DISCUSSION

Delivery of the Instructional Method

The *Laboratory Survey* was administered following the completion of the sixth and final laboratory activity. The results for the individual classes and for the composite experimental and control groups are shown in Table 1.

The mean score for the composite experimental group was 54.94 out of a possible 80. The mean score for the composite control group was 44.29. The means were significantly different, $t(60)=6.16$, $p<.05$. While there were differences between the two classes composing the experimental group and the two classes composing the control group, the differences were not significant, $t(32)=1.32$, $p>.05$ and $t(26)=0.20$, $p>.05$, respectively.

The *Laboratory Survey* was useful in measuring the extent to which the students were experiencing the prescribed treatments. A chi-square item-analysis revealed that both treatments were not equivalent. Students taught under the constructivist method and students taught under the verification method confirmed characteristics of the method specific to their group. There were, however, several characteristics which both groups confirmed to be present which should have been present in only one.____

Characteristic of both methods, the students confirmed the following: (1) problems were solved in the laboratory; (2) the lab helped to develop skills and techniques; and (3) accuracy of data was important. Characteristic of the constructivist method, the students confirmed the following: (1) students worked together to solve problems, to suggest alternate solutions and to develop concepts using a variety of strategies; (2) the instructor challenged assumptions and conclusions; and (3) each activity was dependent upon the others.

Characteristic of the verification method, the students confirmed the following: (1) students followed step-by step instructions and similar procedures to solve problems; (2) students worked individually in the laboratory; and (3) students knew the outcomes of the activities beforehand.

The survey also detected similarities where differences were expected. Students in both groups reported the following: (1) often or frequently data and conclusions were discussed with each other; (2) rarely or only sometimes did students identify the problem to be solved; and (3) often or frequently the instructor or laboratory guide determined the correctness of their work.

While the *Laboratory Survey* may not have been sensitive enough to detect expected differences in certain variables (i.e., level of student interaction, perceived ownership of the problem, and evaluation of results), more likely these areas where no differences were found were a consequence of one of the limitations of this study. While the two graduate teaching assistants who delivered the instruction had previous experience using the verification method, they had none using the constructivist method. In addition, their limited overall teaching experience suggested they may have been naive regarding techniques which were necessary to facilitate the knowledge construction process used with the constructivist method.

While they appeared to deliver successfully the methods as perceived by the students, the areas of no differences point to possible consequences of the limitation. The level of student interaction, perceived ownership of the problem, and perceived evaluator of results, are dependent on the abilities of the instructor to engage the students in thoughtful discussion, argumentation, and persuasion. In addition, the instructor must promote the use of higher-order thinking skills, such as application, analysis, synthesis and evaluation, and to encourage students to think critically. These abilities come with training and experience. The teaching assistants were inexperienced teachers and were using a method which they were not completely sure of or with which, possibly, they were uncomfortable. That is, there may have been a mismatch of teaching style and instructional method. Though the teaching assistants were coached into using techniques and strategies appropriate to the instructional method, the investigator did not assess how these were actually utilized during the laboratory sessions.

It is clear that the design of instruction and the tactics and strategies necessary to deliver the instruction are significantly teacher-dependent, and these may need to be well-matched in order for the method to have a chance at being successful.

Instructional Method & Achievement

To determine the effect of the instructional methods on achievement of declarative and procedural knowledge as measured by the *Laboratory Test,* a treatment x time Repeated

Measures MANCOVA was conducted using the scores on the *Test of Logical Thinking* and prior knowledge test as covariants.

The analysis revealed a significant relationship between the covariants and the posttest scores, $F(3, 59) = 8.42$, $p<.001$. Treatment, however, did not account for any significant variance, $F(3,59) = 0.89$, $p>.05$. There was a significant variance as a result of time, $F(3,59) = 10.72$, $p<.05$, but there was no significant interaction of treatment by time, $F(3,59) = 0.46$, $p>.05$.

Analysis of covariance (ANCOVA) was used to determine whether there were significant differences between mean post-*Laboratory Test* scores of students at different levels of cognitive development and prior knowledge after adjusting for any differences on the pre-test scores. The analysis revealed that students with a higher cognitive development level achieved significantly higher on the post-*Laboratory Test* compared to students at a lower cognitive development level for the experimental and control groups (see Table 2). The ANCOVA yielded a significant main effect considering test score and cognitive development level, $F(2, N=68) = 4.196$, $p<.05$. Although achievement scores were higher for students with a higher level of prior knowledge, the ANCOVA yielded no significant main effect considering posttest score and prior knowledge level, $F(2, N=68) = 1.154$, $p>.05$. Lastly, no significant two-way interactions (treatment X cognitive development level or treatment X prior knowledge level) or three-way interaction (treatment X cognitive development level X prior knowledge level) were found.

The relationships among achievement, cognitive development level, and prior knowledge found in this study were in agreement with other studies. (e.g., Chandran, Treagust, and Tobin, 1985; Haidar and Abraham, 1991; Sanchez and Betkouski, 1986). Upon cursory inspection, however, it would appear that the results of this study do not support theories of meaningful learning, inquiry and conceptual change which served as the basis for the constructivist instructional method. However, though the experimental group did not outperform the control group on the cognition outcome measures, the experimental group did just as well. This study, therefore, provides some evidence that a constructivist teaching method provides a viable avenue for learning college-level chemistry through laboratory work. Failure of the experimental group to outperform the control group may be attributed to several factors.

Instrument sensitivity may be one factor in the failure to detect differences.

Sensitivity of the criteria instruments is extremely important in studies which involve comparisons of instructional methods (e.g., Denison, 1986; Schellenberg, 1980). In the present study, while attempts were made to design the *Laboratory Test* in a way which focused on the laboratory activities, several factors may have reduced its discriminating capability. For one, several questions (11 out of 34) were included which tested higher-order thinking skills in other areas of chemistry. These questions were marginally-related to the laboratory activities. In addition, the test was not designed to measure the organization or relationships among concepts in memory which would be reflected by an assessment of the students' cognitive structure.

A second factor which may have reduced the discriminating capability of the *Laboratory Test* relates to instructional methodology. While the constructivist instructional method focused on conceptual integration, formation, and application and the verification method focused on the examination and confirmation of concepts presented through the textbook, the test items were not directed to either technique.

A third factor may have compromised the discriminatory power of the *Laboratory Test*. The class instruction, the constant variable, may have muted any differences contributed by the laboratory instruction. Besides being enrolled in the laboratory course, students were concurrently enrolled in the same general chemistry lecture section where content was covered relevant to the laboratory content. In fact, all concepts covered in the laboratory course, would also have been covered in the lecture course. While no overt attempts were made to align the sequencing of content of the lecture with that of the laboratory (nor was it possible to do so), clearly the knowledge and understanding which students gained from the lecture course would directly influence achievement in laboratory. This was confirmed by the strong statistical correlation between overall performance in the lecture course and overall performance in the laboratory course ($r=.48$, $p<.01$). The effect of class instruction could have been determined if there was a group of students who were enrolled in the laboratory course and not the lecture course. Three students fell into this category, but the size of the sample was too small to justify comparing that group with the others.

A fourth factor which might explain the groups similar performance on the *Laboratory Test* relates to a combination of treatment duration and sample size. The treatment occurred over a six week period with students in laboratory for three-hours per week. Eighteen hours may have been too brief a time to result in any appreciable differences in cognition between the groups. One would expect that if differences did occur, they would be small ones in any case.

Error variance in a small sample size could further mask the differences (Issac & Michael, 1989). The experimental group actually had a higher mean gain score on the *Laboratory Test* (posttest minus pretest) compared to the control group (8.32 and 7.24, respectively), although the difference was not a significant one. A larger sample might have produced a smaller sampling error and a possible demonstration of significant difference.

Instructional Method & Conceptual Change

To determine instructional method effects on conceptual change as measured by the *Concept Test,* a treatment x time Repeated Measures MANCOVA was conducted using the scores on the *Test of Logical Thinking* and prior knowledge test as the covariants.

The analysis revealed a significant relationship between the covariants and the posttest scores, $F(3,59) = 33.00$, $p<.001$. Treatment, however, did not account for a significant variance, $F(3,59) = 4.27$, $p>.001$. While there was a significant variance as a result of time, $F(3,59) = 10.85$, $p<.05$, there was no significant interaction of treatment by time.

Analysis of covariance (ANCOVA) was used to determine whether there were significant differences between mean post-*Concept Test* scores of students at different levels of cognitive development and prior knowledge after adjusting for any differences on the pre-test scores. The results revealed that students at a higher cognitive development level performed significantly higher on the post-*Concept Test* compared to students at a lower cognitive development level for the experimental and control groups (see Table 3). The ANCOVA yielded a significant main effect considering test score and cognitive development level, $F(2, N=68) = 4.37$, $p<.05$. Although scores were higher for students with a higher level of prior knowledge, the ANCOVA yielded no significant main effect considering posttest score and level of prior knowledge (see Table 3). Lastly, no significant two-way interactions (treatment X cognitive development level or treatment X prior knowledge level) or three-way interaction (treatment X cognitive development level X prior knowledge level) were found.

Upon cursory inspection, it would appear that the results of this study do not support conceptual change theory which served as the basis for the constructivist method. It was expected that if teachers played the role of adversary by posing questions to students and challenging their conceptions, students would critique evidence and theories based on their experiences in the laboratory and grasp the intelligibility, plausibility and fruitfulness of new concepts (Posner et al., 1982) . The instructor also allowed students to test their own hypotheses and to judge their conceptions based on the results of these tests. Lastly, the instructor was required to show conceptual linkages between different laboratory activities and between activities and phenomena which students encountered outside the laboratory. From this, it was expected that students would come to see the relevance of the content. These strategies and tactics would enable the instructors to facilitate and guide the conceptual change process, a principal intent of the constructivist method. There were no overt attempts to facilitate conceptual change using the verification method. Students were essentially on their own to test their conceptions against those developed through the activities. The failure of the study to reveal differences between the performance of the experimental group compared to the control due to differences in the effectiveness of the laboratory instructional method may be traced to several factors.

Students' prior conceptions are often resistant to change. Approximately the same average percentage (10 %) of students in both groups failed to undergo any conceptual change related to the thirteen concepts. This is in agreement with other studies which have revealed that alternative conceptions are resistant to change (e.g., Clement, 1983; Hashway, 1986; Simpson & Arnold, 1982; Viennot, 1979). The findings of other studies were summarized by Basili and Sanford (1991) as follows: "Recent experiments implementing conceptual change strategies...have had...limited success. A high proportion of students retain their misconceptions" (p.294). In addition, while both methods were effective in promoting conceptual change with respect to conceptions at the macroscopic chemistry level, conceptions at the microscopic chemistry level were more difficult to change regardless of the instructional method over the short exposure time involved in this study.

A second factor which could explain the lack of differences in conceptual change resulting from the laboratory teaching method may be the instruction which students received outside the laboratory. As with the *Laboratory Test*, the differences arising from treatment may have been muted by this instruction. The thirteen concepts covered by the *Concept Test* would have been introduced and discussed in the lecture class. In addition, although the lecture used non-constructivist methods, all students may have used these strategies in an informal way in other instructional settings (e.g., group study sessions, tutoring sessions, recitation classes). Students completing the post-*Concept Test* would have drawn upon knowledge and understanding gained from their laboratory and lecture experiences and from other ancillary learning experiences. It may be that conceptual change was facilitated by a combination of factors contributed by the lecture and laboratory with no one agent superior to the other. It has been suggested that understanding concepts depends on the extent and blend of a person's knowledge consisting of knowledge of propositions, intellectual skills, images, and episodes

(White, 1991). The depth and breath of knowledge and the way these various components are integrated will determine the students' understanding and influence conceptual change. Students' learning style (meaningful versus rote) will also impact this process. If students are willing to take responsibility for their own learning by interpreting and constructing representations of what they read, hear and observe and integrating with and changing prior ideas (Smith, 1990), they will promote conceptual understanding within themselves regardless of instructional method used by the teacher. While the constructivist method encouraged this process, the measure used in this study was not adequate to determine the extent to which these metacognitive strategies were used by students if indeed they were used at all. The measure could not partition any conceptual change which may have resulted from the use of these metacognitive strategies.

The effectiveness of the laboratory instructors also might have affected the conceptual change findings. According to conceptual change theory (Posner et al., 1982), students must experience dissatisfaction with their existing concepts, must understand new concepts, and must find them plausible and fruitful. According to Basili and Sanford (1991), "these conditions suggest the need for both active, direct instruction by a knowledgeable and skillful teacher and active participation and cognitive struggle by the students" (p.294). This supports the view of Tamir (1991) who argued that "the teacher is undoubtedly the key factor in realizing the potential of the laboratory...[requiring] a special approach to science...special instructional skills...special management skills...and special attitudes" (p.20). The graduate teaching assistants who delivered the instruction had limited teaching experience (i.e., an average of four semesters). Their skills may not have been sufficiently developed. The investigator, who possessed about twenty years of teaching experience, found the technique challenging during the pilot study. In addition, the teaching assistants reported that frequently students were shy about answering questions or commenting on another student's comments or were unwilling to subject themselves to rigorous questioning by the instructor. The investigator also found this to be the case during the pilot study. In fact, during one episode where a student was forced into cognitive struggle and constructivist thinking, the student reacted negatively and lost her temper. She was not used to this technique and expected to get answers from the teacher. The teaching assistants also reported that students grew tired of the constant questioning and simply wanted to get on with the activity in order to complete it and go home. This suggests that constructivist methods may be inconsistent with the purposes for which students take courses.

Facilitating conceptual change requires skill on the part of the instructor. In the present study, one can presume that the inexperienced teaching assistants did not have the ability to deal with student apathy or student resistance if it occurred and may have failed to initiate and facilitate the required episodes of conceptual change. This was partially confirmed by the results of the *Laboratory Survey*. Only 26 % (9 out of 34) of the students in the experimental group reported frequent occurrences of the instructor asking them to state alternate explanations for observed events, and only 24 % (8 out of 34) of the students reported frequent occurrences of the instructor challenging their assumptions and requiring justification of conclusions. Facilitating conceptual change is an art requiring adequate training to enable laboratory instructors to plan, promote and respond to episodes of cognitive struggle which may result in conceptual change.

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 equal declarative and procedural knowledge attainment and 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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APPENDIX

LABORATORY ACTIVITY #1

PHYSICAL PROPERTIES AND THEIR RELATIONSHIPS

Matter is characterized by its properties. That is, we know we have water and not, for example alcohol, because water has certain properties that distinguish it from alcohol. Matter has both chemical and physical properties. Chemical properties describe how one substance reacts with another. To demonstrate a chemical property, a substance reacts with other substances. In exhibiting physical properties, a substance undergoes no change in composition. Characteristics such as color, hardness, mass, volume, and melting point are examples of physical properties. Physical properties can be evaluated without any changes in the composition of the material.

One physical property may also be related to another. We know, for example, that all matter exists either as a solid, liquid, or gas, depending upon the temperature and pressure and the specific characteristics of the particular type of matter. A particular physical state is determined by the conditions (temperature and pressure) under which the observation is made. The state of the substance, one of its physical properties, is therefore related to its temperature. An increase in temperature may cause the state to change from solid to liquid, liquid to gas, or solid to gas.

In this activity we will investigate some physical properties and look for possible relationships between them. It is divided into four parts: **Demonstration, Guided Inquiry, Concept Formation,** and **Application**. Each part contains questions which will help to focus your observations and help you analyze what is going on. Be sure to answer questions in your laboratory notebook as you go along. During the **Demonstration** and **Concept Formation** portions of the activity, the instructor will meet with the group as a whole for discussion. During the **Guided Inquiry** and **Application** portions of the activity, you will be working with concrete materials individually or in a group to make both qualitative observations (using your five senses) and quantitative observations (using an instrument for measurement).

Part I. Demonstration

Teacher's Notes:

Before the class arrives, fill beaker A about 3/4 full with water and beaker B with the same amount of ethanol and cover them with watch glasses without revealing to students that the liquids are different.

Show the Ss the two pieces of candle. Drop the short piece in beaker A and the longer piece in beaker B. Center the discussion around Qs 1 & 2. For Q1, try to elicit all possible explanations including those that include differences in the cylinders and liquids. For Q2, ask Ss for explanations of their predictions. Ask Ss to think about those factors that determine whether an object will float or sink in a liquid. For the second part of the demonstration, drop the long piece in beaker A and the short piece in beaker B. Ask Ss what may be concluded from these observations. Differentiate between inference and observation.

Observe the first part of the demonstration which is performed by the instructor. Answer the following questions:

1. Why does one object float and the other sink?
2. Predict what would happen if the objects are switched?

Observe the second part of the demonstration which is performed by the instructor. Answer the following questions:

3. Was your prediction correct?
4. What factors determine the behavior of the two cylinders in the two liquids? Are the two liquids the same or different? State your reason(s).

Part II. <u>Inquiry</u>

Teacher's Notes:

In this part of the activity, students will work in pairs with different sets of objects:

** a set of 10 objects of various sizes and composition from the following materials (with density in g/mL listed in parenthesis): lead(gray sphere, 11.3), lead(grey square plate, 11.3), copper (cylinder,8.9), brass(gold cylinder,8.0), steel(grey cylinder,7.6), chromium(metallic lump,6.5), silicon(silvery lump,4.6), aluminum(silver rectangular,2.7), glass(white sphere,2.3), graphite(black round rod,2.2), vinyl plastic (grey clylinder,1.4), PVC(grey disk,1.4), acrylic plastic(white square plate,1.2), polyethylene(white round rod, 0.98), & styrofoam(white irregular lump, 0.05);*

** a set of 3 objects of the same composition but different sizes (hot glue wax)*

** a set of 4 objects of the same size but different composition (brass, aluminum, steel & copper);*

** a set of two different liquids from the following: water, ethanol, methanol, isopropanol)*

Students will be asked to collect data on mass and linear dimensions, and to calculate volume of regular-shaped objects. Students should be encouraged to think about the relationship between mass and volume and whether it is a property of the substance.

Mass and volume are two physical properties of substances. The mass can be determined by weighing a sample of the substance on a balance. The "weight" in both cases, is really the mass of a substance. In the process of "weighing" we find the mass, taken from a standard set of masses, that experiences the same gravitational force as that experienced by the given quantity of matter we are weighing. Solids, unless corrosive or finely divided, can be weighed directly on the balance. In the case of a liquid, the mass of a sample in a container can be found by taking the difference between the mass of the container plus the liquid and the mass of the empty container.

The volume of a substance can be found directly or indirectly. In the case of a liquid or gas, the volume can be found by using a calibrated container. The volume of a solid can be found by direct measurement if the solid has a regular geometrical shape (for example, the volume of a cylinder is found using the equation $V= \ r^2h$). One way to find the volume of irregular-shaped solids is by measuring the volume of liquid the solid displaces when the solid is placed in the liquid. The volume of the solid will equal the volume of liquid it displaces.

In this part of the laboratory activity, you will be asked to think about the behavior of the two cylinders which you observed in Part I and investigate the properties of mass and volume and any relationship which may exist between the two.

Begin by obtaining a set of 10 different solid objects. Divide the objects into two groups: objects which will float in water and objects which will sink in water.

Following your classification, test your prediction. Be sure to keep a record of your observations.

1. Were all your predictions correct?

2. Is the sinking-floating behavior of the solids related to the properties of their mass and volume? Explain.

Next, use 3 cylinders of the same composition but different sizes. For each cylinder, determine its mass and measure in centimeters its height (h) and diameter (d). From the diameter, calculate the radius (r). Using the formula, $V = \prod r^2h$, calculate the volume of each cylinder. Lastly, calculate the mass to volume ratio for each cylinder and compare.

3. What generalization can you make regarding the mass to volume ratio of the three solids?

4. Suppose you were given a solid sample of the same composition as the three cylinders but it was irregularly-shaped. Since you could not measure its length and diameter, how could you find the volume of the irregularly-shaped object using the information you collected about the cylinders? How could you find the volume experimentally?

Obtain an irregularly-shaped sample of the substance from the instructor. Estimate its volume. Test your prediction by determining its volume from the data you already collected about the cylinders made of the same substance or experimentally (e.g., by liquid displacement).

Let's now try working with substances with different compositions but of the same size to see if any other pattern of relationships emerge.

Obtain 4 solid cylinders of the same size but of different composition. For each cylinder, determine its mass and volume. Calculate the mass to volume ratio for each one and compare these ratios.

5. Describe the procedure used and record your results.
6. What conclusions can you draw from the data you collected?

Up to this point you have worked with solids.

7. Is there a relationship between mass and volume for a liquid and is this ratio different for different liquids?

Test your predictions by obtaining 3 different volumes (e.g., 2, 4, and 6 mL) of 2 different liquids (e.g., water and ethanol) and determining their masses. Calculate the mass to volume ratio for each sample used and compare the results.

8. Describe the procedure used and record your results.
9. What conclusions can you draw from the data you collected?
10. How does the sinking and floating behavior you observed earlier relate to the findings you collected in this portion of the activity?

Work in groups of three to discuss the results of the **Guided Inquiry**. Use the following questions to focus the discussion and indicate what data from the **Guided Inquiry** can be used to support your answers:

11. Is the mass of a substance related to its volume?
12. Is the mass to volume ratio a fixed quantity for a particular substance?
13. Can the mass to volume ratio be used to distinguish one substance from another?
14. Can the mass to volume ratio be used to find the mass or volume of a substance? Explain.
15. Can the mass to volume ratio for a solid and the mass to volume ratio for a liquid be used to predict whether the solid will float or sink in the liquid? Explain.
16. What single term describes the mass to volume ratio for a substance?

Part III. <u>Concept Formation</u>

Teacher's Notes:

In the demonstration, the alcohol has a lower density than water. This is why the candle sank in the alcohol and stayed afloat in water. Density is defined as the ratio of mass and volume of a substance, D= M/V. Whether something sinks or floats depends on the relative density of the object compared to that of the liquid it is immersed in. Density is an intensive property and does not depend on the amount of substance.

During this part you will be asked to gather as a group and contribute the data you have collected to a class discussion. The instructor and you will put these data together and formulate the concepts which can be used to explain the observations.

Part IV. **Application**

After observing and describing the behavior of a can of Diet Pepsi and a can of regular Pepsi in water, state a hypothesis which explains the behavior of the cans in terms of differences in the densities of the two liquids in the cans. Design and carry out a procedure for testing this hypothesis. Refer to **Technique #1** for a suggested method of accurately determining the volume of a liquid.

TECHNIQUE #1
VOLUME OF LIQUID

Use a flask fitted with a ground-glass stopper. Be sure the flask is clean and dry. If not, clean it with soap and water, rinse it with a few milliliters of acetone, and dry it by letting it stand for a few minutes in the air or by gently blowing compressed air into it for a few moments. Weigh the dry flask with its stopper on the analytical balance to the nearest milligram. Fill the flask with distilled water until the liquid level is nearly to the top of the ground surface in the neck. Put the stopper gently into the flask, so that it is firmly seated in position. Wipe any water from the outside of the flask with a towel and soak up all excess water from around the top of the stopper. Again weigh the flask, which should be completely dry on the outside and full of water, to the nearest milligram. Using the density of water at the temperature of the laboratory and the mass of water in the flask, you should be able to determine the volume of the flask very precisely. Empty the flask, dry it, and fill it with another liquid. Stopper and dry the flask as you did when working with the water and then weigh the stoppered flask full of the unknown liquid, making sure its surface is dry. This measurement, used in conjunction with those you made previously, will allow you to find accurately the density of your liquid.

The following additional resources which were used to construct this laboratory activity:

Abraham, M.R., & Pavelich, M.J. (1991). Inquiries into chemistry (2nd ed.). Illinois: Waveland Press, Inc.

Liem, T.L. (1981). Invitations to science inquiry (2nd ed.). Chino Hills, CA: Science Inquiry Enterprises.

FIGURE 1

Examples of Items from the *Laboratory Test*

Knowledge, Comprehension, & Application

Knowledge

Mixtures of substances

(A) must be heterogeneous (B) must be homogeneous (C) have definite proportions
(D) have variable composition

Comprehension

A glass-stoppered flask has a mass of 84.70 g. A 25.00 mL sample of an unknown organic liquid is transferred to the flask, giving a mass of 101.68 g for the filled flask. What is the density of the unknown liquid in g/mL?

(A) 0.8330 (B) 0.2952 (C) 0.6792 (D) 1.472

Application

A geologist in the desert finds a huge rock in the shape of a cube. He would like to know the weight of it. However, since the rock is a big as a three-story building, he can't very well weigh it on his balance. What can he do?

(A) He can use a tape measure to determine the dimensions of the cube and determine the total amount of space occupied by the cube using the formula $V=s^3$, where s is the length of one side.
(B) He can arrange to have it moved to a large body of water, submerge the object and determine the amount of water displaced by the object.
(C) He could find the density of the rock by chipping small pieces from it and determining their mass and volume. From the dimensions of the block and its density, he could compute the mass of the large cube.
(D) He could chip a few pieces from the cube, measure their mass, determine the volume of the cube, and compute the mass of the entire cube from a ratio of the mass to the total volume.

FIGURE 2

Examples of Items from the *Laboratory Test*
Analysis & Synthesis

Analysis

If the blue pentahydrate $CuSO_4$ $5H_2O$ is heated to about 300 ^oC, anhydrous copper sulfate, $CuSO_4$, a white powder is formed. This behavior is typical of other hydrates. Suppose a student is determining the weight of the water driven off on heating the hydrate by comparing the weight of an unknown hydrate with the weight of the corresponding anhydrous salt produced. If, unknown to the student, all the water is not driven off, the student would calculate as being lower and higher than the true value, respectively,

(A) the weight of water in the hydrate and the weight of the anhydrous salt.
(B) the weight of water in the hydrate and the weight of the original hydrate.
(C) the weight of anhydrous salt and the weight of the original hydrate.
(D) the weight of the anhydrous salt and the weight of the water in the hydrate.

Synthesis

Several students were involved in the following inquiry:
Metallic iron was added to a solution of copper sulfate. The reaction produced metallic copper, which is seen settling out of solution as a finely divided powder. The iron disappeared into solution. Copper foil was added to a colorless solution of silver nitrate, the solution turned blue, while the foil turned silvery. A silver spoon was placed into a solution of iron sulfate. No visible change was observed.
The students discuss the data and invent an explanation which represents an important concept in chemistry. Which concept might the students have invented as a result of this inquiry?

(A) A metal in a compound can be displaced by another metal in the uncombined state.
(B) Iron metal will displace copper from copper sulfate, copper metal will displace silver from silver nitrate, and iron cannot be displaced from iron sulfate by silver metal.
(C) In certain reactions, the element that enters a solution is more active then the element that is displaced from the solution. From the observed reactions, the order of reactivity of the elements (from most to least reactive) is iron, copper and silver.
(D) Some elements are able to displace other elements from compounds. From the observed reactions, it might be concluded that iron is the most reactive element.

FIGURE 3

Examples of Items from the *Concept Test*
Two-Tier & Completion

Two-Tier Question[1]

One-milliliter of carbon tetrachloride is heavier than 1-mL of water. An experimenter has two twenty-five mL graduated cylinders, one filled to the 15-mL mark with water, the other filled to the 15-mL mark with carbon tetrachloride. If he has two identical lead balls and drops one of them into the graduated cylinder containing water and the other into the graduated cylinder containing carbon tetrachloride, what will happen to the level of the liquid in the graduated cylinders?

(A) The level of the water will rise higher than the level of carbon tetrachloride.
(B) The level of the carbon tetrachloride will rise higher than the level of water.
(C) The levels will rise the same distance in each cylinder.

Reason: (Student is required to give reason for choice.)

Completion Question[2]

A student dissolved 10 g of ammonium chloride (NH_4Cl) in 50 mL of water. The temperature of water decreased by 13 ^{o}C. The reaction took place in a 100 mL container (with thermometer and stirrer) so that thermal energy transfer with the environment was minimized. What are your best answers to the questions: (a) What happened to the NH_4Cl? and (b) Why did the temperature decrease?

[1] Source Gennaro, E.D. (1981). Assessing junior high school students' understanding of density and solubility. School Science and Mathematics, 81(5), 399-404.

[2] Source Cachapuz, A.F., & Martins, I.P. (1987). High school students' ideas about energy of chemical reactions. In J.D. Novak (Ed.), Proceedings of the Second International Seminar on Misconceptions and Educational Strategies in Science and Mathematics (Vol. 3, pp. 60-68), Ithaca, NY: Cornell University.

FIGURE 4

Examples of Items from the *Laboratory Survey*

1. Students follow step-by step instructions in the laboratory manual

2. Students gather together to discuss along with the instructor the outcomes of the laboratory activities.

3. Laboratory activities develop skill in the techniques or procedure of chemistry.

4. In discussion with the instructor, assumptions are challenged and conclusions must be justified.

5. Each laboratory activity is dependent on the activities that preceded it.

6. In the laboratory, students may work together to design a method for solving a problem.

TABLE 1

Mean Scores on Post-*Laboratory Survey*

	Mean	SD
CONTROL(n[a]=28)		
Control #1(n=16)	44.56	6.10
Control #2 (n=12)	43.92	11.17
TOTAL	44.29	8.46
EXPERIMENTAL(n[b]=34)		
Exp. #1 (n=17)	53.82	5.47
Exp. #2 (n=17)	56.06	4.37
TOTAL	54.94	5.00

Note. Maximum score = 80 (representing maximum demonstration of characteristics of the constructivist method).

[a]Five of the 33 students in the control group were absent on the day the survey was administered. [b]One of the 35 students in the exp. group was absent on the day the survey was administered.

TABLE 2

Analysis of Covariance on Post-*Laboratory Test* Scores

with Pretest Score as Covariable

Source of Variation	SS	DF	MS	F
Main Effects				
GROUP	281.059	5	56.212	3.298
TOLT	143.019	2	71.510	4.196*
KNOW	39.325	2	19.662	1.154
2-Way Interactions				
GROUP X TOLT	60.048	2	30.024	1.762
GROUP X KNOW	44.743	2	22.371	1.313
3-Way Interactions				
GRP X TOLT X KNOW	13.044	2	6.522	0.383

* $p < .05$

TABLE 3

Analysis of Covariance on Post-*Concept Test* Scores

with Pretest Score as Covariable

Source of Variation	SS	DF	MS	F
Main Effects				
GROUP	21.144	1	21.144	2.04
TOLT	90.727	2	45.364	4.37*
KNOW	45.788	2	22.894	2.20
2-Way Interactions				
GROUP X TOLT	24.178	2	12.089	1.16
GROUP X KNOW	8.127	2	4.063	0.39
TOLT X KNOW	48.198	4	12.049	1.16
3-Way Interactions				
GROUP X TOLT X KNOW	61.642	2	30.821	2.97

* $p < .05$