SEQUENCING PROBLEM SOLVING AND HANDS ON ACTIVITIES: DOES IT MATTER ?

Sean P. Brophy
brophysp@ctrvax.vanderbilt.edu
Learning Technology Center
Vanderbilt University
Box 45, GPC
Nashville, TN 37203

INTRODUCTION

Problem solving activities can prepare learners to be more independent when they later engage in abstract scientific inquiry processes. It is accepted that problem solving activities provide powerful opportunities for students to acquire and apply new information. In the domain of science, problem solving is a necessary activity to develop the understanding of the inquiry process (Kluhr, Fay, Dunbar, 1993; Adams et al, 1988; Sherwood, Kinzer, Hasselbring, & Bransford, 1987). One important issue is students' readiness to engage in problem solving activities. Do students need to "master" a certain set of basic skills and content before solving a complex problem that includes those skills and content? Starting instruction with a problem may prepare learners to recognize the utility of certain information and transform this information into meaningful knowledge they can apply to future problems.

This paper presents results from a study designed to explore the effects of sequencing problem solving and laboratory activities (often called "hands on") on students' understanding of content, engagement in the activity and self regulation during the activity. The first section highlights two instructional methods designed to engage students in using inquiry skills to discover important scientific concepts. The first method uses a series of inquiry challenges that use actual laboratory equipment to help students explore the concept of density of solid materials. The second instructional method begins instruction with a problem oriented activity supported with a computer environment specifically designed to support students' inquiry during their problem solving. A brief description of this computer environment will illustrate how students can sustain their own inquiry when various tools are available. The next sections outlines the research method, procedures and results. The final section discusses these results and how they relate to learning and instruction.

Theoretical Framework

Problem solving activities are often viewed as a method to practice applying new knowledge and skills learned earlier in a different context; contexts like classroom instruction, textbook readings or laboratory experiments. The assumption is that students who successfully solve the problems show that they learned the concepts needed to solve the problem. However, an alternative use of a problem solving context is to provide students with a conceptual map (Norman, 1972) of the concepts they are to learn more about. One might assume that students can't solve a problem if they don't have any prior knowledge. This might be true if the goal of the instruction is to get them to find a solution to this initial problem. However, if the goal of the instruction is to familiarize students with the concepts, then they may be better prepared to learn these concepts in depth in a different context like classroom lecture, textbook readings (Schwartz & Bransford, in press), and laboratory experiments. Further, they may be able to better apply this new knowledge in novel problem solving situations. Science instruction provides an excellent example of how this idea can be used in practice.

One goal of science instruction is to familiarize students with scientific knowledge that consists of laws, principles, and theories (Carey & Smith, 1993) so they can apply it in problem solving situations. Students need to understand that science is more than memorizing these laws, principles and theories (CTGV, 1992 a) and it is more than collecting and manipulating data. Rather, scientific process is a process of inquiry that requires asking questions, observing, data exploration and data manipulation (National Research Council, 1996). Also, it requires learning to apply and generalize scientific knowledge. Creating a learning environment to demonstrate these characteristics requires engaging students in their own inquiry. The science education community has long been aware that students need to develop their own conceptual understanding through active engagement in learning activities. The challenge is defining a method to support , or scaffold, student's learning that leads to conceptual understanding.

The following theoretical perspectives defines two instructional methods designed to guide students toward conceptual understanding. Each method attempts to embed important scientific principles into interesting challenges. The difference between the two is the level of abstraction these methods use to present the new knowledge. The discussion highlights the key features of each method and the mechanisms they use to guide students toward deep conceptual understanding of scientific concepts.

Creating Challenges with Laboratory Activities

In the domain of science, a problem can be posed through a demonstration or laboratory experiments. A common technique used in science instruction is to get students to see an interesting phenomenon that helps them generate questions about it. "The demonstration that stimulates the greatest need to know is the one that asks a question and asks the student to find the answer... One of the best ways to stimulate interest is to offend the student's intuitions in some way or to confront them with a situation that is not readily acceptable. The student must be asked to find his way out of the intellectual maze that has been set up for him." (Romey, 1968 p. 17) For example, one might begin a lesson on density with a demonstration of how an ice cube floats in one beaker of clear liquid and sinks in another beaker of clear liquid. This result should "offend the students' intuition" (Romey, 1968 p. 17) which induces their natural curiosity to figure out why. Through discussion groups or whole class discussion the class can engage in a process of inquiry that create theories and experiments to test these theories. Alternatively, students could participate in laboratory experiments that stimulate them to ask questions and instill a desire to find the answers. Now that they have "discovered" a problem they are primed to find answers, even if the answers come in the form of a lecture. The experience from the demonstration or lab experiment provides them a context in which to apply the information they are receiving in a lecture. The key points about this method is that instruction is designed to guide students toward discovering important scientific principles and interrelationships between these principles. Teachers guide students discovery to foster a deep understanding of the content.

Establishing "authentic" contexts

Provocative demonstrations and inquiry style laboratory experiments are powerful instructional methods for getting students to engage in "authentic" inquiry process (i.e. asking questions, observing, data exploration and data manipulation) and learn the relationship between important scientific law, principles, facts, concepts, and procedures. One concern is developing methods to help students make the transition toward applying this knowledge to other situations. That is, situations that are "authentic" uses of the new knowledge, not abstract ideas represented by the scientific community. As Collins, Brown and Holum point out "a critical element of fostering learning is to have students carry out tasks and solve problems in an environment that reflects the multiple uses of which their knowledge will be put in the future. Situated learning serves several different purposes." (Collins, Brown & Holum, 1991 p. 42). They explain several reasons why situated learning is important including: (1) learners see the utility of the knowledge they are learning, (2) it is a more active process of learning (3) students learn different conditions to apply knowledge and (4) learning in different contexts leads to abstraction which leads to transfer. These reasons are what supports the premise that problem oriented activities may better prepare learners to understand concepts that are presented in more abstract forms like lectures or inquiry style laboratory experiments.

Creating Challenges with Problem Oriented Activities

Problem oriented activities provide a mechanism to help students define meaningful goals and see the utility of new knowledge. Many researchers use problem oriented situations to facilitate learning (CTGV, 1997; Barrows, 1986; Adams et al, 1988) because it encourages the use of powerful cognitive skills necessary for life long learning. These ideas originate from theories like situated cognition that emphasize how problem contexts help individuals appreciate the utility of knowledge and how concepts interrelate (e.g. Collins, Brown,& Holum, 1991). These theories also emphasize the need for learners to take an active role in transforming new information into useful knowledge that they can apply to new situations. Several methods of instruction based on these theories include problem based learning in medicine (Barrows, 1986) and law (Williams, 1992), and case based reasoning (Kolodner, 1993). These approaches give students authentic situations to explore domain content while simultaneous practicing important cognitive skills that will help them during their profession. Typically, instruction begins with presenting meaningful problems to students who then decompose the problem and search for relevant information. A knowledgeable coach provides assistance at various times to guide learners through the process (Collins & Stevens, 1982). These ideas have been extended from these professional schools to middle school classrooms using anchored instruction (CTGV, 1992), case base reasoning, and project based learning (Krajcik, Blumfeld, Marx, & Soloway, 1994). The complexity of these challenges combined with the novice learners makes it difficult to mediate students learning to ensure everyone in the class in learning. These situated approaches to learning attempts to engage students in meaningful research for important information in pursuit of helping them construct their own knowledge. Computer technology provides an additional mechanism to help teachers with the instructional process necessary to sustain a generative learning environment in a classroom.

Scaffolding problem oriented activities using computers

Computers can provide easy access to volumes of information, but without meaningful structures this information will remain inert. A computer program, called QUEST (Questioning Environment to Support Thinking) (Brophy, 1994), structures media resources to help students sustain their own inquiry during problem solving. Like a human mentor, or coach, the program organizes instruction around a defined model of problem solving that consists of four stages. In the first stage, **problem presentation**, QUEST presents challenges to students in either video, text or sound format (see Figure 1). They use an electronic notebook to record as many potential problems they notice in the challenge. Next, they move to the second and third stage of problem solving which includes, **exploration** and **discovery** of useful information. QUEST supports these stages by providing a simulated lab environment containing virtual lab tools and various reference materials (see Figure 2). Once they discover sufficient information they need to transform it into a viable solution. This is when they transition into the next phase of problem solving, called **reflection**. Here is where students synthesize their solutions into a form that can be communicated to others, for example, a presentation for the class. It is during this phase that the problem solver must evaluate their process and determine if they did it correctly. The context provided by the challenge helps students identifying goals that they can use to discover relevant information that will help them define a solution to the challenge. QUEST encourages learning by presenting interesting challenges that help students establish goals for research. These goals help them seek, notice and apply useful information in a meaningful context.

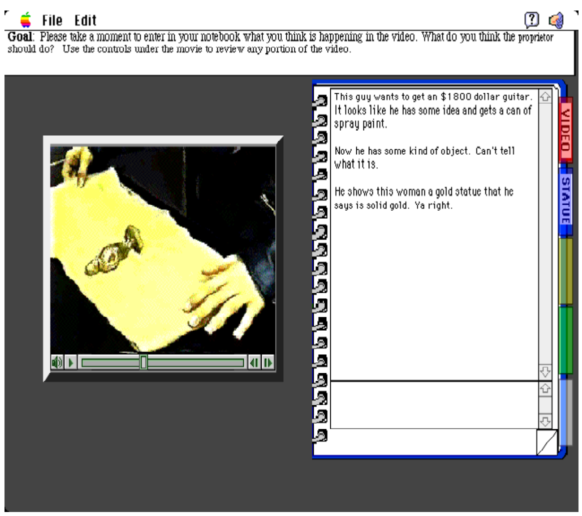

Figure 1 - Problem Presentation

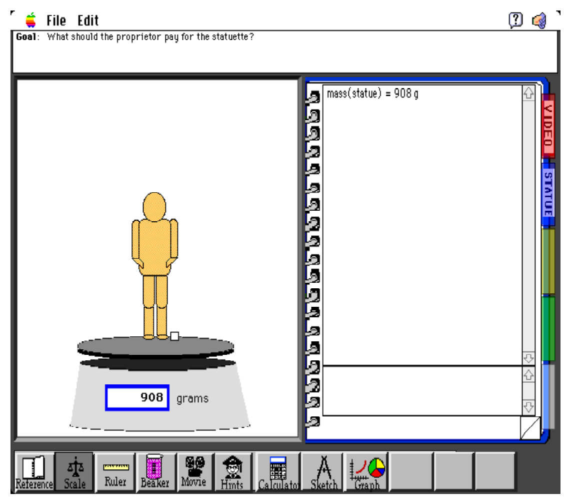

Figure 2 - Simulated lab

<u>Proposed Study</u>

The theoretical foundation of guided generative learning assumes middle school students can begin learning through problem oriented activities if they have sufficient scaffolding. A computer environment designed specifically to support problem solving and the principles of guided generative learning could provide sufficient scaffolding. The proposed study attempts to further validate the assumption that problem oriented activities can be used early in students learning of new content. One method of exploring this assumptions is to observe the effects of sequencing two treatments: (1) problem oriented activities, and (2) "hands on" (i.e. inquiry based laboratory) activities. This will help differentiate whether one treatment is sufficient for orienting students to new information or if one method prepares students to learn more from the treatment that follows it. The QUEST environment is key to helping student sustain their inquiry during the problem oriented activity. Therefore, the computer environment is another factor in this exploration. The overall objective of the proposed study is to understand the effects of sequencing the two treatments on student's depth of understanding, engagement in the activity, and their ability to sustain their own inquiry.

METHOD

The design of this experiment focuses on the theory that students' learning is improved by starting science instruction with a problem solving activity versus beginning with lab experiments. The procedure for this study needs to capture the progression of students' learning over time and their level of engagement and interest in a specific activity. Therefore, in this experiment the two groups performed a sequence of activities where the only difference in procedure is the order in which they perform a particular activity. A variety of measures were instituted to capture changes in students' learning of scientific concepts, problem solving strategy and level of engagement in the activities.

Participants

Two magnet classrooms containing a mix of fifth and sixth grades participated in this study. Each classroom contains 24 students and met twice a week with the same teacher. One section meets on Monday and Wednesday, the other section meets Tuesday and Thursday with the teacher who participated in this study, Teacher 1. On the alternate days the students meet with another teacher, Teacher 2, who team teaches with Teacher 1. These classes join on Friday to work on individual and group projects. The students were randomly assigned to each section. The random association with a specific section and the team teaching approach minimize biases such as teacher effects.

Students in this population represent high achieving students strong in math, science and language. Participants in the magnet classroom must meet a strict set of qualifications. They must score at least 95 percent on the Tennessee Comprehensive Achievement Program (TCAP) just to be invited to take the entrance exam. The 5/6 grade magnet entrance exam is the 8th grade ACT examination, called Explore, which tests students' abilities in (1) scientific reasoning, (2) mathematical reasoning, (3) reading, (4) language and (5) language arts for social science.

Therefore, these students are highly verbal and possess the ability to comprehend text and the reasoning skills to apply to problem solving situations.

Design and Procedures

This study uses a 2 (treatment condition) X 2 (group) mixed design (see Table 1) to explore the effects of sequencing two types of instructional treatments. That is, each group receives the same instruction, but the order of the activities is different. The first activity, **Activity A**, is adapted from an inquiry style approach created by the Center for the Excellence of Math and Science instruction (Hartshorn, Phelps, & Cranford, 1994). Students are presented two challenges related to properties of solid materials. The first challenge encourages students to discover various methods of measuring area and volume. The second challenge is designed to help students discover the proportional relationship of density. Students typically work 'hands on' with actual laboratory equipment and materials. The second activity, **Activity B**, is a problem oriented approach to learning supported by the computer tool called QUEST. Here the students attempt to solve a video based challenge called Golden Statuette (See Appendix A for a story board of the problem. The students were randomly assigned to one of the two groups. One group started with the inquiry based 'hands on' activities (referred to as "hands-on"), then performed the

Table 1. Experimental Design: 2 x 2 matrix of treatments.

GROUP	TREATMENT 1	TREATMENT 2
1. Hands on first (HOF)	**Activity A**: Volume and Density Lessons	**Activity B**: QUEST mediated problem solving activity
2. Problem Orientation First (POF)	**Activity B**: QUEST mediated problem solving activity	**Activity A**: Volume and Density Lessons

problem solving activity using the QUEST computer program. This group is called the "hands on first" (**HOF**) group. The second group did the problem oriented activity with the computer then did the "hands on" activities. This group was called the "problem oriented (activity) first" (**POF**) group.

Table 2 shows an expanded view of the design table shown in Table 1. This table outlines the activities and measures the two groups performed during the various phases of the study including, pre treatment, treatment and post treatment.

Table 2. Procedure of activities and tests

		PRE	TREATMENT						POST
			1			2			
	GROUP	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8-9
Activity	Hands on (**HOF**)	Orientation	**Activity A** Volume Challenge	Density Challenge		**Activity B** QUEST	QUEST		QUEST Chal. 2
Activity	Problem Oriented (**POF**)	Orientation	**Activity B** QUEST	QUEST		**Activity A** Volume Challenge	Density Challenge		QUEST Chal. 2
Reflection	Hands on (**HOF**)		Self Assess	Self Assess		Self Assess	Self Assess		Self Assess
Reflection	Problem Oriented (**POF**)		Self Assess	Self Assess & Reflection Passage		Self Assess	Self Assess & Reflection Passage		Self Assess
Measures		Skills assessment	ETE	ETE	Test A	ETE	ETE	Test B	Trace & Survey

Measures

<u>Pre treatment skills assessment</u>.

Before the first treatment students completed a skills assessment test (SAT). The SAT established proficiency with skills in mathematics, science and problem solving (adapted from Lesh, Landau, & Hamilton, 1983). Students were given as much time as they needed to complete this assessment test. The skills associated with mathematics include multiplication, division, manipulation of fractions and proportional reasoning. The science section focused on students' ability to use measuring tools, calculate volume and convert metric units. The final section targeted students' problem solving ability of complex problems (multiple steps, or abstract representation).

<u>Between Treatment and Post Treatment Mastery Tests.</u>

After each treatment students completed a mastery test to capture their understanding of measurement, quantitative manipulation of density, qualitative relation of density and problem solving process skills. Quantitative reasoning is assessed by a group of short word problems that require students to manipulate the density equation (**D**ensity = **m**ass/**V**olume) to find an unknown value. Qualitative reasoning is assessed through a set of word problems that require reasoning using the concept of density. Theses problems resemble a similar reasoning process to the one needed for the Golden Statuette. The problem statements do not suggest an immediate plan of action like applying the formula of density. Students must recognize that the problem relates to density and then define a plan to calculate the necessary variable related to density (i.e. mass or volume). The remaining sets of questions target students ability to perform simple calculations related to scientific problem solving. The mastery tests were identical to each other except the order of the questions and the numerical values contained in the problem statement.

<u>Self Reports</u>

<u>Experiences That Energize (ETE) - Level of Engagement</u>. Motivation during the activities was monitored using a new experimental instrument called Experiences That Energize (ETE)(Bransford & Schwartz(1995); Brophy (1996)). Based on Csikszentmihalyi's idea of "flow" (1990), the instrument is founded on the premise that highly motivating activities energizes us to continue. If we are highly engaged and want to continue an experience then that particular moment would have a high ETE rating. For example, reading a good book can be very engaging resulting in the reader claiming they "couldn't put it down". This experience energies the person to an intellectual level that motivates them to continue the activity. This experiment used a simple survey form with a 7 point Likert scale. At various times during all the treatments, students were asked to take a second to rate their current ETE level. In addition, they were asked to write down a brief description of the activity they were engaged in at the time of the interruption. The expectation is that when students are highly engaged then they will score a high ETE. They will report a low ETE rating if the current activity is draining (that is they start to “watch the clock”).

Interest and Attitudes Survey. Student’s motivation and performance can depend on a variety of factors including interest in science, interest in using computers, interest in solving problems and individual learning styles. A short survey was used to profile students’ thinking about these factors. The questionnaire was also designed to capture students’ reactions to the software and the actual treatments. For example, several items attempt to capture students feelings about the difficulty of each activity.   Further, it asked when they thought they needed the most help, during the hands on experiment or during the computer environment. This information provides another dimension for exploring the difference in students’ learning or motivation.

RESULTS

The main hypothesis focuses on the sequence of two treatment conditions which suggests they should be compared and contrasted across various dimensions at various times. Therefore, the method of analysis was designed to explore the effects of each treatment condition on students' understanding, engagement in the activity, ability to transfer information and their attitudes about each condition. Each treatment contributes to understanding portions of the major content areas of volume, mass, density and problem solving. The major content areas of this experiment includes the computation of density and its application to problems. It was anticipated that these students would tend to use a much more quantitative approach to exploring density. On the other hand, the problem oriented activity may require a more qualitative approach to determine how the concept of density will help them solve a problem. That is, the Golden Statuette problem does not contain any quantitative data. The students must use qualitative reasoning to decide what type of quantitative data they need to obtain. Therefore, the following results are organized to illustrate the contributions of each treatment toward students quantitative reasoning, qualitative reasoning and their ability to compute volume and density. This analysis focuses on the students performance on the initial Skills Assessment Test, mastery tests and reported scores of engagement and attitudes toward types of instruction.

Pre Assessment Test

Comparing two groups assumes homogeneity of prior knowledge and skill level of both groups. The Skills Assessment Test (SAT) compared several divisions of the population on several categories of questions. Table 3 illustrates the mean of the students in the four divisions of the population. The results showed no significant difference in the total scores between the two treatment groups $F(1,45) = .24, p = .6265, MS_e = .0014$. Regardless of the division of the population, the majority of the students scored high in mathematics and problem solving. However, their overall science skills score were significantly lower compared to the math and problem solving ability. In addition , boys scored significantly higher than the girls in the science skills category $F(1,45) = 5.5624, p = .0228, MS_e = .2956$. It is assumed that this measure indicates a certain level of scientific awareness and skill. Therefore, this science score was used with the mastery as a covarient to compensate for prior scientific skill when comparing the performance of males with females.

Table 3. Mean SAT scores by First Treatment, Gender, Grade and Section

Group		Math	Science	Problem Solving	Total
		36 items	7 items	3 items	46 Items
Treatment					
HOF	M	31.5	2.71	2.53	36.8
N = 21	SD	2.03	1.70	0.60	3.12
POF	M	31.36	2.44	2.56	37.30
N = 25	SD	2.91	1.66	0.71	3.80
Gender					
Male	M	31.20	3.65 *	2.52	37.50
N = 23	SD	2.54	1.72	0.59	3.60
Female	M	31.69	2.56	2.56	36.60
N = 23	SD	2.53	1.53	0.73	3.30
Grade					
5	M	31.27	2.72	2.56	36.5
N = 25	SD	2.70	1.51	0.65	3.40
6	M	31.66	3.50	2.52	37.80
N = 21	SD	2.29	1.83	0.68	3.50
Section					
Mon/Wed	M	31.89	3.26	2.60	37.9
N = 23	SD	2.55	1.76	0.56	3.50
Tues/Thurs	M	31.01	2.96	2.39	36.3
N = 23	SD	2.56	1.66	0.72	3.30

(Column group heading "Category" spans Math, Science, Problem Solving and Total.)

* p < .05

Mastery Tests

The performance of each group was compared using an analysis of variance on total score, quantitative reasoning question and qualitative reasoning questions for each group after each treatment. Also, a repeated measure on a mixed design was used to compare between group and within participants. The following reports on these analysis plus several post hoc analysis on response rate and several items analysis on test items.

Assessment During Treatment - First Mastery Test

The performance of each group was compared using an analysis of variance. Comparison of the total scores revealed no significant difference between the groups $F\,(1{,}27) = 2.65, p = .975$, $MS_e = .431$. Table 4 summarizes the mean scores for each category of question of the mastery test.

Table 4. Results of First Mastery Test

Group		**Category**			
		Qualitative 5 items	Quantitative 5 items	Unit conversion 4 items	Total 15 items
HOF n=13	M	0.76	0.08	1.84	3.07
	SD	.725	0.27	1.46	1.55
POF n=17	M	1.00	0.41	1.64	3.12
	SD	1.17	1.18	1.45	2.52

Post Treatment - Second attempt of Mastery Test

After the second treatment the students completed a second mastery test similar to the first. This test had the same categories of questions; the only differences were in several of the word problems. The numeric values and material types of the objects described were the only things changed. It was predicted that the "problem oriented first" group (POF) would demonstrate a stronger understanding of the concept of density. Specifically, after completing the two instructional treatments, the POF students should be able to correctly apply density both quantitatively and qualitatively during problem solving situations. However, Table 5 shows scores of both groups increased significantly after the second treatment. Also, there was no significant difference between the groups on the various categories of the mastery test.

Table 5. Summary of Second Mastery test

Group		Category			
		Qualitative 5 items	Quantitative 5 items	Unit conversion 4 items	Total 15 items
HOF n=21	M	1.52	2.14	1.86	5.86
	SD	0.98	1.74	1.52	2.70

POF n=22	M	1.68	2.00	1.22	5.00
	SD	1.68	1.74	1.07	3.70

<u>Effects Over Time - Combination of Activities</u>

A repeated measure analysis was performed to explore the effects of each treatment over time. An analysis of variance using a mixed model design compared the differences between the groups and within subjects. The results indicated a significant increase within subjects across the second treatment. This includes comparison by group, gender, section and grade. That is, the means of the total scores increase significantly for both groups across the treatments $F\ (1{,}22) = 10.63$, $p = .004$, $MS_e = .78$. Table 6 summarizes the statistics for this measure. This effect appears in both the quantitative and qualitative score on the mastery test. Figures 3 and 4 respectively reflect this relationship.

Table 6. Repeated measure statistics for total test scores on mastery tests

		Test A	Test B
HOF n= 12	M	3.33	5.92
	SD	1.30	2.39
POF n= 14	M	3.43	5.14
	SD	2.56	3.98

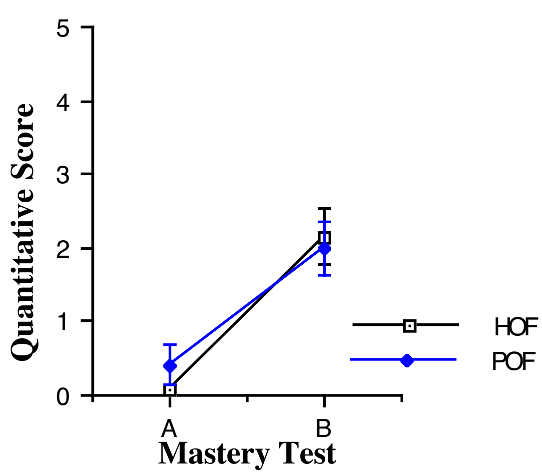

Figure 1. Quantitative Score

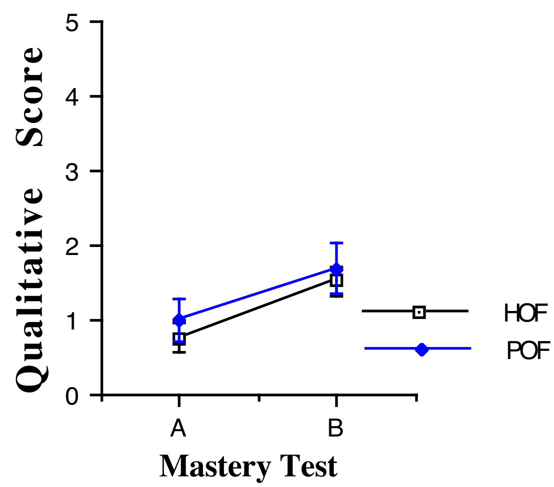

Figure 2. Qualitative score

Response rates on mastery test

While scoring the first mastery test it was observed that many students never attempted to solve several of the problems. The significance of this measure was not anticipated prior to doing the experiment. Therefore, a post hoc analysis explored the relationship of questions attempted, but not necessarily correct, by the various divisions of the groups. The mastery tests were rescored by assigning a value of 0 (zero) for "not attempted" which means the students made no indication that they even attempted to evaluated the problem. A score of 1 was given to students who made some indication of attempting the problem. For example, students were given a point even if they only wrote down the numbers given in the problem or an equation. The mean results of this scoring scheme provided a value related to percentage of problems attempted by the students. This percentage is referred to as the response rate.

A mixed design, analysis of variance was used on the response rate for both mastery tests. The response rate of the POF group was significantly higher than the HOF group, $F(1,28) = 4.62$, $p = .040$, $MS_e = .21$, with a mean of 77 (SD = 19.2 %) percent response rate for the POF versus a mean of 60 (SD = 24.2 %) for the HOF group.

Table 7 summarized these results along the same division of groups and question categories. Table 7 illustrates that the qualitative category is the largest contributing factor to the significant difference found in the total scores. That is, significantly more students in the POF group attempted to solve the problems that required more of a qualitative reasoning approach using density $F(1,28) = 5.33$, $p = .029$, $MS_e = .34$.

A similar comparison was made for the results of the second mastery test. An analysis of variance of the response rates indicates no significant difference between the groups. In addition, a repeated measure across treatments indicates a significant increase within subjects $F(1,41) = .04$, $p = .05$, $MS_e = .826$, but not between the groups. That is, a large majority (80 percent) of the students attempted more problems on the second mastery test regardless of the order of treatments.

Table 7. Summary of Response rate for First Mastery Test

Group		Category			
		Qualitative 5 items	Quantitative 5 items	Unit conversion 4 items	Total 15 items
First Test					
Group					
HOF n=13	M	2.92	1.61	3.00	8.38
	SD	1.50	1.5	1.73	3.80
POF n=17	M	4.00*	2.71	3.41	11.1 *
	SD	1.06	1.9	1.18	3.25
Second Test					
Group					
A n=21	M	4.33	3.47	3.52	12.3
	SD	0.85	1.69	1.25	3.20
B n=22	M	4.27	4.27	3.73	13.27
	SD	0.93	1.24	0.77	2.50

Item Analysis of analogous problem to treatments

There exist several differences between the groups on certain test items. Two items on the mastery test directly target skills learned in either the hands on activity and problem oriented activity. Therefore, a separate chi squared analyses was performed for two specific questions. One targets the understanding of computing the volume of a thin plate and the other poses a problem analogous to the Golden Statuette. This analysis revealed strengths of each group for particular types of questions. On mastery test A the HOF group performed significantly better on the calculation of volume of a thin plate problem ($\chi^2 = 4.88$; $p < .027$). This was anticipated because it is directly analogous to a calculation necessary for the Density lesson. However, one would have expected the problem oriented group to increase also after the second treatment. As shown in Figure 5 the POF group did not increase in this area. A related observation needs to be reported. All of the HOF group used the caliper tool to measure various dimensions of their objects. They used these dimensions to calculate the volume. None of them used a beaker to measure the volume of any of the objects. Conversely, POF group used the virtual beaker to measure the volume of a virtual statuette in QUEST. Therefore, the majority of these students attempted to measure the volume of objects with only the beakers. This may have something to do with their performance with this test item.

Conversely, on mastery test A, the POF group performed better on an analogous problem to the Golden statuette they worked on during the treatment ($\chi^2 = 3.14$; $p < 0.076$). Figure 4 shows that the HOF scores increased after the second treatment. This analysis demonstrates that each treatment results in two different outcomes.

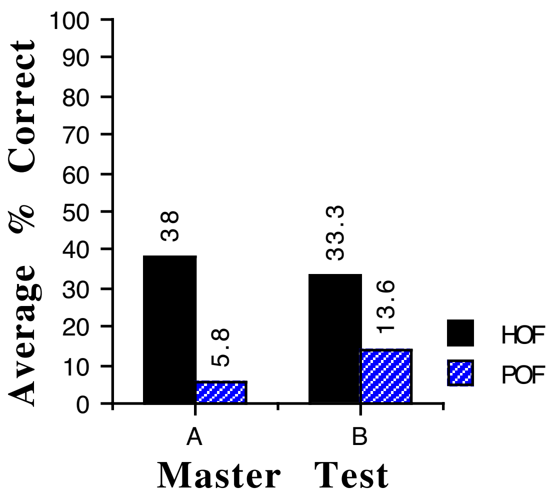

Figure 3. Volume of thin plate

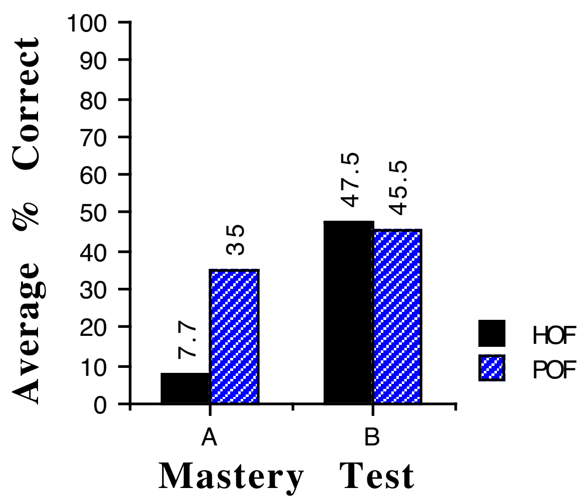

Figure 4. Analog to Golden Statuette

Self Reports

<u>Experiences That Energies (ETE)</u>

ETE data requires a different type of comparison than a standard analysis of variance can provide. The vary nature of the measure anticipates a wide variance in the data over time. In a previous study it was shown that students' interest level actually peaks (or spikes) near the moment of discovery of a possible solution to a problem and then diminishes during the resolution of the problem (Brophy, 1995). An analysis of variance would suggest collapsing the collection of ETE data into a single value and compare it across groups. Unfortunately, collapsing the data into a single point does not provide an interesting indicator of what the learner is experiencing. For example, an analysis of variance of the data for this study indicates no differences between the groups. In fact the overall means for each phase of the interventions are almost identical. Therefore, a more interesting analysis of this data uses a trend analysis of the data to reveal how students' ETE level transitions during the treatment.

The curves in Figure 5 and Figure 6 compare the ETE levels of the volume and density lessons respectively. In the volume lessons both groups start out with relatively high ETE level that diminish over time. Similarly, the lesson on density starts out with a relatively high ETE level but it too diminishes over time for the HOF group. Interestingly, the POF group starts out with a significantly higher ETE level in the density lesson that remains relatively constant and increases near the end. On the other hand, the HOF group decreases after a time.

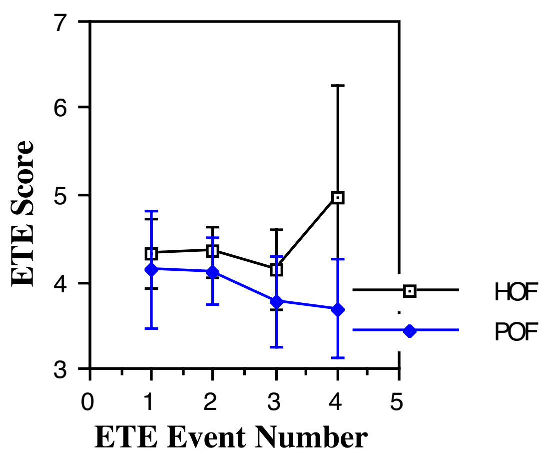

Figure 5. ETE for Volume Lesson

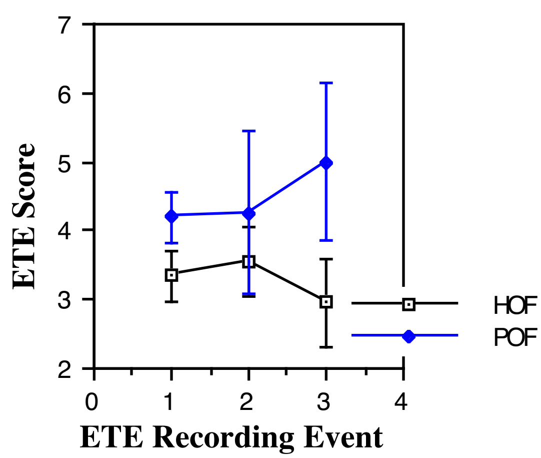

Figure 6. ETE for Density Lesson

Conversely, the problem oriented activity indicates a much different trend. Figure 5 shows students begin the computer supported problem oriented activity with a low ETE level. As the students get further into the activity their ETE level rises. The students in the POF group actually demonstrate a significant rise in their ETE levels from start to finish.

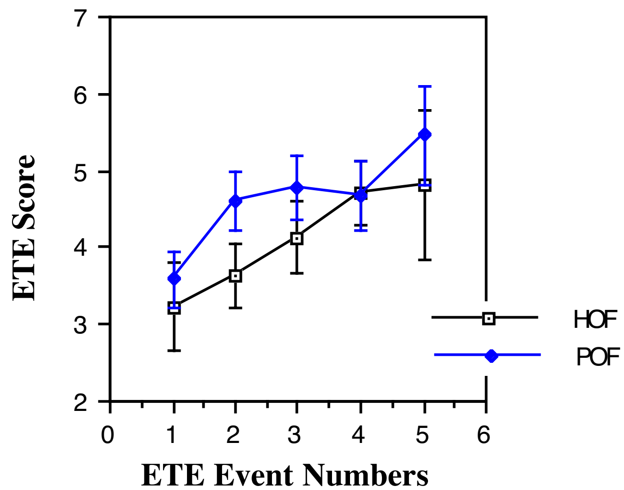

Figure 5. ETE during first day of Problem oriented activity

Attitude Survey

An attitude survey was used to capture students impression about various aspects of the treatments. These questions include such items as: students' preference to particular methods of instruction, level of difficulty of treatments, need for outside assistance, etc. The following section describes one of the more compelling results related to the use of computers and the sequencing of instruction.

Assistance during treatment. One category of questions explore students' attitudes about their ability to work without external assistance. Table 8 shows that both groups felt they needed little assistance when they were working with the computer. A chi squared analysis using Pearson's criteria indicates no difference between the groups ($p < .52$).

However, Table 9 indicates that a large portion of the HOF students felt they needed more help from the teacher when they were doing the hands on experiment. Alternatively, the POF group felt they needed very little external assistance when they were doing the hands on activity. A chi squared analysis using Pearson's criteria indicates a significant difference between the groups ($p < .00531$).

Table 8. Did you feel you needed more help from your teacher in the computer program?

Choice	HOF	POF	Row Total	
	Group			
No	12	11	23	Frequency
	75	65	69.7	Percent
Yes	4	6	10	Frequency
	25	35	30.3	Percent
Column Total	16	17	33	
	48.5	51.5	100.0	

Table 10. Did you feel you needed more help during the hands on activity?

Choice	HOF	POF	Row Total	
	Group			
No	6	14	20	Frequency
	35	82	58.8	Percent
Yes	11	3	14	Frequency
	65	18	41.2	Percent
Column Total	17	17	34	
	50.0	50.0	100.0	

DISCUSSION

The results of this study suggest that each treatment will have better success with certain learning goals, but neither is sufficient for all learning objectives. The original goal of this experiment was to compare two instructional treatments on students' learning and to compare the effects of sequential order of these treatments. The goal of comparing automatically assumes that the two treatments share a common objective of teaching students a set of concepts. One predicted outcome was that only one treatment method was sufficient to result in developing students deeper understanding of the content (facts, concepts, laws, principles and procedures). The results of the first mastery test suggest a flaw in this assumption. Each treatment has its own strengths; therefore, a combination of the two treatments may make the optimal instructional design. Further, the sequence of the two treatments may be a critical factor in students' ability to be more self regulating, as originally hypothesized. Exploring these considerations leads to several compelling implication. The following discussion reflects on the original treatments process to highlight the key components they provide toward students learning.

Hands on Activities help students notice features

The process of using real scientific instruments for measuring length and mass encouraged students to notice and differentiate units of measurements. Before any instruction many students fail to notice the units. For example, on the Skills Ability Test (SAT) almost every student failed to notice the units while calculating the volume of a thin plate. The problem presented an illustration of a thin plate with the sides measured in centimeters and the width in millimeters. In this test, students simply multiplied the length, height and width without doing a unit conversion. However, many HOF students began to differentiate the units resulting in correctly answering this test item on the first mastery test.

One probable reason for HOF students' improvement comes from the density challenge that required students to calculate the volume of a thin plate. On the first mastery test the volume question is a near transfer task for the students who started with the hands on activity. These students begin to notice the distinction of units through the process of using a caliper style ruler to measure these dimensions. In addition, the scales used for measuring mass included a vernier scale to measure to the nearest milligram. The unit scales of the instruments help students notice the precision of the scales. Also, actually measuring a single object with a sharp contrast in dimensions helped students notice this feature of collecting data. As a result students appear to consider units in their calculations of volume that they did not consider previously.

Problem solving contexts encourage qualitative thinking

Several design features of anchored instruction, and QUEST, encourage students to use a goal directed approach to solving a challenge. Expert solving a routine problem can define a plan of action and execute it using her prior knowledge. However, non routine problems make it difficult for an expert to create and execute a plan of action. The expert, like a novice, without the prior knowledge must enter into a cycle of gathering new information and redefining goals. As Kluhr, Fay and Dunbar (1993) point out this problem solving process is an inquiry process. In terms of the IDEAL problem solver model (Bransford & Stein, 1993) students will cycle through various stages of the problem solving process because they lack the prior knowledge to formulate a plan. Therefore, their plan becomes an exploration for new information that will help them obtain insight for solving the initial problem. It is the problem solving context that primes students to notice when information is relevant. For example, in the Golden Statuette the challenge is to find out how much to pay for the statuette. However, certain events of the story need to be identified before the problem solver can begin to explore the problem. Here is a discussion between two boys after viewing the video.

> S1: Ask him [the experimenter] what we're doing... I don't get it.
> S2: Please take a moment... what do you think is happening in the video [reading goal statement at top of screen]
> Ok what do you think is happening in the video.
> Um... ew... a guy is trading a golden statuette. [Starts typing into the notebook.]
> S1: Wait a second! That's gold paint.
> S2: Oh! He painted it gold.

S1: I'll write that in.
S2: Oh ho ho.
S1: It's gold... [start typing}
S2: He's trying to rip somebody off.
S1: That guitar was eighteen hundred dollars. He painted a small stone statue to be gold. [Types again] The guy is trying to trade...
S1:-S2: He painted a statue gold
S2: All right we know he painted it.
S1: He...painted... it...
{call for ETE as they break to do an ETE}
S2: We're piecing it together. [Used this for "Activity" description on ETE form.]
(From 5/10 phase 1, day 1 computer station 1).

The goal statement did not direct them to make any preconceived assumption about the task. The video did not directly show the young man spray painting the statue. Before they actually begin to gather quantitative data on the statuette, they must think about the problem first. Without outside prompting, the boys reviewed the problem which resulted in a “eureka moment” for them. This insight helped them establish the goal of finding out what type of material the statuette is rather than finding the price of a gold statuette. The boy’s experience of thinking about the challenge prior to gathering information was not unique. Many groups realized their goal was not to find a price, but to find the type of material and then the price. This qualitative understanding of the problem is the catalyst that will help them notice relevant information in the resource materials. And the structure of the computer environment guides their research (i.e. inquiry).

Another example of students development of qualitative understanding of the content appears in their test performance. The first mastery test provides some indicators that suggest problem solving activities encourage more qualitative reasoning. We must assume that qualitative reasoning helps good problem solvers notice relevant features of a problem (Chi, Feltovich & Glaser, 1981) similar to the boys discussed earlier. Experts demonstrate the ability to recognize general classes of problems as one of the first steps in determining a solution to a problem. In addition, if knowledge is active in memory, then features of a novel problem should activate, or remind, a problem solver of this knowledge (Bransford, Vye, Adams & Perfetto, 1989). Again, if an expert is having trouble noticing a general categorization of a problem, then she may utilize a heuristic approach to expose certain qualities of the problem that will help define a general category for the problem. These heuristic helps the expert notice relevant feature of the problem that ultimately lead to insight toward possible solutions to the problem. How might a novice just learning the content display a similar approach to problem solving?

A person's confidence to start a problem could provide an indication they notice key features similar to other problems they have solved. If someone is given a problem and they feel they don't know anything about it, then they will not attempt it. However, if the problem has some familiarity, then one might begin to explore possible solutions. This exploration may terminate quickly because they don't have enough knowledge; however, the issue is that they attempt to solve the problem. The assumption is that if someone thinks they know anything about the problem, then they will spend a little time attempting to solve it. Therefore, improvements in qualitative reasoning might manifest themselves through students' willingness to attempt problems where the true goal state is inferred in the problem statement.

The mastery tests contained two classes of word problems related to density. The first set, called quantitative problems, contains problems requiring simple manipulations of the density formula **D**ensity = **M**ass/**V**olume. Some problems require multiple steps to solve because volume needs to be computed from length dimensions given in the problem statement. The second class of problems related to density, called qualitative problems, do not mention density directly. Therefore, these questions require a more qualitative approach to identifying what needs to be found. They are qualitative because they require the problem solver to notice the relevant features of the problem and relate them to the density equation. The groups' response to these two classes of problems could indicate students' knowledge is more active; therefore, this knowledge can be more easily retrieved.

Students who started their instruction with a computer supported problem oriented activity could feel more confident answering questions that require more qualitative reasoning. The POF group didn't scored higher on these question than the hands on groups on the first mastery test. However, in absolute scoring no answer and a wrong answer are equivalent. Scoring attempts versus no attempts shows a striking difference between the groups. Significantly more students in the POF group attempted more problems than the HOF group. After reading the problem these students recognized something familiar about the problem. Their confidence to attempt the problem may come from their familiarity with the content and situation of the Golden Statuette. The HOF first had lessons on density, but these lessons did not provide the knowledge structure they needed to recognize they had the knowledge required to at least attempt a problem. It appears that problem solving situations may help students integrate new knowledge so they can apply it in to new situations.

Starting Instruction with Problems Can Lead To More Self Directed Learning

The computer guided problem solving activity better prepares students to explore the concepts of density before they used traditional laboratory equipment in a hands on activity. The majority of all students felt they required little help from the teacher during the computer supported problem solving activity. Very few students who started with the computer environment felt they needed more help from the teacher during the hands on activity. This supports the design principle for QUEST that attempts to provide resources for the students to explore on their own before asking the teacher for assistance. Much like the boys who were troubled about what to do, but repaired their own dilemma by rereading the instructions and reviewing the problem statement (the video). Alternatively, starting instruction immediately with the hands on activity resulted in students feeling like they could have used more help from the teacher during the activity. The reason for this difference originates from the presentation of the challenge. The problem oriented challenge encourages a top down approach to inquiry while the hands on challenge results in a much more bottom up approach. The type of inquiry process of each challenge suggests the source of variance between the groups. However, both treatments could greatly be enhanced by using the classroom environment as a resource. The sequence of activities have prepared learners to learn more and are ready to deepen their understanding with the assistance of peers, teachers and outside experts.

The need for discussion

This study attempted to focused on how well students direct their own learning toward understanding. Therefore, the level of discourse was restricted to the students working in pairs and indirect prompting by the teacher and the researcher. In this experiment, the hands on activity was presented like many older traditional experiments. The designers of this activity (Hartshorn, Phelps, & Cranford, 1994) group envisioned that the hands on activity would end with a culminating discussion to share and bring together the data the students collected. They recognized that not all of the students would make proper measurements and calculation, therefore, students would not successfully "discover" the property of density. However, through a spirited class discussion the students would prove to the teacher that density is a constant property of any given material despite its size and mass. The use of problem oriented activities provides another dimension to extend the potential of this learning activity.

The sequence of challenges helped students notice important scientific properties while employing good scientific inquiry skills. However, their learning could have been deepened through classroom discussion related to the abstract properties they discovered and its application to the problem. This sequence of activities prepared the student to learn more about the proportional relationship of density and how it can be used. For example, a small group of students met with the researcher in an informal situation. One of the students initiated a discussion about the proportionality of density and how it works. Through subtle prompting and feedback by the researcher these students began to demonstrate an understanding of the proportional relationship of density. Clearly, this type of discussion could help many other students.

Implications

The outcomes of this study have implications for classroom instruction, computer interface design and foci for future research. This paper only focuses on the implications to instruction.

The goal of integrating technology into a classroom setting should include (1) increasing the potential for learning and (2) increasing the effectiveness of the teacher's instruction. Obtaining these goals requires creating a learning environment that integrates technology to support students' generation of knowledge without increasing the instructional load of the teacher. The follow explores the implications of this study for obtaining these goals and how to evaluate the successful implementation of technology in a classroom environment.

Classroom instruction - Establishing a Context for building knowledge

The constructivist notion of understanding requires an instructional method that helps learners build their own understanding. Learners build from their prior knowledge (both informal and formal), therefore instructional methods that take advantage of learners' prior knowledge will help learners make sense of new information presented during a learning situations. That is, learners with a lot of prior knowledge can use this knowledge base to actively process new information. Those without prior knowledge require more help to make sense of new information.

Novice learners require a context in which to make sense of new information. "Making sense" implies learning when to apply this information and how. Problems provide a frame of reference in which to build new knowledge into. The problem oriented activity helped the POF group see how density can be used and when to use it. After this activity they were better prepared to apply this knowledge to novel problems in the mastery test. Their experience with the Golden Statuette and the scaffolding by QUEST made it possible for them to work with little outside help during the computer activity and the following hands on activity. The structure and content of the QUEST environment helped students establish goals and provided supports for attaining these goals. Students easily accessed information and found relevant information in the available resources. This allowed them to make conscious decision about what to measure and provided a method to obtain this information. These students interacted in the Density Challenge with a higher level of engagement that was more stable over time. This may indicate that they are getting more from the hands on activity because of their experience with the Golden Statuette problem and the computer environment QUEST.

Alternatively, many hands on activities are unidimensional. The constrained context for the HOF group made their new knowledge inert during problem solving. Students failed to realize they had the knowledge necessary to solve problems that required density. Their hands on experience only provided them with the knowledge to perform quantitative manipulations of the formula and notice important features of measurement. Unfortunately, their experience in the hands on activity did not provide them with the context to realize when to use this concept of density. The hands on activity lacked sufficient support to help sustain students' inquiry. Students who started with the hands on activity needed a lot of help figuring out how to use the laboratory equipment and the reference materials.

These observations suggest learning should start with a computer supported problem orientation activity to prepare students for future lessons. The combinations of problem complexity and computer scaffolding provides an excellent method to help students explore a domain in a meaningful way. The problem provides a reason to search for information and practice noticing relevant information. Students become excited and more engaged as they discover new relevant knowledge. The computer environment makes it more probable that students will find this information. These hands on activities provide authenticity to the task by providing real tools and in thinking like a scientist to learn more. However, these discovery activities lack the ability to help student learn when to apply this knowledge. Therefore, classroom instruction needs to provide context to help students anchor new discovered knowledge into. Problems or cases provide an excellent opportunity for students to become familiar with new knowledge and applicable situations for this knowledge. Introducing a computer agent to facilitate this instruction appears to make it easier to manage the instructional burden of scaffolding novice learners.

SUMMARY AND CONCLUSION

The combination of guided problem solving and discovery based laboratory experiments provide a strong instructional sequence for learning about volume and density and how to use them in problem solving situations. This sequence improved students' ability to sustain their own inquiry. All the students in this study showed a significant increase in their understanding of density. The two treatments appear to have similar outcomes for both groups based on their second mastery test score, their engagement level during each activity. The major difference between these groups was their report on how much help they needed from the teacher during the treatment. The students in the POF requested very little help from the teacher or the researcher. The experience with the problem oriented activity and the simulated tools better prepared them to enter the hands on activity and confidently work on the experiment with little teacher assistance.

Problem oriented activities provide a rich context that allow students to sustain their inquiry over an extended period of time. The active process of seeking information motivated students to continue their search. Also, the complexity of the problem naturally leads to a progression of interesting challenges. Students get very excited when they find one piece of the puzzle, but the problem is not complete. Therefore, they remain engaged and anxious to find the next piece of the puzzle. Hands on activities often explore isolated concepts; therefore, these experience often result in a low level of student engagement over time.

Science instruction should make problem solving an integral portion of its instruction. Demonstrations and laboratory experiments have been vital tools for engaging students in authentic practices of inquiry. However, sometimes these experiences are too abstract or too unidimensional to allow students to make the necessary connects to real situations. Therefore, students are unable to use this knowledge in their everyday lives. However, contexts like problem solving provides mechanisms to show both what the concepts are and how to use them. Further, middle school students with little prior domain knowledge can apply inquiry skills to solve complex problems, if they are given sufficient scaffolding. Computer technology has the potential to provide this scaffolding without making instruction more difficult for the teacher. In fact, computer environments like QUEST may increase the learning potential of students and decrease the instructional burden of a teacher who traditionally uses only hands on laboratory experiments.

REFERENCES

Adams, L., Kasserman, J.,Yearwood, A.,Perfetto, G.,Bransford, J. & Franks, J. (1988). The effects of fact versus problem-oriented acquisition. Memory & Congintion, 16, 167-175.

Barrows, H. S. (1986). A taxonomy of problem-based learning methods. Medical Education, 20, 481-486.

Bransford, J. D.,& Stein, B. S. (1993), The IDEAL problem solver: A guide for improving thinking (2nd ed). New York: W. H. Freeman.

Bransford, J. D., Vye, N., Adams, L., & Perfetto, G. (1989). Learning skills and the acquisition of knowledge. In A. Lesgold & R. Glaser (Eds.), Foundations for a Psychology of Education. (pp. 199-249). Hillsdale, NJ: Lawrence Erlbaum Associates.

Brophy, S. P. (1995). Computer partner in the classroom: Fostering small group problem solving. Proceedings from the Computer Support for Collaborative Learning 1995 Conference.

Brophy, S. P. (1994). Questioning environment to support thinking (QUEST): Computer mediated instruction for scientific inquiry [Computer program]. Nashville, TN: Independent project for dissertation materials, Vanderbilt University.

Carey, S., & Smith, C. (1993). On understanding the nature of scientific knowledge. Educational Psychologist, 28(3), 235-251.

Chi, M. T., Feltovich, P. J.,& Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. Cognitive Science, 5, 121-125.

Collins, A.,Brown, J. S., & Holum, A. (1991). Cognitive apprenticeship: Making thinking visible. American Educator, 15(4), 6-46.

Collins, A., & Stevens, A. I. (1982). Goals and strategies of inquiry teachers. In R. Glaser (Ed.), Advances in Instructional Psychology (Vol. 2). Hillsdale, NJ: Erlbaum

Cognition and Technology Group at Vanderbilt. (1997). The Jasper project: Lessons in curriculum, instruction, assessment, and professional development. Mahwah, NJ: Erlbaum.

Cognition and Technology Group at Vanderbilt (1992 a). Technology and the design of generative learning environments. In T. M. Duffy & D. H. Jonassen, Constructivism and the Technology of Instruction: A Conversation. New Jersey: Lawrence Erlbaum Associates.

Cognition and Technology Group at Vanderbilt (1992 b). The Jasper series as an example of anchored instruction: Theory, program description and assessment data. Educational Psychologist,27(3) 291-315.

Csikszentmihalyi, M. (1990). Flow: The psychology of optimal experience. NY: Harper & Row.

Hartshorn, R. L., Phelps, L. B., & Cranford, W. R. (1994). Physical science activities manual. University of Tennessee at Martin:Tennessee.

Kluhr, D,& Fay, A. L.,& Dunbar. K., (1993). Heuristics for scientific experimentation: A developmental study. Cognitive Psychology, 25, 111-146.

Kolodner, J. L. (1993). *Case based reasoning*. San Mateo, CA: Kaufmann.

Krajcik, J., Blumfeld, P., Marx, R., & Soloway, E. (1994). A collaborative model for helping middle school grade science teachers learn project-based instruction. The Elementary School Journal, 94(5), 483-497.

Lesh, R. A., Landau, M. & Hamilton, E. (1983). Conceptual models and applied mathematical problem-solving research. In. R. Lesh, & M. Landau (Eds.) Acquisition of Mathematical Concepts and Processes. New York: Academic Press.

Morris, C. D., & Bransford, J. D., Franks, J. J., (1977). Levels of processing versus transfer appropriate processing. Journal of Verbal Learning and Verbal Behavior, 16, 519-533.

National Research Council (1996) National Science Education Standards. National Academy Press: Washington DC.

Romey, R. (1968).

Norman, D. A. (1973). Memory, knowledge, and the answering of questions. In R. I. Solso (Ed.), Contemporary Issues in Cognitive Psychology: The Loyola Symposium. Washington, D. C,:Winston.

Schwartz, D. L. & Bransford, J. D. (1996). Experiences that energize. Manuscript in preparation. Nashville, TN: Peabody College of Vanderbilt University.

Schwartz, D. L. & Bransford, J. D. (1997). A time for telling. Manuscript in preparation. Nashville, TN: Peabody College of Vanderbilt University.

Sherwood, R. D. & Kinzer, C. K. & Hasselbring, T. S. & Bransford, J. D. (1987). Macro-contexts for learning: Initial findings and issues. Applied Cognitive Psychology, 1(2), 93-108.

Williams, S. M. (1992). Putting case-based instruction into context: Examples from legal and medical education. Journal of Learning Sciences, 2, 367-427.