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ABSTRACT

This report describes a project for improving problem solving skills in students at the secondary level. The targeted population consisted of high school students in growing communities located in the suburbs of a large Midwestern city. Various studies have indicated that students lack problem-solving skills. Analysis of student and teacher interviews show that the lack of problem solving abilities comes from the lack of student motivation, the lack of experience with problem solving, and the inability to think critically. Standardized tests should provide baseline data about the students' problem-solving skill level previous to the intervention. Review of the literature revealed that the educational system emphasizes the end result as opposed to the learning process, which may be a factor in the negative attitude students have toward problem solving. The literature review also shows several solution strategies. After considering the needs of the targeted students, the following categories of major interventions were selected: (1) cooperative learning; (2) multiple intelligences; and (3) Problem Solving Teaching (PST). Various strategies within each category were employed. Post-intervention data indicate an improvement in the problem-solving abilities of the targeted students. The post intervention student survey also shows a more positive attitude toward problem solving. (Contains 27 references.) (Author/NB)

IMPROVING THE PROBLEM SOLVING SKILLS OF MATH AND SCIENCE STUDENTS AT THE HIGH SCHOOL LEVEL

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This report describes a project for improving problem solving skills in students at the secondary level. The targeted population will consist of high school students in growing communities located in the suburbs of a large midwestern city. Various studies have indicated that students lack problem-solving skills.

Analysis of students and teacher interviews may show the lack of problem-solving abilities comes from lack of student motivation, lack of experience with problem solving, and the inability to think critically. Standardized tests should provide baseline data about the students' problem-solving skill level previous to the intervention. Review of the literature revealed that the educational system emphasizes the end result as opposed to the learning process, which may be a factor in the negative attitude that students have toward problem solving.

A review of the literature shows several solution strategies. After considering the needs of the targeted students, the following categories of major interventions were selected: cooperative learning, multiple intelligences, and Problem Solving Teaching. Various strategies within each category will be employed.

Post-intervention data may indicate an improvement in the problem-solving abilities of the targeted students. The post intervention student survey may also show a more positive attitude toward problem solving.

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CHAPTER 1

PROBLEM STATEMENT AND CONTEXT

General Statement of Problem

Students in math and science at the secondary level at the schools being researched have not developed critical thinking skills necessary to solve problems. Evidence of the existence of the problem includes teacher observations, poor performance on higher level tasks, and problem-based test scores. Samples of each will be included in the appendix.

Local Setting – Site A

Site A is one of two high schools in a unit district that has an enrollment of 1,856 students in grades 9 through 12. Based on the 1997 school report card, the teacher to pupil ratio is 20.7: 1. The attendance rate is 93.4%. The dropout rate is 17.9% and the mobility rate is 2.9%, both of these figures are higher than the district average of 11.5% and 1.9% respectively. The ethnic make-up of the school reported for the school is 84.5% white, 6.4% Asian, 5.0% Black, 3.8% Hispanic, and 0.3% Native American. Both bilingual and ESL programs are available for non-English speaking students. Low-income families make up 11.8% of the school population which is considerably higher than the district average of 7.9% (School Report Card, 1997).

The school is located at the most northern part of the community and draws students from the community as well as a portion of a neighboring town. Single family dwellings surround the school, which allows many students to walk to school. The building is air-conditioned and newly expanded due to a continual increase in enrollment. Included in the expansion is a new science wing, complete with laboratory equipment and computers, two new computer labs with 30 computers each, an entirely new gymnasium with a dance facility, training room, and a fitness center, and expanded office space for each department. The school also boasts a courtyard, allowing students to use it during passing periods and at lunch. The library is modern with common computer search engines and training programs for students to learn how to use them.

The length of the school day is seven 50-minute classes with five minute passing periods between classes. Total graduation requirements include 21 hours of academic credits. Courses are available in remedial, intermediate, honors and AP levels. Students are required to take two years of math, two years of science, four years of English, four years of physical education, two years of social sciences including U.S. government, and one course in Consumer Education. One course in health must also be completed, which counts toward a semester of physical education. Other credits available are from courses in the following departments: fine and performing arts, business and applied technology and foreign language. One study hall per semester is an option which students may use to study, receive help from one of the departmental study labs, or become a teaching assistant. Another available option for students is Quest 2000 that allows students to have internships with members of the community.

The 240 faculty and staff members include classroom teachers, administrative and departmental secretarial staff, custodial staff, a guidance and social work staff of seven, two certified nurses, a police liaison, two deans, two assistant principals and one principal. The support services for special education include six classroom teachers, three aides, two self-contained classroom teachers and three inclusion facilitators. The average teacher salary is $48,867 while the administrator average salary is $86,500. The average teacher experience is 13.9 years. The average number of teachers holding a bachelor's degree is 41.7% and 58.3% of the teachers have a master's degree or higher. The spending per pupil correlates with the district amount of $5,733. This is below the state average of $6,158 (School Report Card, 1997).

District Setting

The school district encompasses two high schools, four middle schools and 13 grade schools. The superintendent was recently removed by the board of education and placed as a classroom teacher at Site A. Previously the superintendent salary was $140,000 with a bonus of a home in the community (Local newspaper, 1994). Currently the superintendent position remains vacant. The assistant superintendent is assuming the position until a replacement is found.

The ethnic disbursement for the district is 87.1% White, 5.0% Asian, 4.0% Black, 3.8% Hispanic and 0.1% Native American. The rate of students considered low-income is 7.9%. The attendance rate is 95.9%. The dropout rate is 11.5% with a mobility rate of 1.9%. The district pupil to teacher ratio is 20.7:1. The per pupil expenditure is $5,733. The average teacher salary is $48,867 and the average administrator salary is $87,450.

The average teacher experience is 13.9 years with 58.3% of the teachers holding a master's degree or higher (School Report Card, 1997).

Community Setting

The community in which the school is located is a western suburb of a major midwestern city settled in 1839. It covers an area of 12 square miles and has a population of 54,753. The median home value is $193,263 and the average family income is $77,558. The average age of a member in the community is 35.6 with and average of 15.5 years of formal education. The community has 6.2% of its members listed as low-income, with an average household income below $15,000. The low-income households are distinctly placed in the northern section of the community, which can be seen by comparing the two high schools. The school in the southern part of the community has only 3.5% of its students from low-income households, while the northern school (Site A) has 11.8% of its students from low-income households. The ethnic breakdown of the community follows the same pattern with 91.5% White, 3.8% Asian, 2.7% Black and 2.0% Hispanic. The majority of the minority populations (85%) reside on the north side of town (Census Report, 1990).

The employment rate for the community is 70.3%, with 28.0% not in the work force, leaving 1.7% of the community listed as unemployed. Of the employed, 61% have managerial, professional or administrative positions. The remaining 39% hold positions in sales, factories, crafts, agriculture, transportation, service occupations, or as technicians. There is a large community center, library and courthouse in the town. There are 40 places of worship and 14 public childcare facilities (Census Report, 1990).

Local Setting – Site B

Site B is a medium-sized school with an enrollment of 1,744 students in grades 9 through 12. The school day is divided into eight 50-minute periods, one of which is a lunch period (for most students). There is also a five-minute passing period between each class. The average course load for students is six, although many take seven and even eight courses. Most courses are offered at three levels: basic, average and honors. This school also offers several AP courses. In addition to the core academic courses, Site B offers courses in foreign languages, computer science, business, fine and performing arts, physical education, technology, and life studies. Some Limited English Proficient (LEP) courses are available for ESL students as well. There are also opportunities to be involved in JROTC and work-study programs. A child-care center is located on campus, and is utilized by faculty and staff as well as members of the local community.

Every classroom is equipped with a computer (connected to the Internet) and a television. Teachers can access videotapes and laser disks via the Video Retrieval System housed in the Audio-Visual Department. Four computer labs are located throughout the building, two of which include Internet access for students as well as staff. A new heating, ventilation and air-conditioning system was installed in the fall of 1997. Due to increasing enrollment, two new classrooms were built in 1997, and there are plans to complete a few more in the near future. A new technology lab was also added in 1997, equipped with CAD and computer simulation software.

The student population at Site B is fairly homogeneous. The racial breakdown of the students is as follows: 84.1% White, 8.0% Asian, 5.4% Hispanic, 2.1% Black, and 0.4% Native American. The attendance rate is 94.3%, the dropout rate is 7.4%, the mobility rate is 3.1%, and the percent of low-income students is 5.5% (School Report Card, 1997). Students are required to complete 21 credits for graduation. This includes four years of English, two years of science, four years of physical education (one semester of which is health), two years of mathematics, two years of social science, one year of fine or performing arts, one course in Consumer Education, and several electives.

The total number of faculty and staff at Site B is 230. There are 115 teachers, seven guidance counselors, one certified nurse, a police counselor, a psychologist, several custodians, many educational support personnel, two deans, two assistant principals, one associate principal and one principal. The pupil/teacher ratio is 18.3:1 and the spending per pupil is $12,250, which is far above the state average of $6,158. The average teacher salary is $70,458, also above the state average of $42,429. The average of years of teaching experience is 18.8. The percentage of teachers with a bachelor's degree is 20.3% and with a master's degree or higher, 79.7% (School Report Card, 1997).

District Setting

This school is part of a district that includes six regular high schools and three alternative high schools. A new superintendent was appointed in 1997. The average administrator salary is $97,235, and the percent of low-income students is 12.2%. The racial breakdown for the district is 77.5% White, 11.0% Hispanic, 8.8% Asian, 2.4% Black, and 0.3% Native American. The attendance rate is 94.1%, the dropout rate is 13.1%, and the mobility rate is 3.1%. The academic courses offered by the district are designed to prepare a student for college level work (as opposed to vocational or personal-service courses).

Community Setting

The community immediately surrounding Site B is suburban and has a population of 41,743. It covers almost eight square miles in a northwestern suburb of a major midwestern city. Although most students at Site B do live in the surrounding community, this school does include students from two other nearby communities. The median home value is $214,798, with 83.8% of the homes being single-family units, and 16.2% multifamily units. The median age of the residents is 34.5 years, with 15.7 years of school completed. The median family income is $87,804, and the racial distribution is 93.2% White, 4.2% Other, 1.5% Hispanic, and 1.1% Black. The employment rate for this community is 78.4%, with 19.6% listed as not in the labor force, leaving 2.0% unemployed. Most of the employed hold managerial, professional or administrative support positions (59.0%). The other 41.0% are employed as technicians, sales people, factory workers, helpers, laborers, or in service, agriculture, craft, repair or transportation occupations (1990 Census Report). The community in which Site B resides boasts exceptional Park District programs for children and adults and very little crime. It includes 12 places of worship and seven child-care facilities.

National Context of the Problem

A problem educators have identified is students' lack of critical thinking skills and their inability to solve problems. In a study looking at problem solving in the average classroom, McCabe & Rhoades (1992) have suggested that many of our students are not developing the skills necessary for problem solving and decision-making. The National Assessment of Education Progress and other programs underwrites teachers' impressions that students do not think nearly as well as we would like (Perkins & Swartz, 1992).

Teachers of math and science often hear students express frustration when asked to solve problems. Barb and Quinn (1997) note that a comment often heard in their algebra classes is "I can't do word problems." Gallet (1998) noted that in studying high school science classes that students are not being taught to think, but learn a process. A chemistry teacher from Canada realized after three years of teaching organic chemistry using a standard laboratory manual, that his high school students were becoming good cooks (who could follow a "recipe"), not good scientists. It is clear that students are not born with the critical thinking skills necessary to solve complex problems. These skills must be taught along with the content.

In a study looking at teaching critical thinking, Norris (as cited in Dickinson & Flick, 1997) points out that critical thinking (and problem solving) can not occur in a vacuum; individuals are required to apply what they know about the subject matter as well as their common sense and experience. There are many factors to be considered when researching the lack of critical thinking and problem solving skills in students. Several of these factors will be addressed in the second chapter. Problem solving is a complex issue that affects every aspect of daily life. It is a necessary skill for everyone. According to Gardner (1997),

> To my mind, a human intellectual competence must entail a set of skills of problem solving – enabling the individual to resolve genuine problems or difficulties that he or she encounters and, when appropriate, to create an effective

produce – and must also entail the potential for finding or creating problems – thereby laying the groundwork for the acquisition of new knowledge (p. 60-61).

CHAPTER 2

PROBLEM DOCUMENTATION

Problem Evidence

Educators are constantly being told that students cannot think and are unable to solve problems. In a study focusing on teaching strategies used in high school science classes, Laing (1996) point out that there is a demand for teachers to teach skills and process rather than content, but it is certainly not clear how this should be done (Laing, 1996). Through teacher interviews, the researchers found agreement among several educators at the target schools that students have difficulty with problem solving. Furthermore, discussions among teachers at Sites A and B have often revolved around how lacking the students are in the area of problem solving.

Problem solving is really a concern of most educators, which is evident in the teacher interviews conducted as a part of the research. (Appendix A) One of the interview questions asked teachers what skills are necessary for problem solving. Many of the teachers could not give concrete examples of skills that students must acquire in order to become better problem solvers. A few teachers suggested strong basic skills as a need, but could not go beyond that. A major concern of the researchers at Sites A and B is that there is not a clear understanding among teachers or students of what problem solving really involves. In addition, when asked how problem solving is assessed, the results of the teacher interview were much the same. Either teachers were not sure how to assess problem-solving skills, or there was a wide variety of responses. In addition, the teachers were asked if problem solving is a teachable skill. All teachers interviewed agreed that students can be taught to become good problem solvers, but none were very sure how this could be done. It seems to the researchers that problem solving is difficult for the following reasons: it is not clearly defined, it is difficult to assess, it is not being taught in the traditional school system, and there is a negative connotation associated with problem solving.

In order to document the level of problem-solving skills of the targeted students, several preintervention tools were selected. One tool used was a student survey. (Appendix B) The following charts represent the self-assessment of the students' problem-solving skills and the importance of such skills.

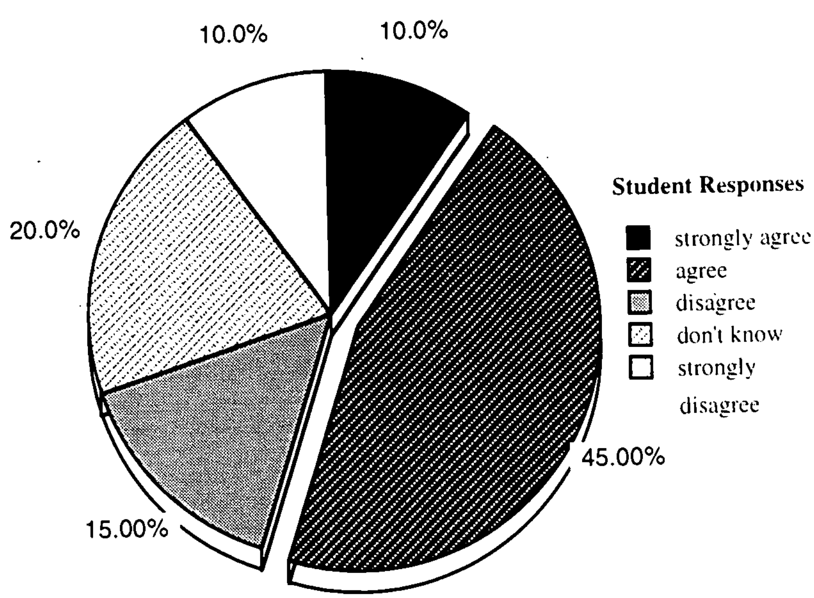

Figure 1. Distribution of preintervention responses by the targeted students at Site A to the statement "I am good at solving word problems."

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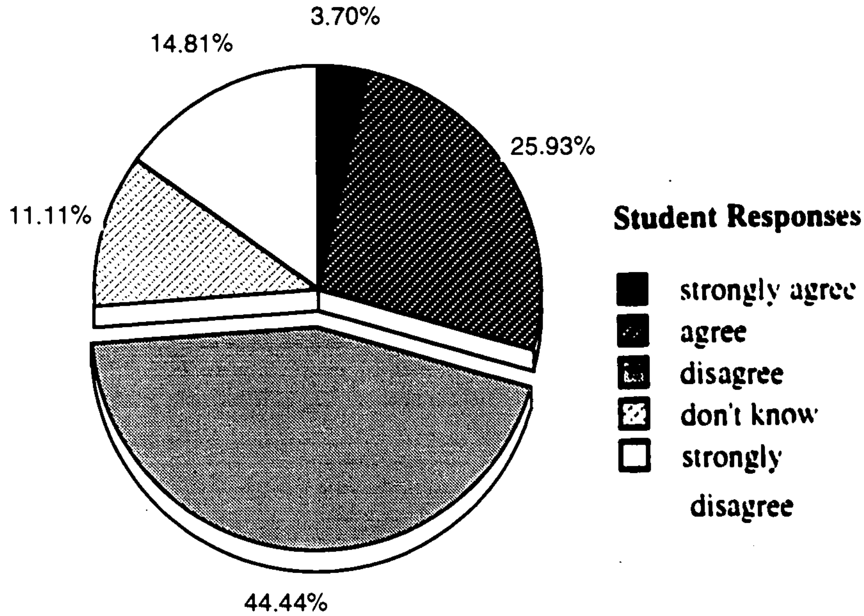

Figure 2. Distribution of preintervention responses by the targeted students at Site B to the statement "I am good at solving word problems."

The charts show that the majority of students at Site A felt that they were already competent problem solvers. At Site B however, the majority of students categorized themselves as poor problem solvers. It is interesting to note that the honors students (at Site A) have a more positive image of themselves than the students grouped in the average range at Site B.

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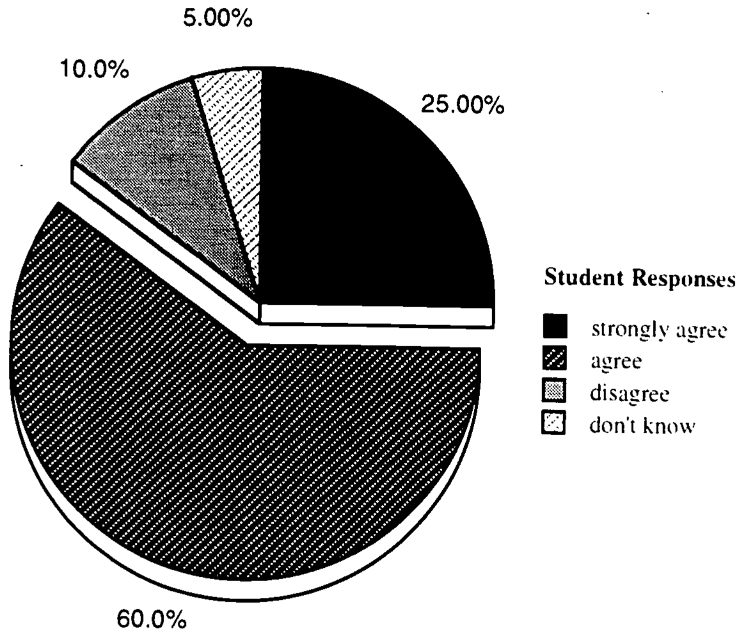

Figure 3. Distributions of preintervention responses by the targeted students at Site A to the statement "To be a successful person, I need to be a good problem solver."

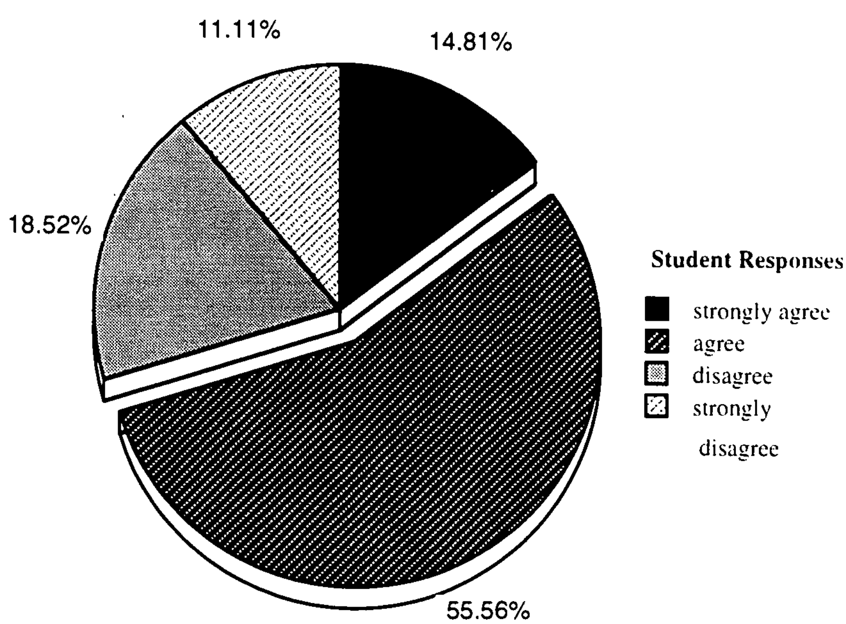

Figure 4. Distribution of preintervention responses by the targeted students at Site B to the statement "To be a successful person, I need to be a good problem solver."

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Regardless of the academic placement of the students, a majority at both sites found problem solving to be necessary for success in life. Approximately 85% percent of the students at Site A agreed to some extent that problem solving was important. Likewise, at Site B almost 70% responded in the same way.

Another tool utilized to establish baseline data was a standardized test. Each site used a different test.

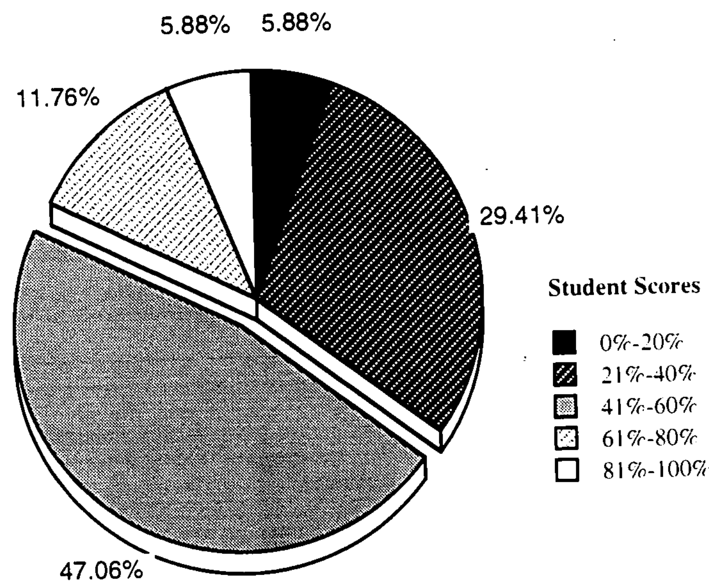

Figure 5. Distribution of scores represented as a percentage for the targeted students at Site A on the American High School Mathematics Examination pretest. (Committee on the American Mathematics Competitions Mathematical Association of America)

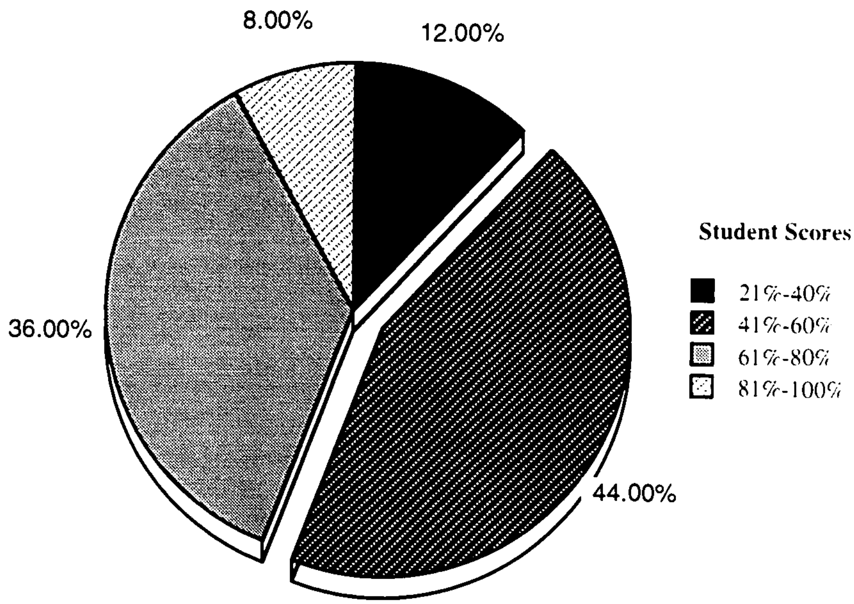

Figure 6. Distribution of scores for the targeted students at Site B on the Science Reasoning/Problem Solving pretest. (PLAN test: forms 09B, 10A, 24A, and 25A)

The researchers at Sites A and B conclude from the results of the pretest (Appendices C and D) that the majority of students, at both Sites A and B, scored between 41% and 60%, which indicates low levels of problem solving abilities. The second highest category at Site A was the 21%-40% range, while at Site B it was the 61%-80% range. The researchers attribute the discrepancy in scores to the use of different standardized tests at each site.

The students in the targeted classrooms believe that the techniques of problem solving should be taught in school. In Figures 7 and 8 whose responsibility it is may not be clear.

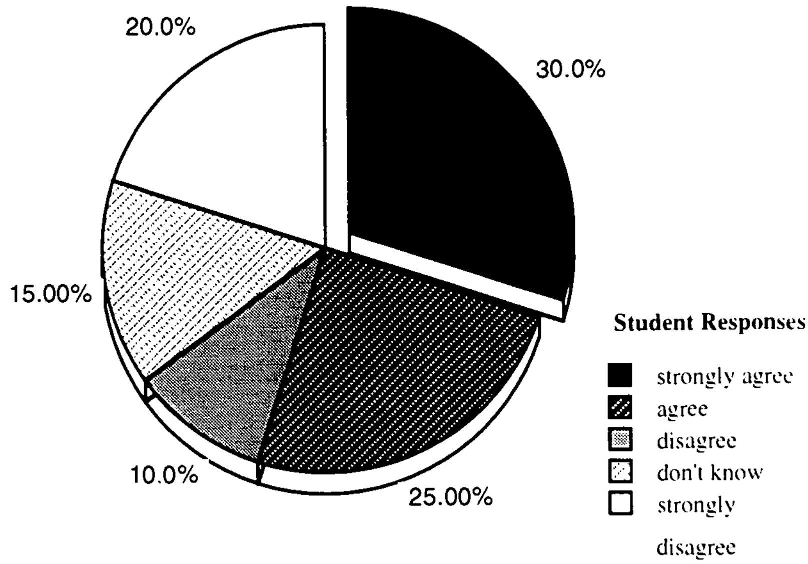

Figure 7. Distribution of preintervention responses by the targeted students at Site A to the statement "Teachers should teach students how to solve problems."

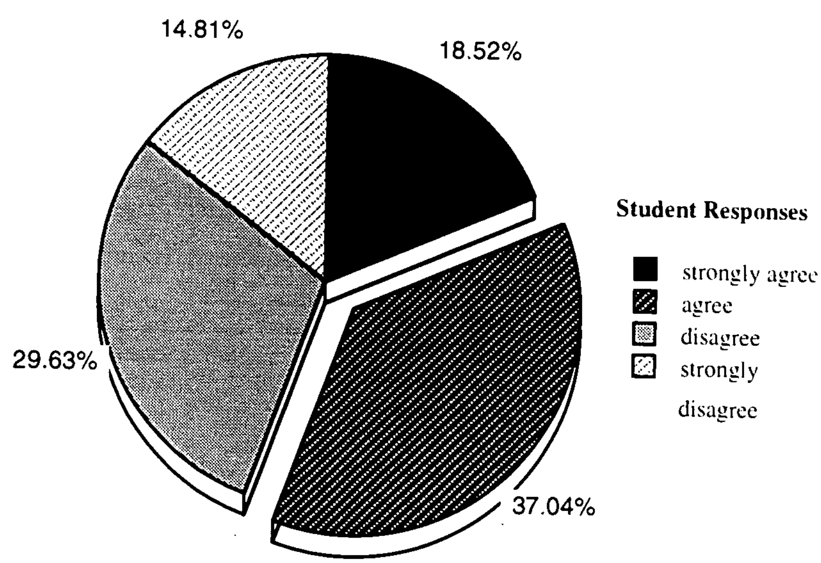

Figure 8. Distribution of preintervention responses by the targeted students at Site B to the statement "Teachers should teach students how to solve problems."

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While many students at both sites believe that it is the responsibility of the teacher to teach problem solving, some feel differently. Approximately 55% of the students at both sites feel that the responsibility needs to be placed on the teacher, while the remaining 45% do not agree, or are not sure. Again, this points out a large discrepancy in problem solving. It is not clear who should be doing what in the classroom.

In Figures 9 and 10, a summary of the students' opinions of the importance of problem solving in school is shown.

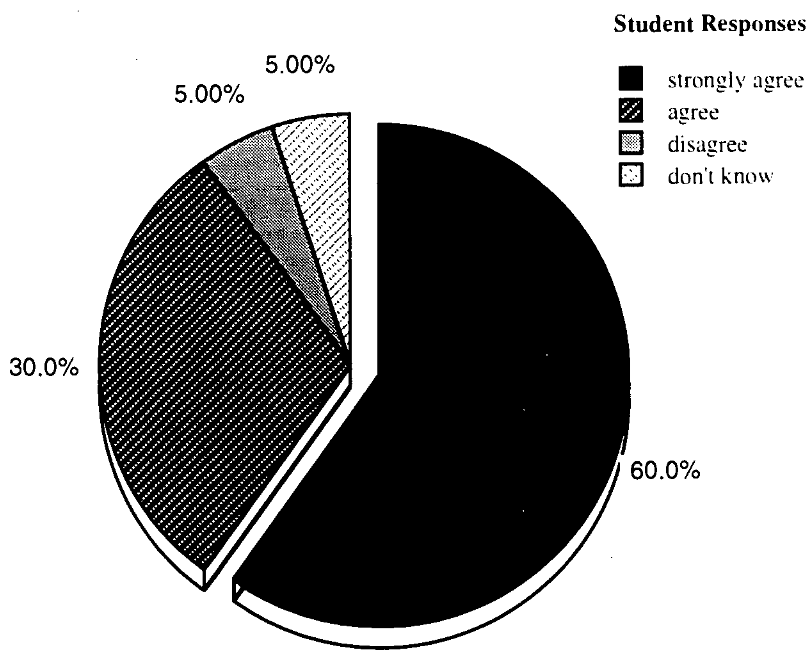

Figure 9. Distribution of preintervention responses by the targeted students at Site A to the statement "Learning how to solve problems is an important part of school."

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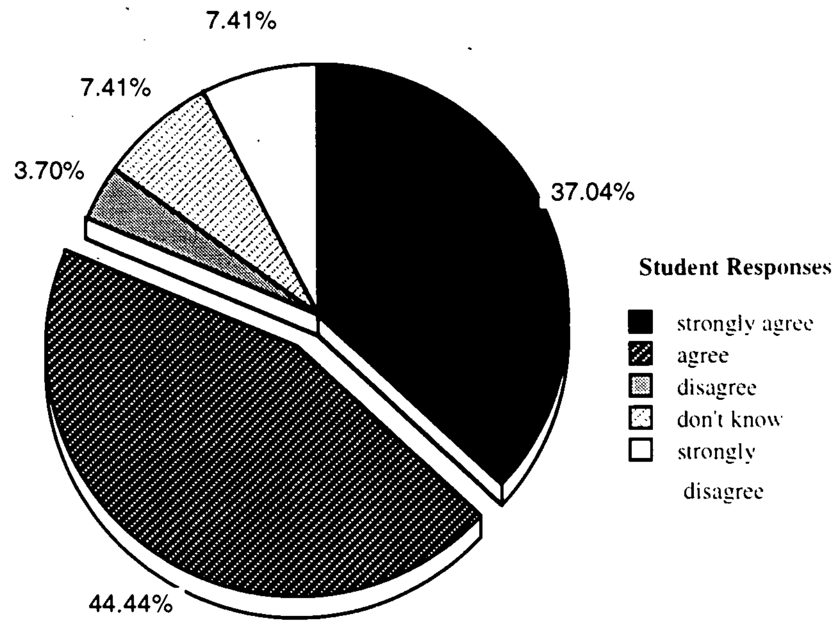

Figure 10. Distribution of preintervention responses by the targeted students at Site B to the statement "Learning how to solve problems is an important part of school."

Although some students do not agree with whose responsibility the teaching of problem solving is, between 80% and 90% of the students at both sites agree or strongly agree that it should be a part of school.

Students may also have difficulty with problem solving because of a negative attitude toward it. The students in the targeted classrooms were asked to respond to an interview question about how they feel when they are given a problem that makes them think. The interview was completed before the intervention. (Appendix E) A summary of their responses is presented in table one.

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Table 1

Types of Responses by the Targeted Students at Both Sites to the Question "How Do You Feel in Class when You are Given a Problem That Makes You Think?"

Site	Positive	Neutral	Negative
A	12	4	4
B	8	6	13

Of the 20 students at Site A, 60% responded in a positive way, 20% were neutral, and 20% had a negative attitude toward thinking through a problem. Conversely, at Site B only 30% of the students responded positively, 22% were neutral, and 48% indicated a negative response to the question. The discrepancy may be due to the difference in levels of the students at each site: Site A is an honors level class while Site B is an average level class. Honors students tend to have more self-confidence than average students do and that certainly may have an effect on how a student would respond to this particular question.

In addition to the student interview question mentioned above, four of the students survey statements addressed attitude toward problem solving and level of self-confidence. The results of that survey (administered before the intervention) are described in the pie charts that follow.

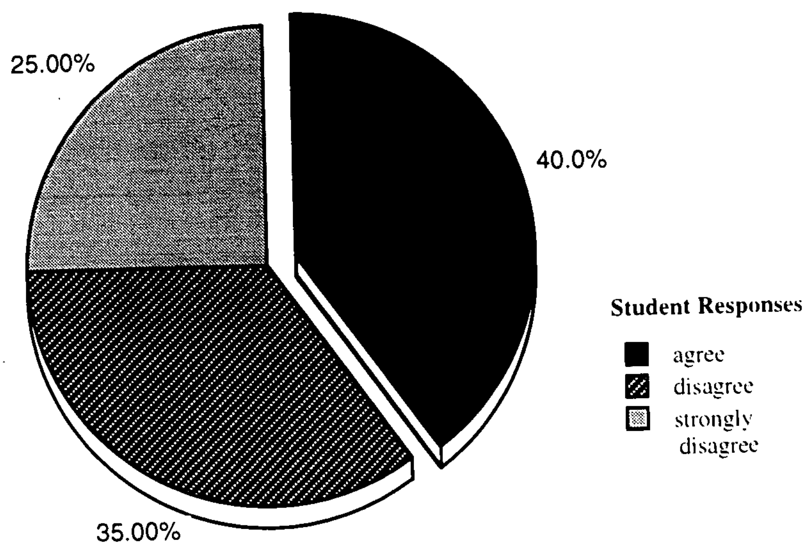

Figure 11. Responses by students at Site A before the intervention to the statement "I like to solve word problems."

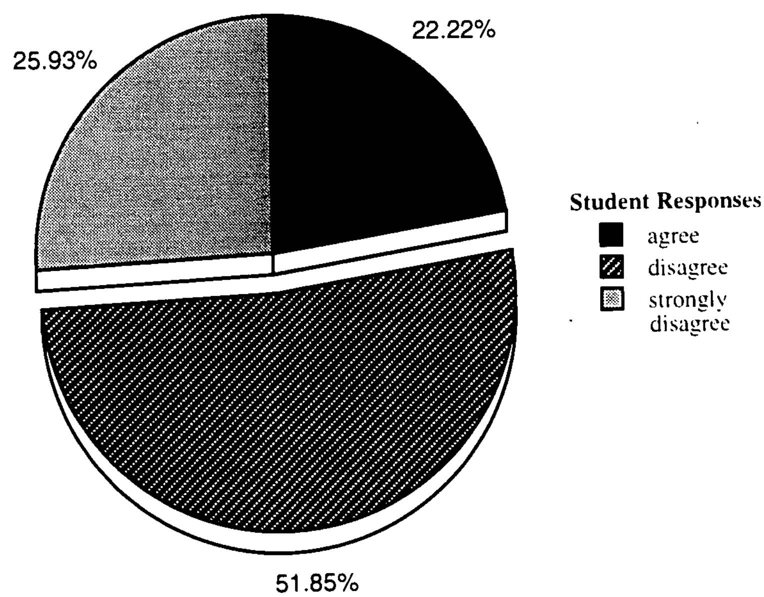

Figure 12. Responses by students at Site B before the intervention to the statement "I like to solve word problems."

According to Figure 11, the majority of the targeted students at Site A indicated that they like to solve word problems. At Site B, however, more than half of the targeted students disagreed with the statement. Once again, the researchers at Sites A and B point out that Site A represents an honors level class while Site B represents an average level class.

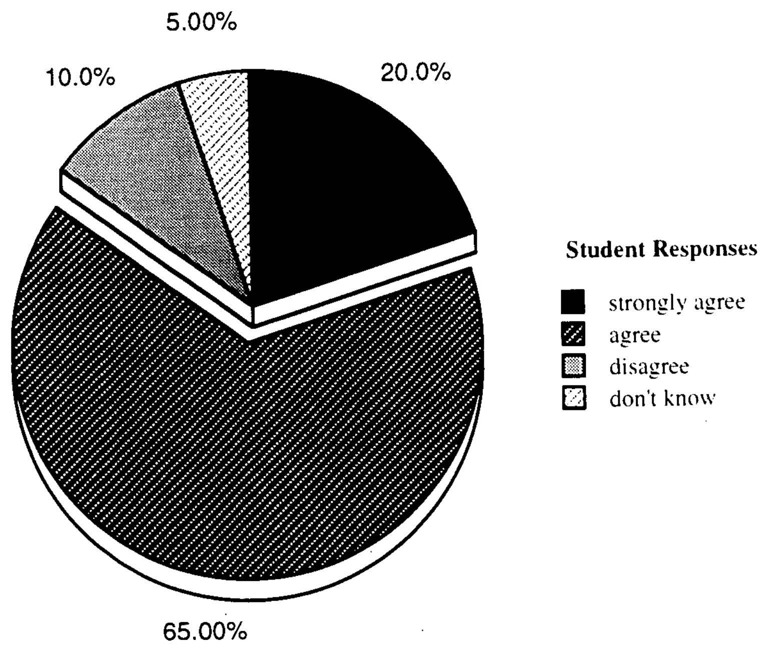

Figure 13. Responses by students at Site A to the statement "I can apply what I have learned in school to outside situations."

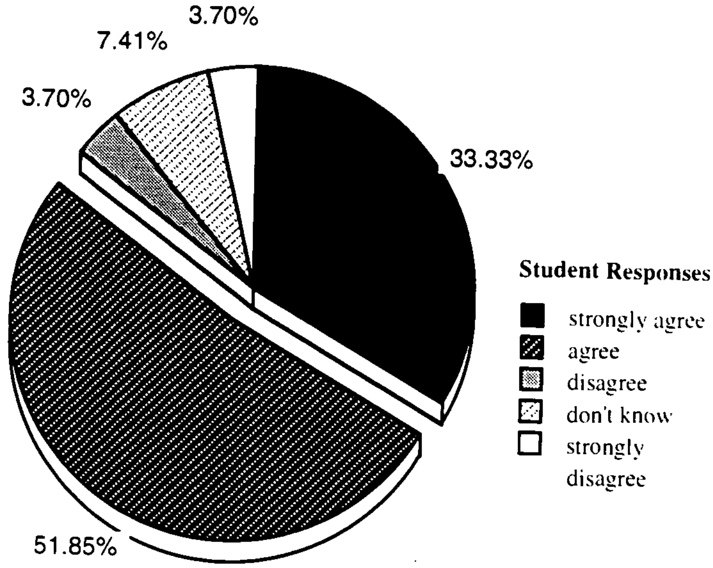

Figure 14. Responses by students at Site B before the intervention to the statement "I can apply what I have learned in school to outside situations."

The majority of the targeted students at both sites felt they could apply what they had learned in school to outside situations. Even though the targeted students at Site B had a less positive attitude toward problem solving than those at Site A, they had a similar level of self-confidence. This seems to indicate that there is not a direct relationship between attitude and self-confidence with respect to problem solving.

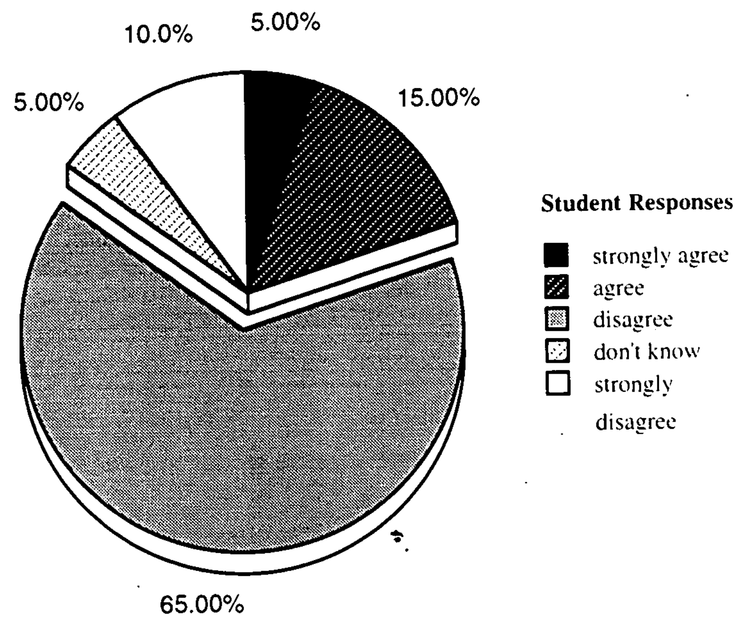

Figure 15. Responses by students at Site A before the intervention to the statement "Having the right answer is more important than the process used to get it."

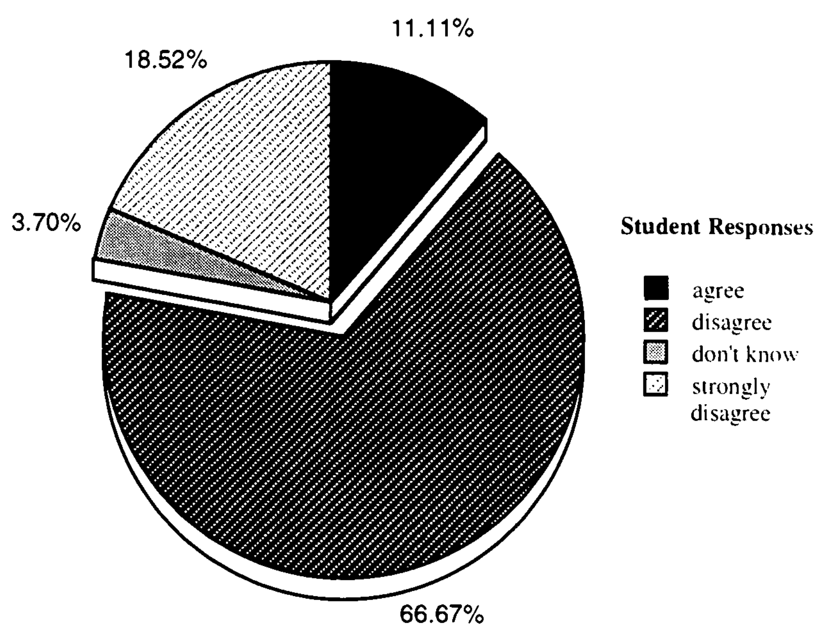

Figure 16. Responses by students at Site B before the intervention to the statement "Having the right answer is more important than the process used to get it."

At both sites, more than 60% of the targeted students disagreed with the right answer being more important than the process used to get it. This reveals that the targeted students have an underlying value of the process used to solve problems, which may allow the intervention to proceed more smoothly.

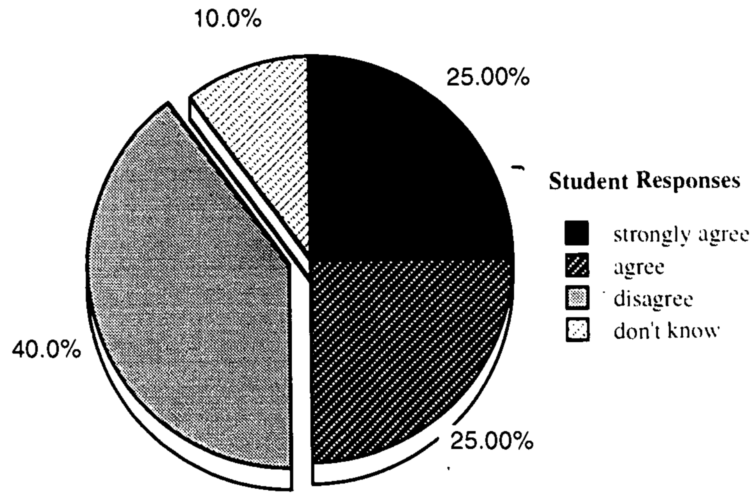

Figure 17. Responses by students at Site A before the intervention to the statement "I get frustrated when the answer to a problem does not come to me immediately."

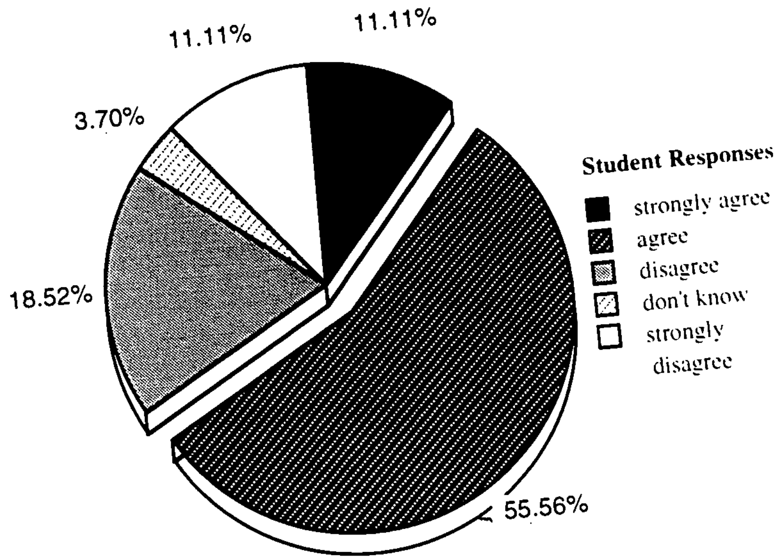

Figure 18. Responses by students at Site B before the intervention to the statement "I get frustrated when the answer to a problem does not come to me immediately."

At Site A only one quarter of the targeted students indicated that they get frustrated when the answer to a problem does not come immediately, where at Site B over one half of the targeted students indicated feeling frustration when problem solving takes time. This discrepancy may be due to different academic experiences had by honors and average level students.

Probable Causes

The past decade has seen repeated calls to place high priority on problem solving in education. Many college students do not posses the problem-solving skills necessary to transfer to the work place. Business leaders have expressed concern over the lack of problem-solving skills in prospective employees. Other researchers have shown that there is increasingly compelling evidence of serious deficiencies in the ability to reason among college students and the limited influence of college education on problem-solving skills (Nomanbhoy, 1997). The lack of problem-solving skills is not limited to postsecondary education. There is evidence that it also appears at other levels including secondary math and science classrooms. Gallet (1998) states that some students panic when given open questions that require problem-solving skills. Often the cause is a result of lack of confidence due to poor problem-solving skills. Until the problem-solving skills improve, students will continue to have little confidence, and as a result, be reluctant to even attempt any challenging problems.

In addition to little confidence, absence of problem-solving skills result in students not understanding the goal of the problem presented to them. Often when students are asked to solve a problem, they do not even know how to identify the problem (Laing, 1996). Students also have difficulty sorting out important information necessary to solve problems. According to Cawley, Frazita & Parmar (1996), students lack problem-solving skills pertaining to identifying relevant information in a problem, including the goal of the problem.

Adding to the concern of educators is that when students are asked to perform problem-solving tasks, they do not understand the problem nor do they have an idea where to begin. The students lack experience in thinking and problem solving. Their only experience often is mimicking the actions of the teacher (Barb & Quinn, 1997). Just as athletes must practice their skills to excel, one cannot be successful at solving problems without practice. Teachers need to provide students with the opportunity to practice these skills. Students need the experience of struggling with a collection of disconnected ideas and information, then they can move toward finally solving problems (Laing, 1996). Educators need to teach students to problem solve, otherwise they will not learn how to do it. Sternberg (1997) relates that if students do not have experience with problem solving, they will not develop new skills. They need to learn that the world does not always provide problems that follow a step-by-step procedure.

The only place that students will face problems where they can be certain of the procedure and the accuracy of their solution is in school. According to research by Checkley (1997), those best equipped to cope with complicated real-world issues later in life are those students who are allowed to struggle with problem solving in school. Many students are not prepared to deal with real problem situations because they have never experienced that struggle. "Students cannot be successful at solving problems if they have not practiced solving problems" (Laing, 1996, p.1007). The students need to experience the struggle with a wide variety of information and figure out how it fits together.

Several other researchers agree that only through experience will students become successful problem solvers. According to a study on problem solving by Ross (1998), intelligence is important in problem solving, but so is experience. Without experience students limit their ability to solve problems. In a study of high school science classes, Gallet (1998) shows that interpretations of scientific data is often difficult for students because they lack the experience in solving problems.

A major factor in the inability of students to solve problems is that they do not understand concepts involved or current approaches to problem solving. Many students have not been taught how to approach solving a problem. Students have difficulty selecting an appropriate process for problem solving because they had only been taught to get the right answer (Whiteford, 1998). Often teachers do not believe that students are capable of understanding the complex concepts involved in problem solving. As a result, many teachers do not give the students the opportunity to try. It is easier for the teacher to expect the students to do mostly rote work (Alper, Fendel, Fraser and Resek, 1996).

In geometry classes Ross (1998) explains that when a teacher writes a solution to a proof on the board, the students can look at it and agree that it is correct, but they do not understand the thought process behind it. Students often struggle with math and science because they do not know how to approach problems. They are unaware of approaches that teachers assume they understand. In math classes, students have difficulty not only because they did not understand the math concepts, but also they do not understand the current approaches to problem solving (Whiteford, 1998).

Also having an impact on the inability of students to perform problem-solving tasks is the traditional educational system. While students may not have the necessary experience to solve problems, the traditional educational system does not encourage problem-solving skills. Students often are assessed on their ability to memorize information and recognize patterns. Those who are able to consistently excel at these tasks are categorized as intelligent and successful problem solvers. In reality, there is very little problem solving involved (Sternberg 1997).

Many students follow a step-by-step procedure given to them by their teacher. Often this is the only strategy students are exposed to. According to Alper, Gendel, Fraser and Resek (1996), in a traditional classroom teachers give students specific procedures for a particular sample problem and then expect them to use the same procedure on future problems. The result is that students do not need to use any problem-solving skills. They are merely following a prescription. By using a single strategy to solve several problems, a teacher runs the risk of some of the students failing to understand or find no meaning in the strategy. This could lead to the student failing to attempt any strategy at all (Barb & Quinn, 1997).

Educators often do not give students the opportunity to attempt problem solving because they do not want to take the time to change their curriculum (Gardner, 1997). Many schools do not have current curriculum as related to problem solving. Teachers have not been instructed on instructional approaches or they have no desire to learn new strategies. The current curriculum may also be at fault. According to Cawley, Frazita & Parmar (1996), current curriculum and instruction do not provide students with the opportunity to practice the analytical thinking necessary to solve problems.

The traditional classroom does not develop problem-solving skills. It also does not always allow students to think for themselves. According to Gallet (1998, p.72), "The traditional teaching method I was using could allow a high school student to obtain good results, regardless of her understanding of chemistry." The traditional teaching model implies that a student can memorize information given to them and be successful. Traditional teaching creates only superficial learning, which leads to no learning at all.

CHAPTER 3

THE SOLUTION STRATEGY

Review of the Literature

Problem solving should be integrated into all areas of the curricula and be treated as an ongoing process. It is better to use fewer problems and spend more time on each with emphasis on multiple solutions. The four phases to problem solving are understanding the problem, devising a plan, carrying out the plan, and looking back. (Polya as cited in Barb & Quinn, 1997). This report describes a project for improving problem-solving skills in students at the secondary level. The targeted population consists of high school students in growing communities located in two suburbs of a large midwestern city. Various studies such as those by Barb & Quinn, Gardner, Gordon and others, have indicated that students lack problem-solving skills.

A review of the literature shows the lack of problem-solving abilities comes from the absence of student motivation, experience with problem solving, and the inability to think critically. Review of the literature also has revealed that the educational system emphasizes the end result as opposed to the learning process, which may be a factor in the negative attitude that students have toward problem solving.

A review of the literature has also revealed several solutions strategies. After considering the needs of the targeted students the following categories of major interventions were selected: cooperative learning, multiple intelligences, and Problem Solving Teaching (PST). Various strategies within each category will be employed. According to Dee Dickinson, students experience greater success when the following teaching/learning strategies are standard equipment in the educational process. They include knowledge of learning styles, multiple intelligences, and cooperative learning (Dickinson, 1992).

Cooperative learning has become an integral part of most teacher education programs due to its continued success in the classroom. Cooperative learning differs from group work in that students learn content by working in a cooperative interpersonal structure, performing assigned roles, assisting others in learning, and sharing responsibility for a group task. The success of the cooperative group relies on the roles of each member. "Working together to achieve a common goal produces higher achievement and greater productivity than does working alone" (Johnson & Johnson, 1992, p.173). Cooperative learning also allows students the opportunity to approach a problem from a variety of points of view. According to Barb & Quinn (1997):

> If students work collaboratively in sharing ideas, developing explanations, and making sense of the ideas of others, they can be convinced that problems can be solved in more than one way. Research has shown that classrooms in which discussions of multiple solutions are allowed have higher-achieving students. (p.538)

Students often experience enhanced development of their thinking skills when involved in a classroom that consistently employs cooperative learning. By using cooperative learning in the classroom students are more active in their learning, both physically and mentally (Gordon, 1998). In situations outside the classroom, students will often be asked to collaborate with others. Without prior experience in cooperative learning, students may find collaboration difficult. According to Gordon (1998), "for students to succeed with real-life problems, it helps if they have experience working in collaborative problem-solving teams" (p.393).

The research suggests numerous cooperative learning strategies as possible interventions. The researchers chose to utilize three strategies. A description of the selected strategies follows:

1. Encourage students to gather information through a jigsaw. The jigsaw is a cooperative learning strategy that distributes portions of a whole concept to each person in a group to learn and then teach to the other members of the group. According to Bray, Cotton, Miller, and Secules (1997), "This deliberate combination of specialization and sharing facilitates both depth and breadth in students' learning" (p.58).

2. Think-pair-share is another cooperative learning strategy that allows individual thinking time, discussion with a partner, and then all-class sharing. According to Lyman & McTighe (1992), "the use of think-pair-share promotes student involvement and increases verbal interaction, resulting in positive effects on attitude and achievement. The think-pair-share method combines the benefits of wait time and cooperative learning" (p.74).

3. Through the use of experiments, students can be placed in cooperative groups in order to utilize specific roles outlined in cooperative learning. The use of experiments emphasizes the cooperation of all of the members of the group in order to achieve success. "Students work very hard and consider the experiments to be fun. Students are

anxious to try out their solutions. Discussions are stimulated, arguments arise. The students' brains are at work" (Gallet, 1998, p.77).

The Theory of Multiple Intelligences was first proposed by Howard Gardner in 1983 in his book Frames of Mind. More recently, he defined intelligence as the human ability to solve problems or to make something that is valued in one or more cultures (Checkley, 1997). This seems to imply that there is a relationship between intelligence and problem solving. Gardner has also asserted that traditional education stresses only the logical-mathematical and the verbal-linguistic intelligences:

> This premise has very serious educational implications. If we treat everybody as if they are the same, we're catering to one profile of intelligence, the language-logic profile. It's great if you have that profile, but it's not great for the vast majority of human beings who do not have that particular profile of intelligence (Checkley, 1997, p.10).

The Theory of Multiple Intelligences alone is not going to improve education. Linking it with curriculum, however, could have a major impact on learning. Many educational scholars have stated that in order for students to reach their intellectual potentials, there must be an optimal match between students and material. According to Gardner, if one adopts MI theory, the options for such matches increase (1983). "MI is not a quick fix. But educators who thoughtfully use the theory to support their larger educational goals find that it is a worthy partner in creating schools of excellence." (Gardner, 1997, p.20). Therefore, utilizing what is known about the intelligences to design lessons that go beyond the logical-mathematical and the verbal-linguistic intelligences should allow all students an opportunity to improve their problem-solving skills.

An example of a math lesson that requires the use of bodily-kinesthetic intelligence is from an algebra class at Mountlake Terrace High School in Edmonds, Washington. The teacher states that when studying how to graph equations, her students head for the school's courtyard. They identify X and Y coordinates in the cement blocks that form the pavement, and then plot themselves as point on the large cement axes. The teacher maintains that when her students physically pretend to be graphs, they learn more about equations in a single class session than they do in a month of textbook study (Campbell, 1997). Students who have trouble understanding math through paper-and-pencil exercises (logical-mathematical) often grasp concepts easily when they build models or role-play math formulas (bodily-kinesthetic).

Another example of an MI lesson comes from the small town of Lakewood, Washington where middle school students learn biology concepts by solving a mock crime. They conduct investigations, gather and study evidence, and suggest hypotheses they must support. Once they solve the crime, they analyze the problem-solving approaches that led to the correct answer (Campbell, 1997). The emphasis of this lesson is clearly not on the correct answer, but on the process used to arrive at that answer. This metacognition (intrapersonal intelligence) is absolutely critical to the improvement of problem-solving abilities.

A third example of teaching that requires students to use nontraditional intelligences is from a sixth grade class at Lakes Elementary School in Lacey, Washington. Here, when students are performing tests on water samples they've obtained, even those who are not strong readers can become chemists if they have the directions read to them. In their inclusive classrooms, there may be five or six students who are struggling academically. All of their students, however, understand that they have merit even if they are not talented in the traditional school sense (Meyer, 1997). Because they use multiple intelligences to tailor their curriculum, their sixth graders are involved in a variety of learning experiences that reach them in ways they can all understand.

Problem solving is a very complex process that often requires strengths in more than one intelligence (Gardner, 1997). By exposing students to instruction emphasizing each type of ability, we enable them to capitalize on their strengths while improving their weaknesses. This approach is also important because students need to learn that the world cannot always provide them with activities that suit their strengths. At the same time, if students are never presented with activities that suit them, they will never experience a sense of success and accomplishment (Sternberg, 1997).

Another intervention is problem solving teaching (PST). In PST, students are given a problem to solve. In order to solve the problem, students must apply and gather new knowledge, investigate, make decisions, and often work with others. According to Gallet (1998, p. 73), "PST or its variations lead students to learn in depth; they are more involved in conceptual process than in memorization". In learning how to solve problems, students practice solving problems. The teacher can model a process for solving a particular problem, however there is not simply one strategy for solving problems. Emphasis should be placed on reasons rather than answers and there is also a need to encourage the acceptance of divergent perspective and free discussion

(Nomanbhoy, 1997). Through PST students are encouraged to think about and analyze the problem posed to them. They are also encouraged to organize their thoughts and findings in order to help interpret the information of the problem. Cawley and Miller (as cited in Cawley, Frazita & Parmar, 1996) state that to truly solve a problem, the individual must analyze and interpret information. Problem solving involves thinking and analysis by students, not simply looking for cue words, and problems that may involve more than one step solutions.

A major focus of problem solving teaching is to use real-world problems. These problems often are more meaningful to students. Gordon believes that students are more engaged in problems that are based on real-world situations and they will spend more time examining their work and reflecting on what they have learned (Gordon, 1998). Experiments and lab work provide students with the opportunity to practice their problem-solving skills with real-world applications. Experiments develop students' scientific initiative, creativity, and communication skills. It allows room for students' hypotheses and errors, teaches them to assume responsibility in a group, and helps them in decision making (Gallet, 1998).

The roles of the teacher and student change dramatically. The teacher is now a guide, not a lecturer, and the student is an active participant rather than a spectator. Neufeld proposes that learners should experiment with hands-on materials to discover patterns, make conjectures, and test the conjectures (Neufeld, 1996). This gives the students more opportunities to explore ideas, experiment, and reflect on their results without direct instruction from the teacher. Emphasis is placed on discussion, organization and reflection. If students fail initially, Alper, Fendel, Fraser and Resek

(1996) believe that they will return to the problem for more exploration, new conjectures, and more experimentation. The real thinking in problem solving takes place in examining an unfamiliar situation.

Problem solving teaching is an ongoing process, and does not require just one strategy. In order for PST to be successful, it is important for students to understand that problems can be solved in many different ways. Barb and Quinn (1997) point out that it is important to examine and discuss those strategies used frequently by problem solvers and to point out links between strategies. Students are also encouraged not only to learn common strategies but also to invent their own.

Through the selected interventions, post intervention data may indicate an improvement in the problem-solving abilities of the targeted students. The post intervention student survey may also show a more positive attitude toward problem solving.

Project Objectives and Processes

As a result of implementing cooperative learning, multiple intelligences theory and Problem Solving Teaching during the period of January 1999 to May 1999, the high school students will increase their ability to solve problems in mathematics and science, as measured by standardized tests.

In order to accomplish the project objective, the following processes are necessary:

1. Lessons that require problem solving in mathematics and science will be developed.

2. Direct instruction on methods of problem solving will be incorporated into the curriculum.
3. Teachers will model effective problem-solving skills.

Action Plan

I. Site A/ Honors Geometry (Grade 9)

A. Teacher will gather data utilizing interviews, a survey, and test scores.

1. Time line: January to May, 1999
2. The first interview is a teacher interview. Teachers will respond to questions pertaining to problem solving. The teachers will indicate opinions on skills necessary for successful problem-solving strategies, uses, and areas of difficulty.
3. The second interview is a student interview. Students will respond pertaining to their perception of problem solving and their attitudes toward it.
4. The survey will be completed by the students before and after the interventions. The survey addresses the problem-solving abilities of the students, their feelings about problem solving and their understanding of its purpose.
5. A standardized test will be administered pre and postintervention. The pretest will assess the problem-solving skill level of the students prior to the intervention. This will provide baseline data. The posttest will evaluate the problem-solving skill level of the students after the intervention.

B. The teacher will implement an intervention designed to improve the problem-solving abilities of the targeted students.

1. Time line: January to May, 1999
2. Cooperative learning lessons may encourage students to share ideas and collaborate on problem solving. Cooperative learning activities will be incorporated into the curriculum a minimum of one day per week.
3. The use of multiple intelligences theory may allow students to approach problems using a variety of strategies. Through the various strategies, the students may achieve success by utilizing their strengths and also developing their weaknesses.
4. Problem Solving Teaching will be implemented as a part of the intervention. This will include specific instruction on how to approach a problem, helpful steps to be taken, the concept of multiple solutions, and reflection.

C. Course Outline

1. Week 1
   a. Action Research Project explanation
   b. Student survey
   c. Student interviews
   d. Introduction to problem solving
   e. Introduction to cooperative learning
   f. Introduction to similarity
   g. Preintervention assessment

2. Week 2
   a. Development of base groups
   b. Similarity project
   c. Similarity applications
   d. Presentation of projects
   e. Similarity test
3. Week 3
   a. Introduction to right triangles
   b. Multiple solution problems
   c. Pythagorean theorem applications
4. Week 4
   a. Introduce graphic organizers
   b. Jigsaw special right triangles
   c. Process vs. results
   d. Presentation of graphic organizers
   e. Right triangles quiz
5. Week 5
   a. Right triangle trigonometry
   b. Open-ended questions
   c. Trigonometric applications
   d. Angle of elevation/depression activity
   e. Right triangle test

6. Week 6

    a. Introduction of multiple intelligences

    b. Discovery of equations of circles

    c. Jigsaw related circle terms

    d. Base group challenge problem

    e. Presentation of multiple solutions

7. Week 7

    a. Introduction of portfolio

    b. Begin individual circle portfolio

    c. Related angles

    d. Circle applications

    e. Circle quiz

8. Week 8

    a. Brainstorm angle/arc relationships

    b. Students develop webs

    c. Group evaluations

    d. Individual reflections

    e. Creating models

    f. Presentation of models and webs

9. Week 9

    a. Completion of circle portfolio

    b. Modeling problem solving

    c. Open-ended applications

d. Student created problems

e. Circle test

10. Week 10

a. Formulas for areas of triangles and rectangles

b. Discovery of methods to finding areas of irregular shapes

c. Group discussion

d. Derivation of formulas for other common shapes

e. Multiple solution problems

11. Week 11

a. Computer discovery activity – trapezoids

b. Construction activity

c. Flowerbed activity

d. Area quiz

12. Week 12

a. Regular and similar polygons

b. Derivation of regular polygon area formulas

c. Applications of formulas

d. Group challenge problem

e. Introduction to segments and sectors of circles

13. Week 13

a. Student created problems – shaded regions

b. Presentations of group problems – troubleshooting

c. Balloon problem

d. Group evaluation

e. Individual reflection

f. Area test

14. Week 14

a. Introduction to volume

b. Prism discussion

c. Relating two dimensions to three dimensions

d. Unfolding the box activity

e. Lateral area

15. Week 15

a. Cylinders and pyramid jigsaw

b. Group activity – three shapes with the same volume

c. Trip to Mars activity

d. Gasoline problem/application and discussion

e. Volume quiz

16. Week 16

a. Discovering the relationship between cones and other shapes

b. Creating a model – two intersecting spheres

c. Student reflection

d. Volume test

e. Student survey

f. Post-intervention assessment

II. Site B/ General Chemistry (Grades 10-12)

A. Teacher will gather data utilizing interviews, a survey, and test scores.

1. Time line: January to May, 1999
2. The first interview is a teacher interview. Teachers will respond to questions pertaining to problem solving. The teachers will indicate opinions on skills necessary for successful problem-solving strategies, uses, and areas of difficulty.
3. The second interview is a student interview. Students will respond to pertaining to their perception of problem solving and their attitudes toward it.
4. The survey will be completed by the students before and after the interventions. The survey addresses the problem-solving abilities of the students, their feelings about problem solving and their understanding of its purpose.
5. An adapted version of a standardized test will be administered pre and postintervention. The pretest will assess the problem-solving skill level of the students prior to the intervention. This will provide baseline data. The posttest will evaluate the problem-solving skill level of the students after the intervention.

B. The teacher will implement an intervention designed to improve the problem-solving abilities of the targeted students.

1. Time line: January to May, 1999

2. Cooperative learning lessons may encourage students to share ideas and collaborate on problem solving. Cooperative learning activities will be incorporated into the curriculum a minimum of one day per week.
3. The use of multiple intelligences theory may allow students to approach problems using a variety of strategies. Through the various strategies, the students may achieve success by utilizing their strengths and also developing their weaknesses.
4. Problem Solving Teaching will be implemented as a part of the intervention. This will include specific instruction on how to approach a problem, helpful steps to be taken, the concept of multiple solutions, and reflection.

C. Course Outline

1. Week 1
   a. Review of Course Expectations
   b. Introduction to Nuclear Chemistry Unit
   c. Student survey
   d. Student interview
   e. Preintervention Assessment
   f. Introduction to Cooperative Learning
   g. Mystery Containers Lab
2. Week 2
   a. Radioisotopes and Half-life
   b. Isotopic Pennies Lab

3. Week 3

   a. Half-life Lab

   b. Introduction to Nuclear Chemistry Project

   c. Spontaneous Reactions Lab

   d. Quiz over Sections A &B

4. Week 4

   a. Library Research for Project

5. Week 5

   a. Exhibition of Projects

   b. Unit Test

6. Week 6

   a. Introduction to the Chemistry of Air Unit

   b. Demonstration of Properties of Air

   c. Gas Production Lab

7. Week 7

   a. Introduction to Problem Solving Teaching

   b. Combined Gas Law Problems

8. Week 8

   a. Ideal Gas Law Problems

   b. Quiz over Sections A & B

   c. Pressure-Volume Calculator-Based Lab

9. Week 9
   a. Analysis of Atmospheric Data
   b. Acid Rain Lab
10. Week 10
    a. Concept of pH
11. Week 11
    a. Unit Test
    b. Introduction to Health/Risks Unit
    c. Introduction to Theory of Multiple Intelligences
    d. Analysis of Self-Test Data
    e. Buffers Lab
12. Week 12
    a. Neutralization Reactions
    b. Titration Lab
    c. Quiz over Sections A-C
13. Week 13
    a. Personal Health Choices
    b. Sunscreens Lab
14. Week 14
    a. District Performance Assessment
    b. Cigarette Demo/Lab

15. Week 15

    a. Introduction to Chemical Industry Unit

    b. Oxidation/Reduction Reactions

16. Week 16

    a. Fertilizer Lab

    b. Explosive Reactions

    c. Student Survey

    d. Post-intervention Assessment

Methods of Assessment

In order to assess the effects of intervention, standardized tests focusing on problem-solving skills will be used. In addition, samples of student work will be collected throughout the intervention. Interviews with students and teachers, as well as student surveys will be considered as part of the assessment process.

CHAPTER 4

PROJECT RESULTS

Historical Description of the Intervention

The objective of this project was to increase problem-solving skills in students. Cooperative learning, Multiple Intelligences Theory, and Problem Solving Teaching strategies were implemented to obtain the desired results.

Site A

Cooperative learning was implemented in order to build confidence in the students as well as provide the students an opportunity to observe the way others think and solve problems. The students were given direct instruction on what cooperative learning is and its purpose as used in our class. The base groups were formed the second week of the semester and used two to three times each week throughout the intervention. Each group worked on a similarity project and presented their results to the class. A sample project can be found in Appendix F. The students were also given problems with multiple solutions in order to facilitate discussions within the group and allow the students to see other methods for solving the problems. A sample problem can be seen in Appendix G. The students were also taught how to use the jigsaw method of instruction where each student in the group was an expert on a specific topic and then returned to the group to share the information with the other members. The students then were able to observe alternative learning styles. Cooperative learning was used throughout the semester by integrating it into the other intervention strategies.

After the base groups were established and had several weeks to work together, multiple intelligences theory was introduced. The students were first instructed on what multiple intelligences theory includes and were given examples of each intelligence as related to our class. Several tasks that the students performed were completed within their base groups. Students used jigsawing and brainstorming techniques within their groups and created webs and other graphic organizers which samples of are included in Appendix H. Students were also given the opportunity to experience other intelligences by conducting experiments and reflecting upon the results. Samples of both activities are included in Appendices I and J. Multiple intelligences theory was the focus of most lessons for approximately six weeks. At the end of the six weeks, each student created a portfolio including reflections. A partial sample of the requirements of the students is included in Appendix K. After the six weeks of concentrated multiple intelligences theory, the multiple intelligences tasks were not abandoned, but became more integrated into other activities involving the final intervention.

The final intervention implemented was the Problem Solving Teaching strategy. The teacher as well as the class through brainstorming activities identified problem-solving skills. The main aspects of problem solving included: understand the problem, form a plan, carry out the plan, and reflect upon the solution. The students participated in discovery activities, group discussions, and challenge problems. A sample of a challenge problem is included in Appendix L. Upon completion of several challenge problems, the students discussed methods of solving problems as well as any troubleshooting issues that arose. Also included in the class discussions was the importance of process rather than just results. The focus on Problem Solving Teaching occurred over a six-week period. During the fourth week the students created their own problems for other students to solve. A sample problem is included in Appendix M. After several problem-solving activities, the students were given the "Trip to Mars" activity. The problem-solving activity was solved within the base groups and lasted one week. The problem is found in Appendix N.

During the final week of the intervention the students conducted a series of experiments. As a culminating activity, the experiments implemented cooperative learning, multiple intelligences, and problem solving. The students also completed reflections after the experiment. A sample of the experiment and the reflections can be found in Appendices O and P.

Site B

The first strategy implemented after the collection of baseline data was cooperative learning. Base groups were formed and specific roles were brainstormed and defined. The students agreed to switch roles each week. It took a couple of weeks for the students to get used to the roles and to be able to remain in them during cooperative activities. The teacher had to consistently monitor the students, giving subtle reminders, during this time.

Cooperative activities were utilized approximately two times per week for the first six weeks. The purpose of the cooperative activities was to create a classroom environment in which the students felt comfortable working with others. The intent was to build a framework which allowed the students to seek help from each other (not just the teacher) so that if they struggled with the problems later on, they would have a support system already established. All of the labs, as the Nuclear Chemistry Research Project, were designed to be completed cooperatively. A sample lab can be found in Appendix Q and a description of the Project is in Appendix R. Also during the first six weeks of the intervention, students were taught how to use the jigsaw method of instruction (as at Site A). Much of the content was delivered in this way, allowing students to get accustomed to learning from and teaching their peers.

At the start of the seventh week, Problem Solving Teaching was implemented. Since the topic of the gas laws was coming up next, it seemed appropriate to teach the students some specific strategies for solving these kinds of problems. In their base groups, the students discussed how they approached problem solving, and the difficulties and frustrations they often experienced. Then, as a class, we decided on a plan for solving problems: understand what the question is asking, identify given information, devise a plan, carry out the plan, and reflect upon the solution. Most of the problems to which the students applied the strategy were gas law problems. However, some of the problems also involved graph analysis and graph interpretation. Sample problems are located in Appendix S.

The last strategy to be implemented was the theory of multiple intelligences. Most of the students had already heard of the theory, but were not sure how each of the intelligences would apply to chemistry. During week eleven we started the Chemistry of Health Unit. This unit was designed as a Multiple Intelligences unit so the teacher gave each student a concept map outlining the unit and illustrating how each intelligence could be utilized throughout the unit. The concept map is located in Appendix T. Students were given some choices regarding lessons, but most of the lessons were required. This forced students to try out all of the intelligences, not just the ones with which they were comfortable. Because the entire unit was designed around Multiple Intelligences Theory, the strategy was integrated into the last eight weeks of the intervention. Cooperative learning and PST continued to be integrated as well during many of the individual lessons; labs and role-plays for cooperative learning, and conversion problems for PST.

Presentation and Analysis of Results

In order to assess the success of the intervention strategies, cooperative learning, multiple intelligences and Problem Solving Teaching, a post survey was given to the students. The post survey targeted attitudinal changes as well as changes in confidence levels as related to problem solving. Figures 19 and 20 are in response to the changes in confidence levels according to the students.

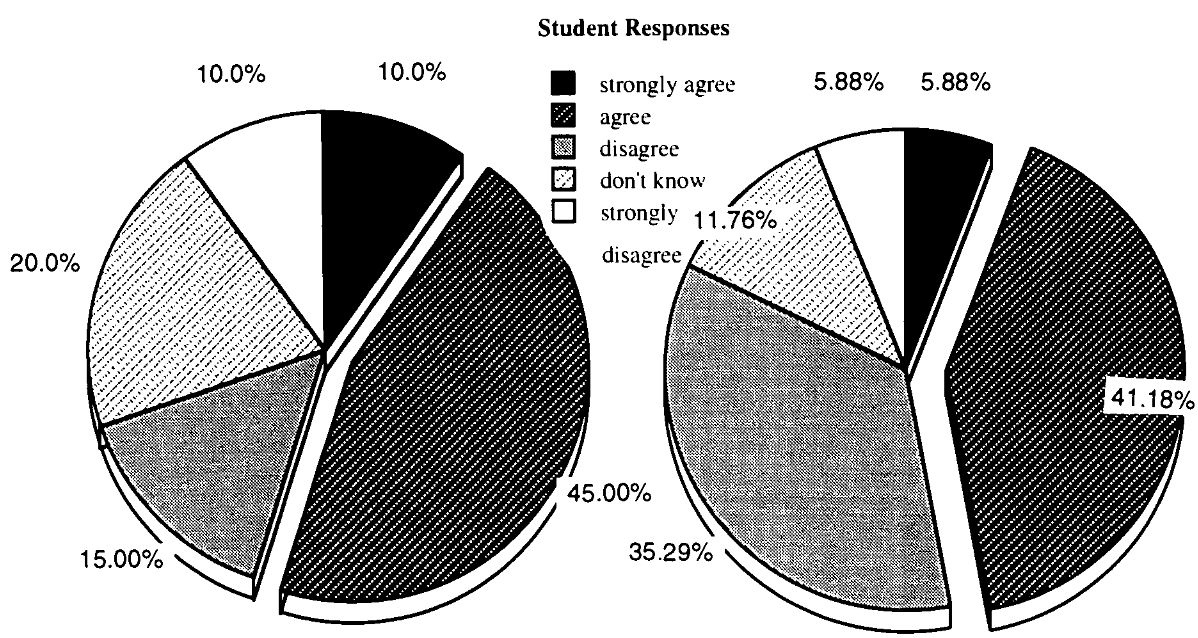

Figure 19. Distribution of pre and postintervention responses by the targeted students at Site A to the statement "I am good at solving word problems."

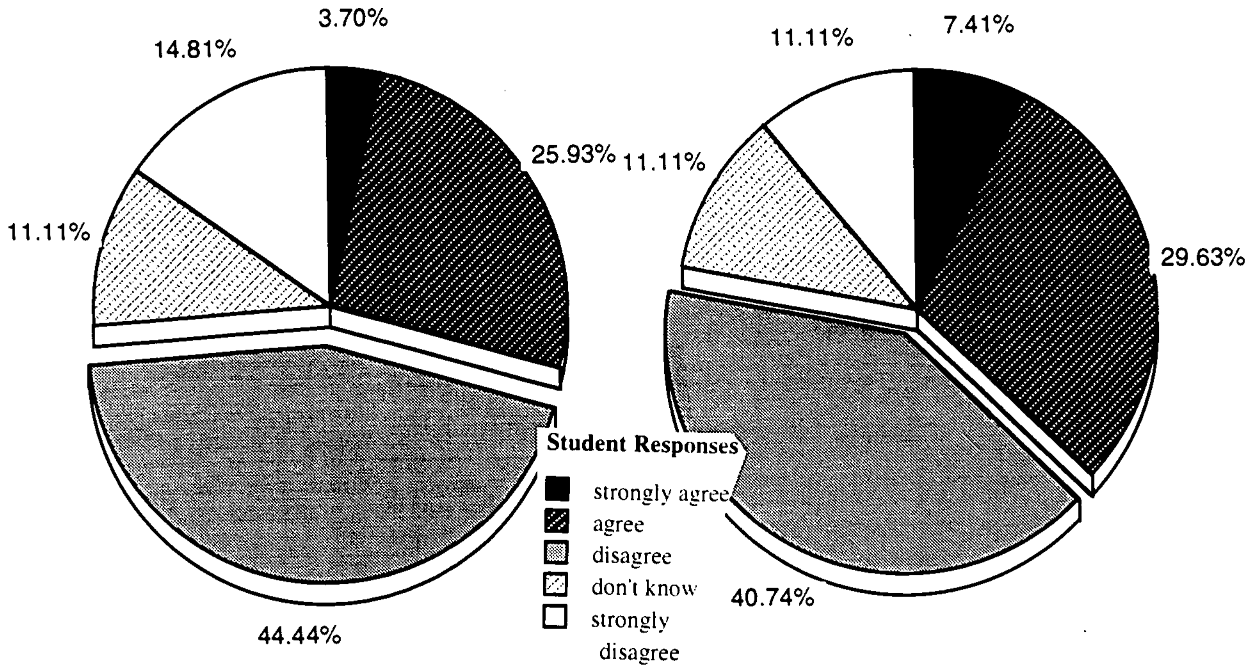

Figure 20. Distribution of pre and postintervention responses by the targeted students at Site B to the statement "I am good at solving word problems."

At Site A, the number of students who disagreed with the statement in the post survey increased by approximately 20% from the original response. This would indicate that the intervention strategies were not successful in raising the confidence level of the targeted students. At Site B however, there was a slight increase in the students who agreed and strongly agreed with the statement. It is unclear to the researchers whether the slight increase in confidence levels of the students at Site B was due to the intervention strategies or a result of other factors such as maturity of the students or experience.

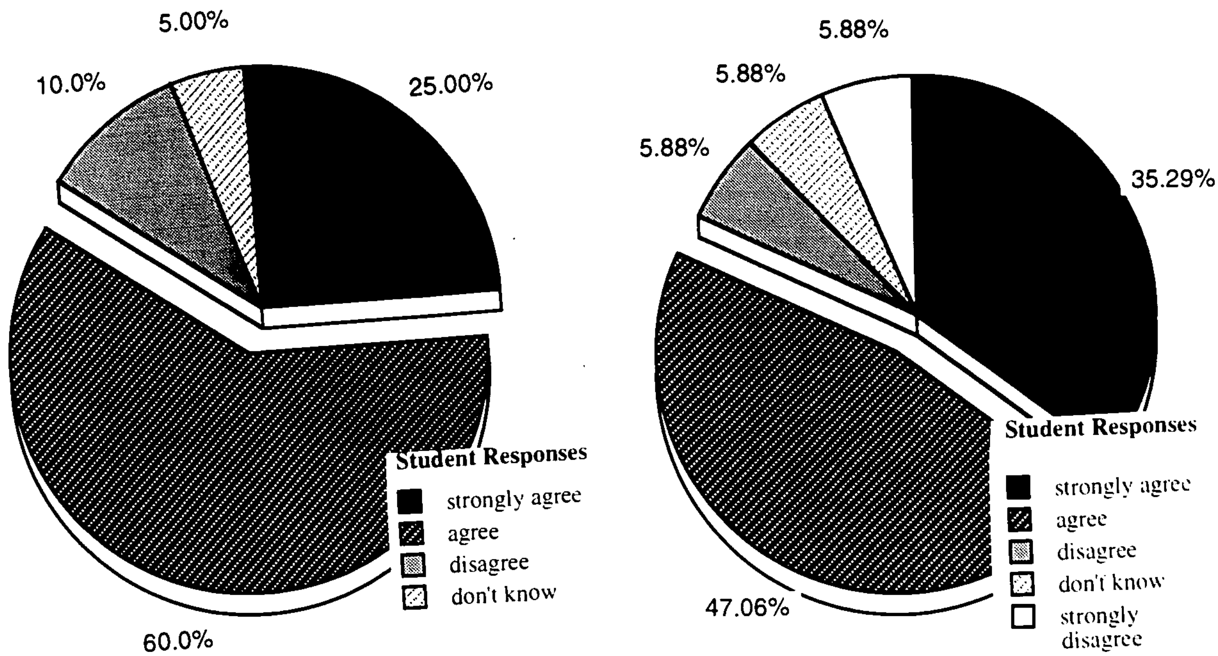

Figure 21. Distributions of pre and postintervention responses by the targeted students at Site A to the statement "To be a successful person, I need to be a good problem solver."

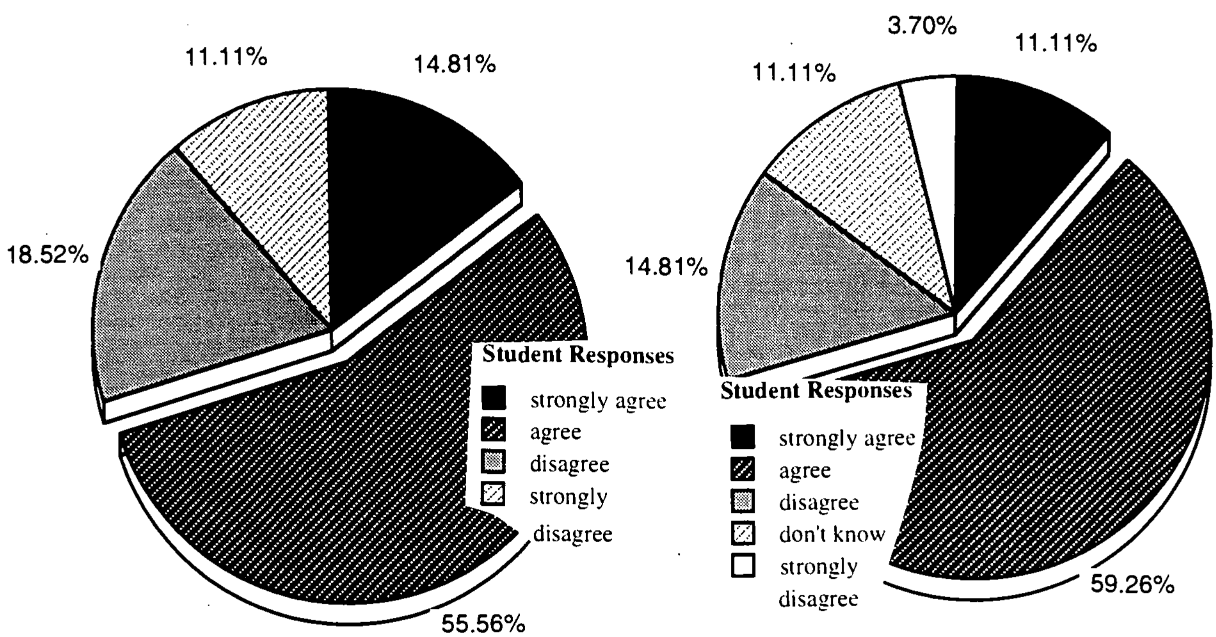

Figure 22. Distributions of pre and postintervention responses by the targeted students at Site B to the statement "To be a successful person, I need to be a good problem solver."

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At Site A, the overall response to agree and disagree remained the same as in the original survey. The number of students responding to strongly agree increased by 10% while agree decreased by approximately 13%. This would indicate that the beliefs of the students who value problem solving became stronger as a result of the intervention strategies. At Site B, the change in student response was minimal. The researchers conclude that the intervention had no significant impact on the students' beliefs that problem solving is important.

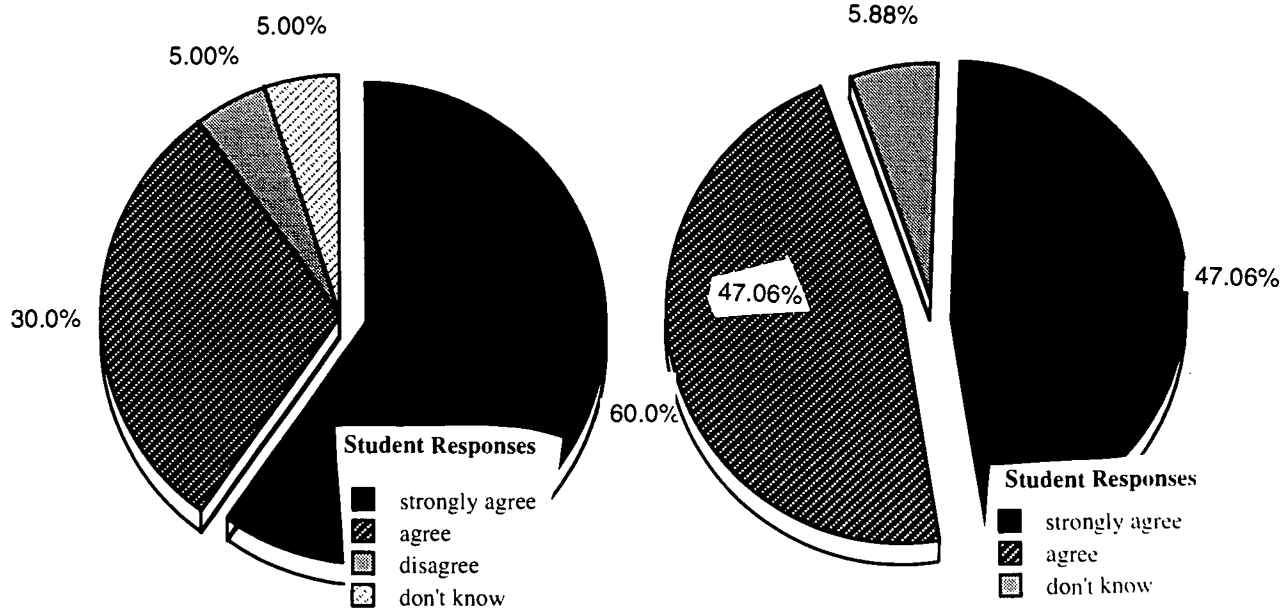

Figure 23. Distribution of pre and postintervention responses by the targeted students at Site A to the statement "Learning how to solve problems is an important part of school."

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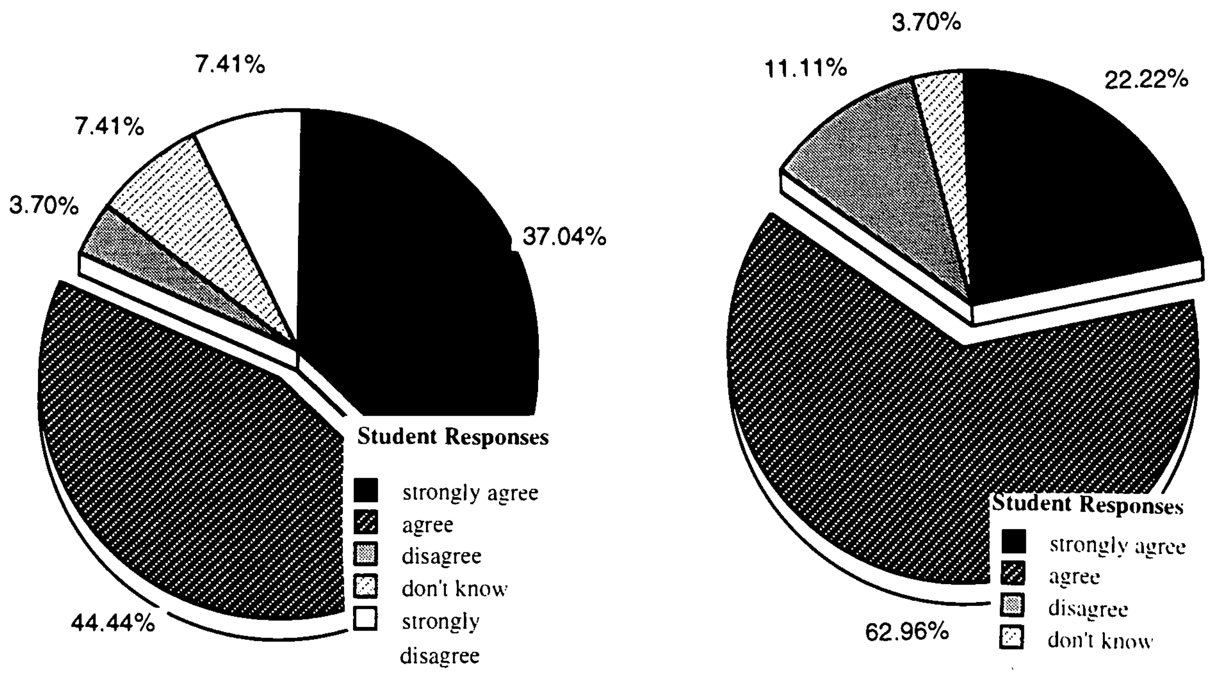
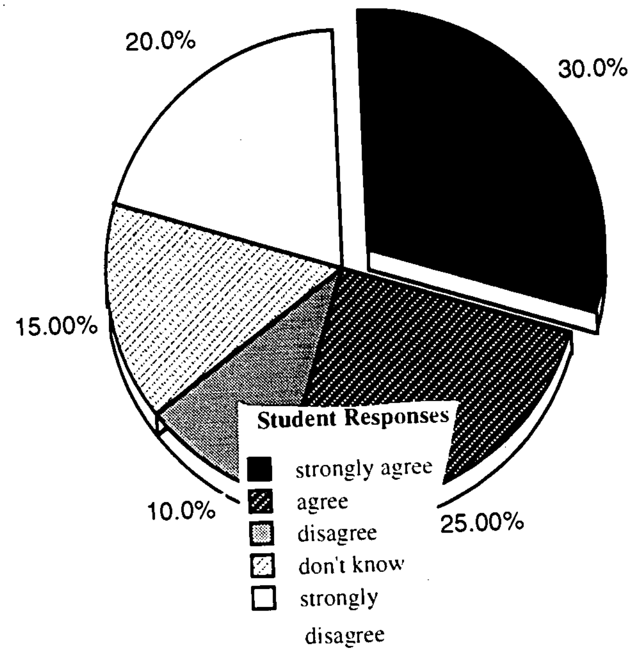


Figure 24. Distribution of pre and postintervention responses by the targeted students at Site B to the statement "Learning how to solve problems is an important part of school."

At Site A, 5% of the responses from students changed from disagree to agree or strongly agree, resulting in none of the students disagreeing with the statement from the postsurvey. The researchers believe that this is a result of exposure to a variety of problems and methods with which to solve problems throughout the intervention. At Site B, 81% of the targeted students agreed or strongly agreed that problem solving is an important part of school in the original survey. When responding to the postsurvey, 85% of the students agreed or strongly agreed with the statement. This suggests that the intervention had a positive impact on a few students.



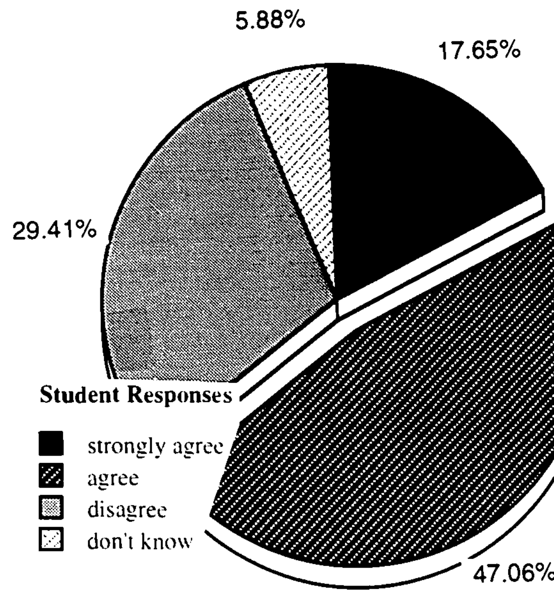
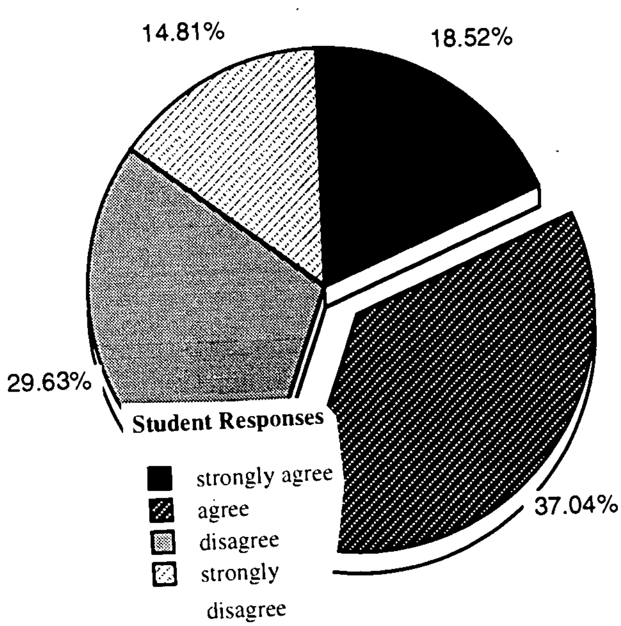


Figure 25. Distribution of pre and postintervention responses by the targeted students at Site A to the statement "Teachers should teach students how to solve problems."



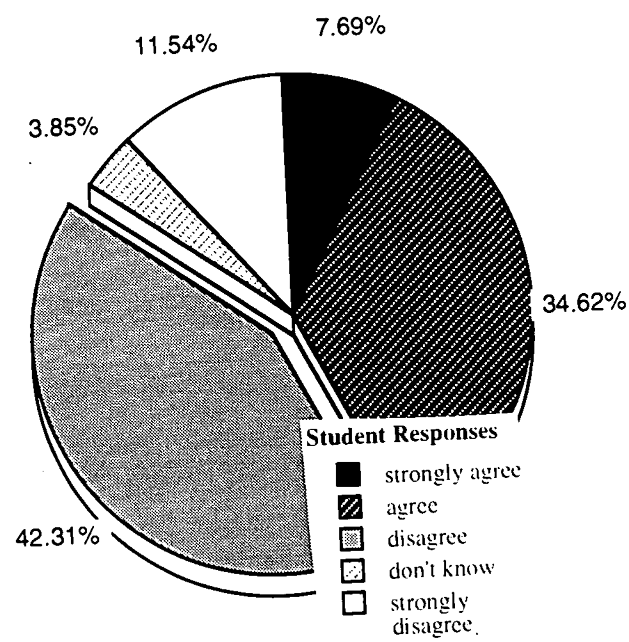


Figure 26. Distribution of pre and postintervention responses by the targeted students at Site B to the statement "Teachers should teach students how to solve problems."

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At Site A approximately 50% of students on both surveys agreed or strongly agreed that it is the responsibility of the teacher to teach students to problem solve. The researchers believe that the intervention did not affect the beliefs of the students with the exception of those who were undecided in the presurvey. The students who responded "don't know" decreased by approximately 10%. At Site B, the students who agreed or strongly agreed with the statement decreased from the pre to postsurvey by approximately 13%. The results may be an indication of the reluctance of students to solve problems. It does not appear that the intervention strategies were successful in changing the attitudes of the students toward problem solving.

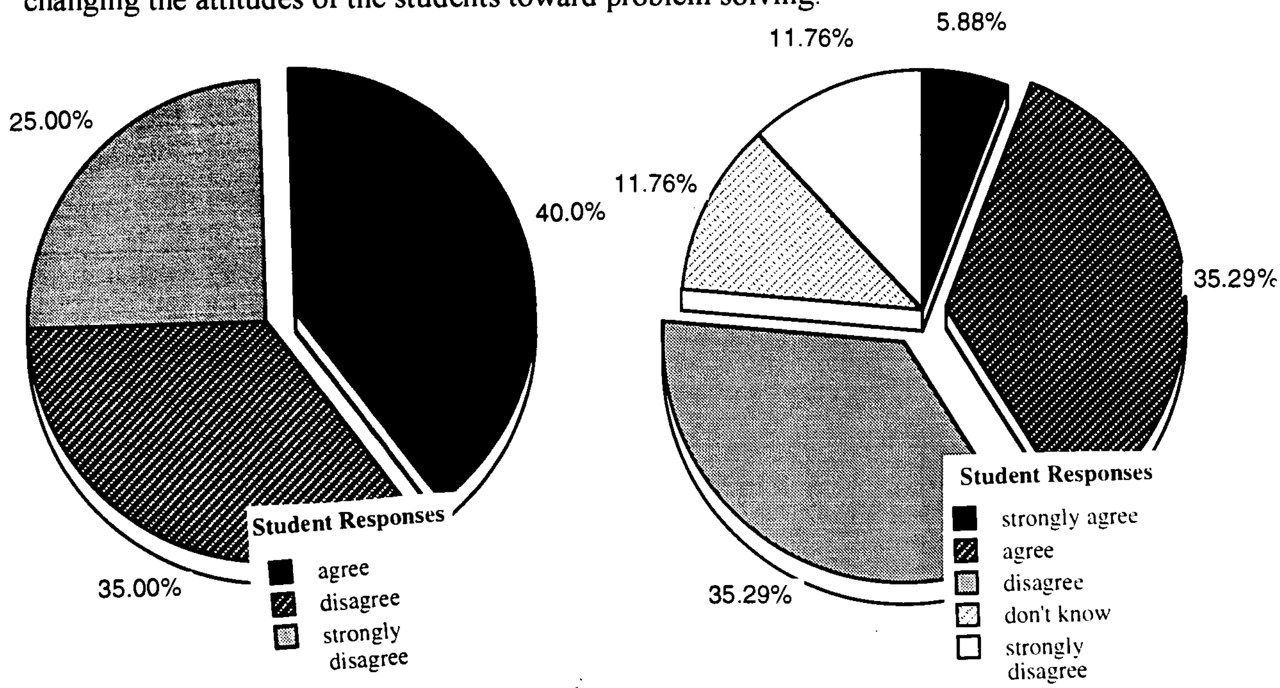

Figure 27. Responses by students at Site A, pre and postintervention, to the statement "I like to solve word problems."

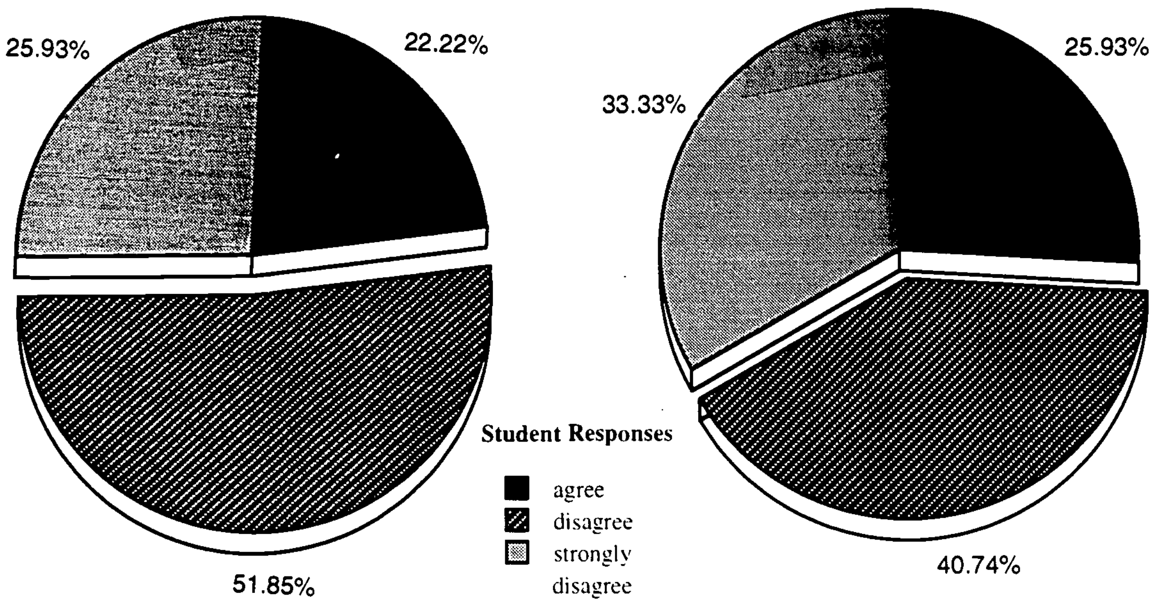

Figure 28. Responses by students at Site B, pre and postintervention, to the statement "I like to solve word problems."

At Site A, the percentage of students who agree or strongly agree that they like to solve word problems remained unchanged while the percentage of students who disagreed or strongly disagreed decreased by approximately 9%. As a result of the intervention, the researchers found that the students were not as opposed to solving problems as they were before the intervention. At Site B, the students who agreed with the statement increase, from preintervention to postintervention, by approximately 3%. This would indicate that after the intervention, the students have a more positive attitude toward solving problems.

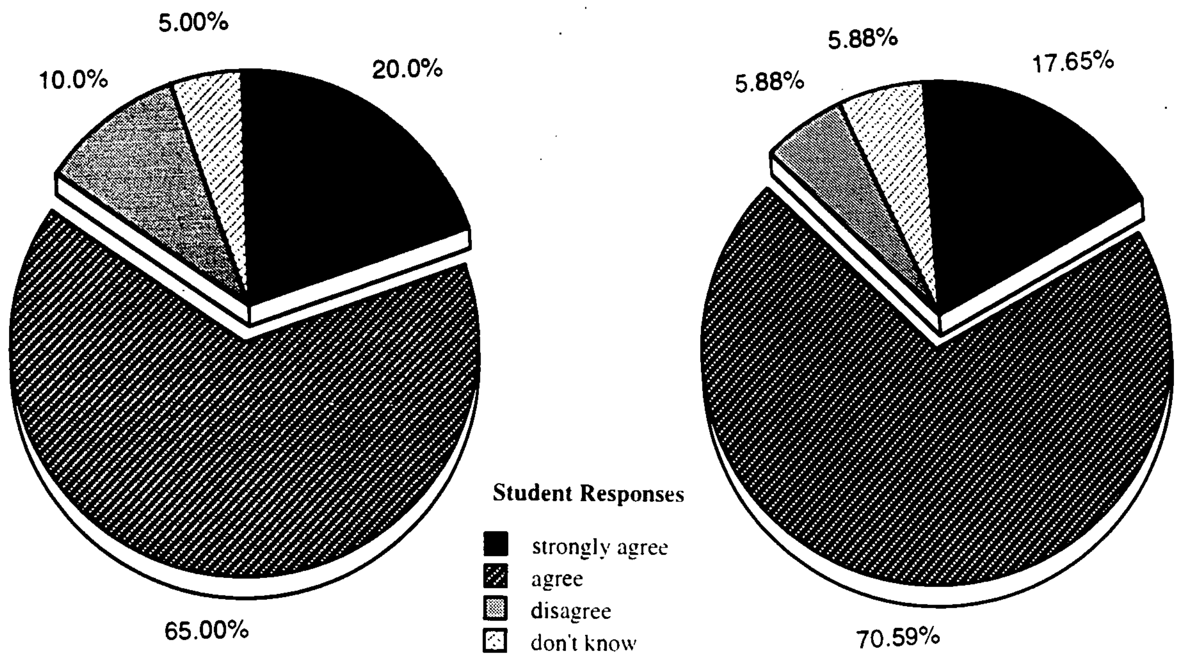

Figure 29. Pre and postsurvey responses by students at Site A to the statement "I can apply what I have learned in school to outside situations."

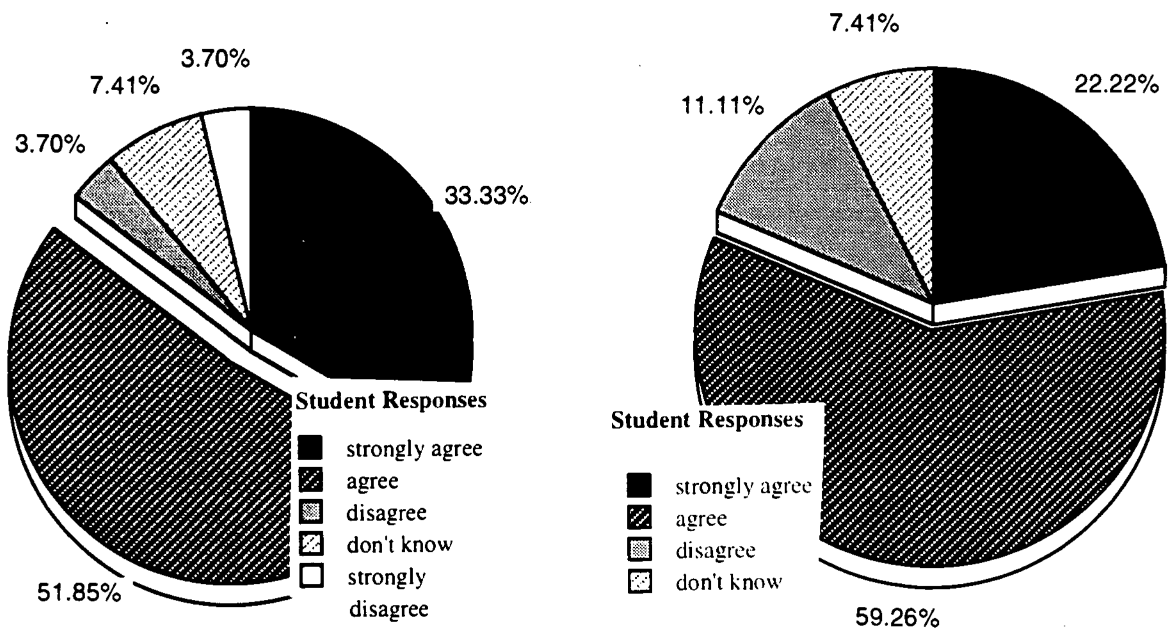

Figure 30. Pre and postsurvey responses by students at Site B to the statement "I can apply what I have learned in school to outside situations."

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At Site A, 85% of the students in the presurvey agreed or strongly agreed that they can use problem solving in other situations outside school. The postsurvey results were approximately 88% for the same responses. The researchers believe that the strategies used in the intervention had an impact on the student understanding of problem solving. At Site B, 85% of the students in the presurvey agreed or strongly agreed with the statement. The postsurvey results decreased by approximately 3%. While the impact of the intervention on the students is slight, it suggests that the students lack confidence in their problem-solving skills.

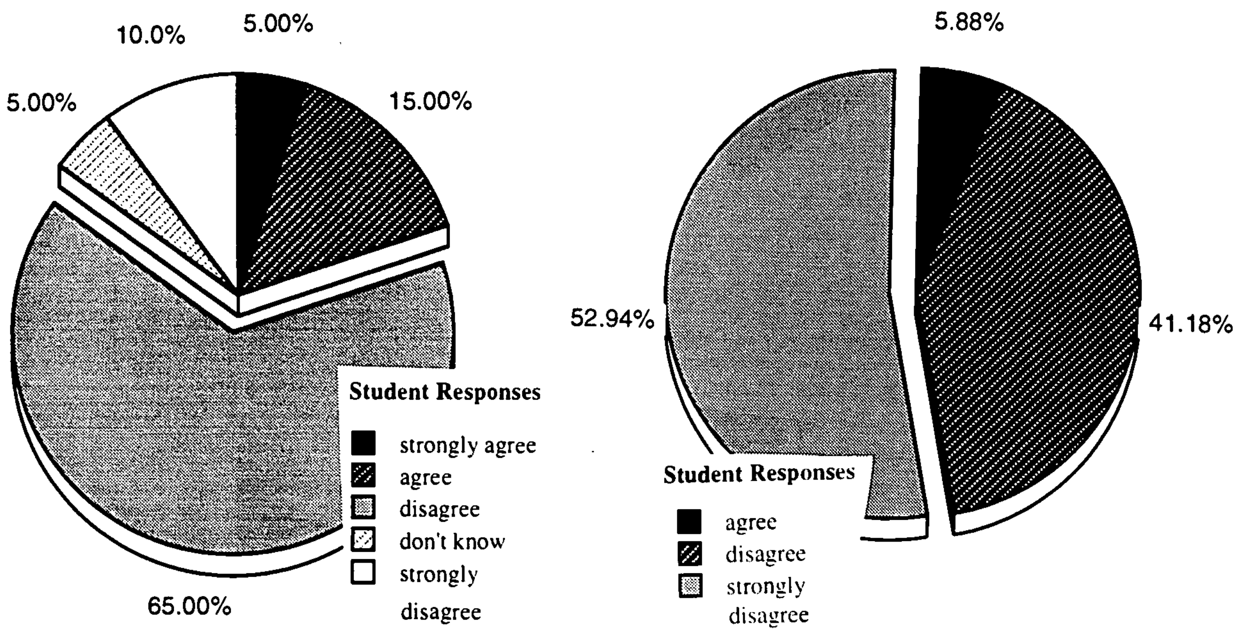

Figure 31. Pre and postsurvey responses by students at Site A to the statement "Having the right answer is more important than the process used to get it."

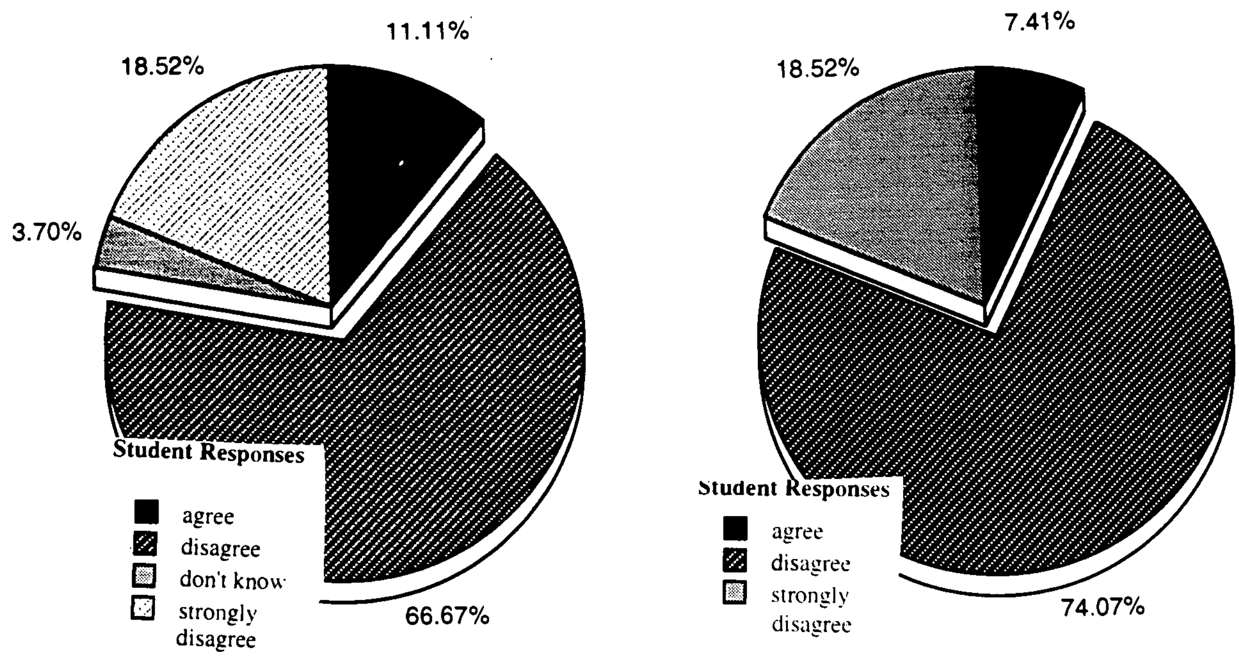

Figure 32. Pre and postsurvey responses by students at Site B to the statement "Having the right answer is more important than the process used to get it."

At Site A, 20% of the students surveyed before the intervention agreed that the right answer is more important than the process used to get it. After the intervention, only approximately 6% of the students felt this way. These results are supporting the belief that the intervention had a positive impact on the students' understanding of problem solving and its purpose. At Site B, the results were similar to those at Site A. Again this indicated the positive impact of the intervention on the students.

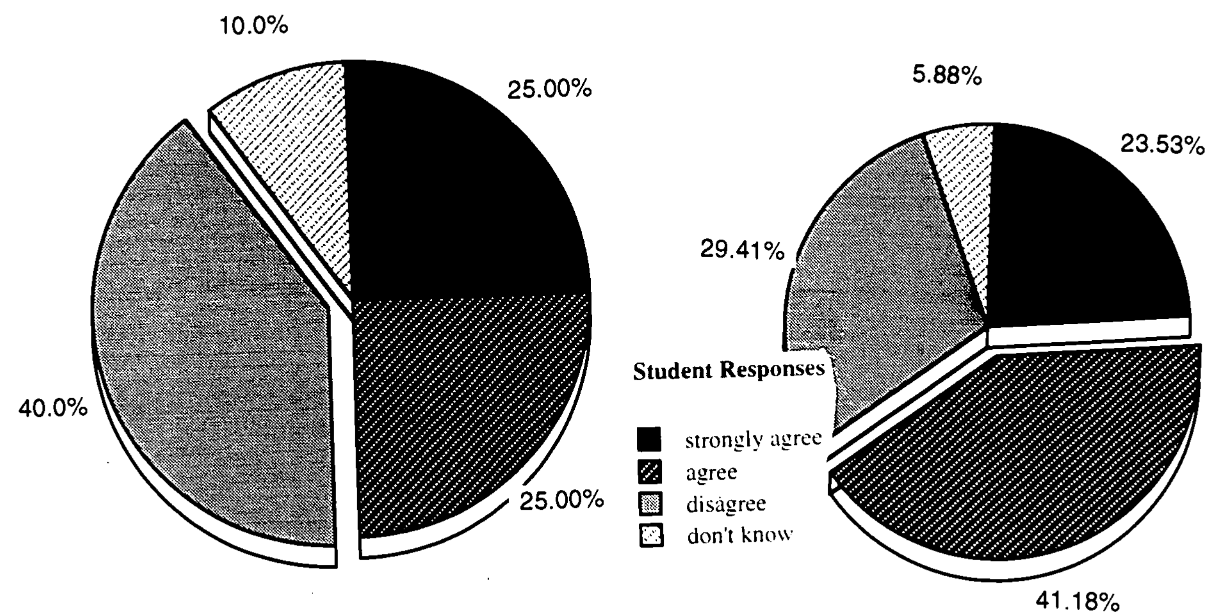

Figure 33. Responses by students at Site A, pre and postintervention, to the statement "I get frustrated when the answer to a problem does not come to me immediately."

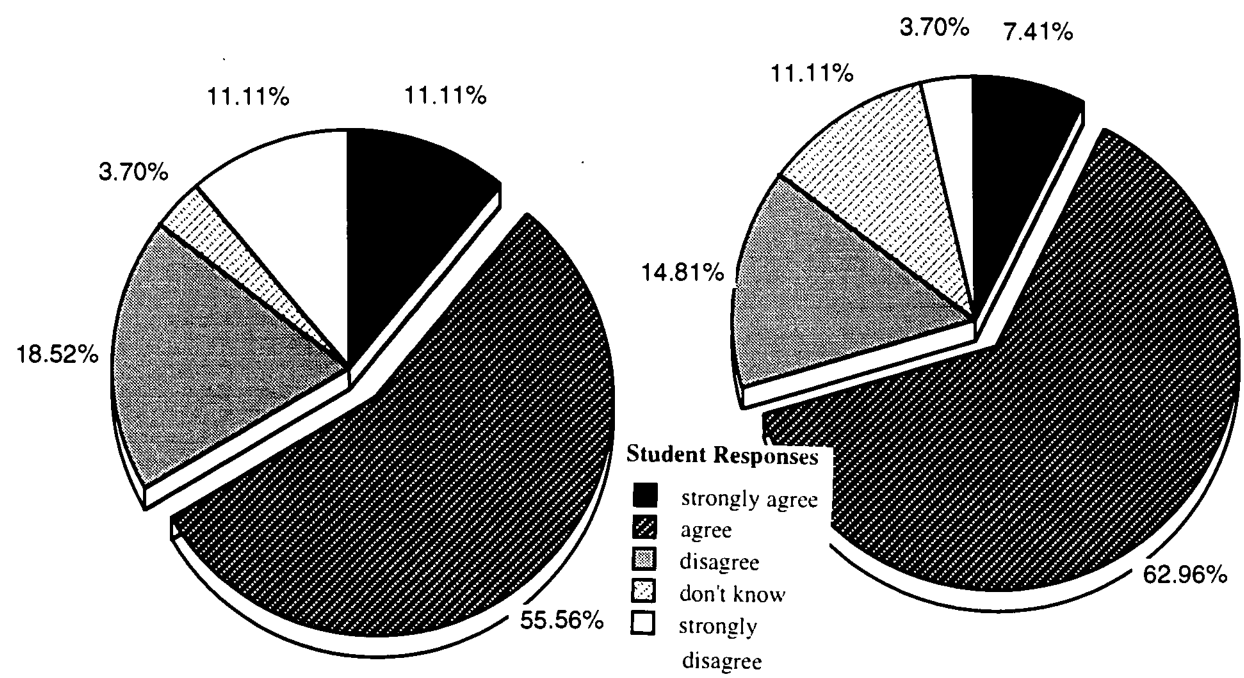

Figure 34. Responses by students at Site B, pre and postintervention, to the statement "I get frustrated when the answer to a problem does not come to me immediately."

At Site A, 50% of the students agreed or strongly agreed with the statement in the presurvey. After the intervention, the results increased to approximately 65%. After the intervention the students found problem solving to be more frustrating than before. It would appear that the intervention had a negative impact on many of the students. At Site B, the students felt in both surveys that problem solving is frustrating when the answer is not quickly obtained. After the intervention, the percentage of students who felt frustrated increased from 66% in the presurvey (agree and strongly agree) to 70% in the postsurvey. These results are similar to those at Site A.

In order to evaluate the success of the intervention on the ability of the students to solve problems, a pre and posttest was given at both Sites A and B. The results of the pre and posttests are found in figures 35 and 36.

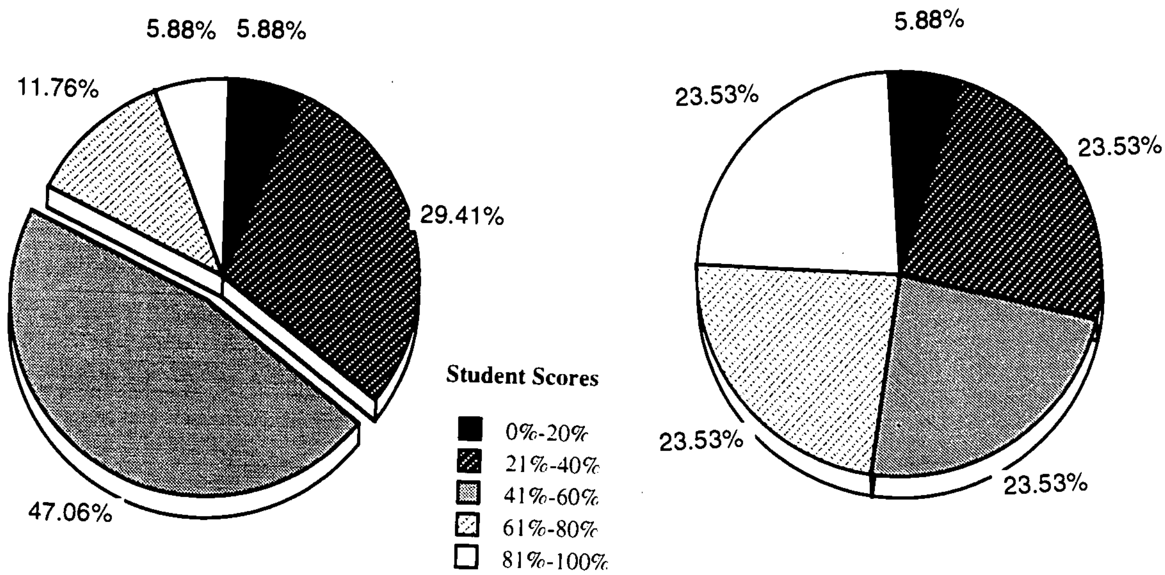

Figure 35. Distribution of scores represented as a percentage for the targeted students at Site A on the American High School Mathematics Examination pre and posttest. (Committee on the American Mathematics Competitions Mathematical Association of America)

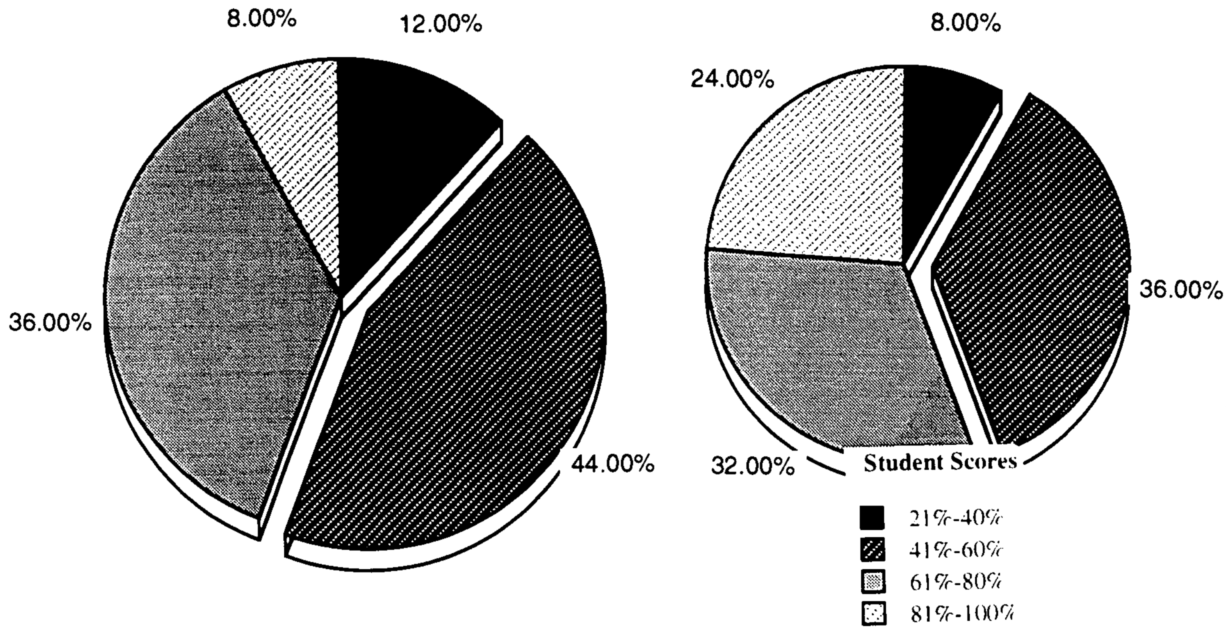

Figure 36. Distribution of scores for the targeted students at Site B on the Science Reasoning/Problem Solving pre and posttest. (PLAN test: forms 09B, 10A, 24A, and 25A)

At Site A, the percentage of students in the 81% - 100% range increased from 6% to 24%. The 61% - 80% range also increased from 12% on the pretest to 24% on the posttest. The other categories indicated “failing” grades. In the pretest the failing grades included 83% of the students while 54% of the students received those grades on the posttest. This shows that the intervention strategies had a significant impact on the ability of the students to solve problems. At Site B, the percentage of students who scored 61% or better increased from 44% on the pretest to 56% on the posttest. The percentage of students who scored below 61% decreased from 56% on the pretest to 44% on the posttest. This indicates that the intervention strategies were successful in improving the problem-solving skills of the students at Site B.

Conclusions and Recommendations

Based on the presentation and analysis of the data on problem solving, the targeted students showed a slight improvement with respect to their problem-solving skills. The use of cooperative learning, multiple intelligences and Problem Solving Teaching may have influenced the increase in scores on the posttests. However, the increase in scores may just be a result of other factors such as maturity of the students. It is possible that the results of the posttest were impacted by the interaction between students throughout the intervention. With each strategy implemented, the students were given the opportunity to work with others and share ideas.

The other objective of the action plan appears to have been met to a certain degree as well. It is difficult to evaluate how much of the interventions played a part in this attitude change. At the end of the intervention, most students agreed that problem solving is an important part of school. Perhaps this does not reflect an attitudinal change, but rather is a result of the amount of time devoted to the intervention as perceived by the students.

An unanticipated result of the time given to the intervention may be a shift toward a negative attitude relating to all aspects of problem solving. Students at both sites responded on the post survey that they had become frustrated or more frustrated with solving problems when the answer was not easily obtained. This may be due to an overload of problems given to the students throughout the intervention.

Many of the attitudinal results of the postsurvey were inconclusive. Often the results at Sites A and B conflicted or remained unchanged throughout the intervention. This may be due to the fact that the majority of students at both sites had a positive outlook on problem solving at the onset of the intervention. Since the intervention began at the start of the second semester, many of the students had already been exposed to problem-solving strategies by the researchers during the first semester. This made a change in problem-solving skills harder to detect in the students from pre to postintervention.

This action research project targeted three specific teaching strategies. There are certainly numerous other strategies that can be used to improve problem-solving skills in students. In order to draw more valid conclusions, the researchers should have assessed the students at the conclusion of each individual strategy implemented. This may also help other teachers determine which strategies work best for their students.
Regardless of the overall impact the interventions may or may not have had on the specific objectives, the researchers noted an increase in student motivation. If students are given the opportunity to work together, it is probable that they will devote more time to problem solving and as a result, their solutions will be more thoughtful.

The researchers found that the structure of Problem Solving Teaching was a tool that students used and found helpful throughout its implementation and beyond. By giving the students a step-by-step procedure to follow, at least in the early stages, the students are more willing to attempt the problems posed to them. Eventually their experience should allow them to attempt problems without a rigid structure.

Without sufficient experience, students will not learn how to become successful problem solvers. Like any other skill, problem solving must be learned and practiced. While students should be given plenty of opportunities to solve problems, they should not be forced to do them. If students view problem solving as a chore, they will develop a negative attitude that can undermine even the most effective teaching or strategies.

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Appendices

Appendix A
Teacher Interview

TEACHER INTERVIEW

1.) How often do you require your students to use problem solving in your class? In what ways?

2.) Do you think students have difficulty with problem solving in your class? If so, why?

3.) What skills are necessary for problem solving?

4.) Do you assess problem solving? If so, how?

5.) Can you teach problem solving? Why or why not? How?

Appendix B
Student Survey

Student Survey: Problem Solving

Directions: Choose the letter that best describes your response to the following statements.

A = strongly agree B = agree C = disagree D = strongly agree E = don't know

1. I like to solve word problems.
2. I am good at solving word problems.
3. Teachers should teach students how to solve problems.
4. Accumulating facts is an important part of learning.
5. The most important aspect of school is the grades you earn.
6. Learning how to solve problems is an important part of school.
7. I can apply what I have learned in school to outside situations.
8. Having the right answer is more important that the process used to get it.
9. To be a successful person, I need to be a good problem solver.
10. I get frustrated when the answer to a problem does not come to me immediately.

Appendix C
Pretest A

1. If for any three distinct numbers a, b and c we define $\boxed{a,b,c}$ by

$$\boxed{a,b,c} = \frac{c+a}{c-b},$$

then $\boxed{1,-2,-3} =$

(A) -2 (B) $-\frac{2}{5}$ (C) $-\frac{1}{4}$ (D) $\frac{2}{5}$ (E) 2

2. $|3-\pi| =$

(A) $\frac{1}{7}$ (B) .14 (C) $3-\pi$ (D) $3+\pi$ (E) $\pi-3$

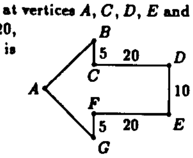
3. $(4^{-1}-3^{-1})^{-1} =$

(A) -12 (B) -1 (C) $\frac{1}{12}$ (D) 1 (E) 12

4. Which of the following triangles cannot exist?

(A) An acute isosceles triangle (B) An isosceles right triangle
(C) An obtuse right triangle (D) A scalene right triangle
(E) A scalene obtuse triangle

5. In the arrow-shaped polygon [see figure], the angles at vertices A, C, D, E and F are right angles, $BC = FG = 5$, $CD = FE = 20$, $DE = 10$, and $AB = AG$. The area of the polygon is closest to



(A) 288 (B) 291 (C) 294
(D) 297 (E) 300

6. If $x \geq 0$, then $\sqrt{x\sqrt{x\sqrt{x}}} =$

(A) $x\sqrt{x}$ (B) $x\sqrt[4]{x}$ (C) $\sqrt[8]{x}$ (D) $\sqrt[8]{x^3}$ (E) $\sqrt[8]{x^7}$

7. If $x = \frac{a}{b}$, $a \neq b$ and $b \neq 0$, then $\frac{a+b}{a-b} =$

(A) $\frac{x}{x+1}$ (B) $\frac{x+1}{x-1}$ (C) 1 (D) $x - \frac{1}{x}$ (E) $x + \frac{1}{x}$

8. Liquid X does not mix with water. Unless obstructed, it spreads out on the surface of water to form a circular film 0.1 cm thick. A rectangular box measuring 6 cm by 3 cm by 12 cm is filled with liquid X. Its contents are poured onto a large body of water. What will be the radius, in centimeters, of the resulting circular film?

(A) $\frac{\sqrt{216}}{\pi}$ (B) $\sqrt{\frac{216}{\pi}}$ (C) $\sqrt{\frac{2160}{\pi}}$ (D) $\frac{216}{\pi}$ (E) $\frac{2160}{\pi}$

9. From time $t = 0$ to time $t = 1$ a population increased by $i\%$, and from time $t = 1$ to time $t = 2$ the population increased by $j\%$. Therefore, from time $t = 0$ to time $t = 2$ the population increased by

(A) $(i+j)\%$ (B) $ij\%$ (C) $(i+ij)\%$ (D) $\left(i+j+\frac{ij}{100}\right)\%$

(E) $\left(i+j+\frac{i+j}{100}\right)\%$

10. Point P is 9 units from the center of a circle of radius 15. How many different chords of the circle contain P and have integer lengths?

(A) 11 (B) 12 (C) 13 (D) 14 (E) 29

11. Jack and Jill run 10 kilometers. They start at the same point, run 5 kilometers up a hill, and return to the starting point by the same route. Jack has a 10-minute head start and runs at the rate of 15 km/hr uphill and 20 km/hr downhill. Jill runs 16 km/hr uphill and 22 km/hr downhill. How far from the top of the hill are they when they pass going in opposite directions?

(A) $\frac{5}{4}$ km (B) $\frac{35}{27}$ km (C) $\frac{27}{20}$ km (D) $\frac{7}{3}$ km (E) $\frac{28}{9}$ km

12. The measures (in degrees) of the interior angles of a convex hexagon form an arithmetic sequence of positive integers. Let m° be the measure of the largest interior angle of the hexagon. The largest possible value of m° is

(A) 165° (B) 167° (C) 170° (D) 175° (E) 179°

13. Horses X, Y and Z are entered in a three-horse race in which ties are not possible. If the odds against X winning are 3-to-1 and the odds against Y winning are 2-to-3, what are the odds against Z winning? (By *"odds against H winning are p-to-q"* we mean that the probability of H winning the race is $\frac{q}{p+q}$.)

(A) 3-to-20 (B) 5-to-6 (C) 8-to-5 (D) 17-to-3 (E) 20-to-3

14. If x is the cube of a positive integer and d is the number of positive integers that are divisors of x, then d could be

(A) 200 (B) 201 (C) 202 (D) 203 (E) 204

15. A circular table has exactly 60 chairs around it. There are N people seated at this table in such a way that the next person to be seated must sit next to someone. The smallest possible value of N is

(A) 15 (B) 20 (C) 30 (D) 40 (E) 58

16. One hundred students at Century High School participated in the AHSME last year, and their mean score was 100. The number of non-seniors taking the AHSME was 50% more than the number of seniors, and the mean score of the seniors was 50% higher than that of the non-seniors. What was the mean score of the seniors?

(A) 100 (B) 112.5 (C) 120 (D) 125 (E) 150

17. A positive integer N is a *palindrome* if the integer obtained by reversing the sequence of digits of N is equal to N. The year 1991 is the only year in the current century with the following two properties:
(a) It is a palindrome.
(b) It factors as a product of a 2-digit prime palindrome and a 3-digit prime palindrome.
How many years in the millenium between 1000 and 2000 (including the year 1991) have properties (a) and (b)?

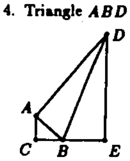
(A) 1 (B) 2 (C) 3 (D) 4 (E) 5

18. If S is the set of points z in the complex plane such that $(3+4i)z$ is a *real* number, then S is a

(A) right triangle (B) circle (C) hyperbola
(D) line (E) parabola

19. Triangle ABC has a right angle at C, $AC = 3$ and $BC = 4$. Triangle ABD has a right angle at A and $AD = 12$. Points C and D are on opposite sides of $\overline{AB}$. The line through D parallel to $\overline{AC}$ meets $\overline{CB}$ extended at E. If $\frac{DE}{DB} = \frac{m}{n}$, where m and n are relatively prime positive integers, then $m+n =$

(A) 25 (B) 128 (C) 153 (D) 243 (E) 256



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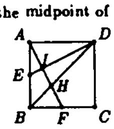
20. The sum of all real x such that $(2^x-4)^3+(4^x-2)^3=(4^x+2^x-6)^3$ is
(A) 3/2 (B) 2 (C) 5/2 (D) 3 (E) 7/2

21. If $f\left(\frac{x}{x-1}\right)=\frac{1}{x}$ for all $x \neq 0,1$ and $0<\theta<\frac{\pi}{2}$, then $f(\sec^2\theta)=$
(A) $\sin^2\theta$ (B) $\cos^2\theta$ (C) $\tan^2\theta$ (D) $\cot^2\theta$ (E) $\csc^2\theta$

22. Two circles are externally tangent. Lines $\overline{PAB}$ and $\overline{PA'B'}$ are common tangents with A and A' on the smaller circle and B and B' on the larger circle. If $PA=AB=4$, then the area of the smaller circle is

(A) 1.44π (B) 2π (C) 2.56π
(D) $\sqrt{8}\pi$ (E) 4π

23. If $ABCD$ is a 2×2 square, E is the midpoint of $\overline{AB}$, F is the midpoint of $\overline{BC}$, $\overline{AF}$ and $\overline{DE}$ intersect at I, and $\overline{BD}$ and $\overline{AF}$ intersect at H, then the area of quadrilateral $BEIH$ is



(A) $\frac{1}{3}$ (B) $\frac{2}{5}$ (C) $\frac{7}{15}$ (D) $\frac{8}{15}$ (E) $\frac{3}{5}$

24. The graph, G, of $y=\log_{10}x$ is rotated 90° counter-clockwise about the origin to obtain a new graph G'. Which of the following is an equation for G'?
(A) $y=\log_{10}\left(\frac{x+90}{9}\right)$ (B) $y=\log_x 10$ (C) $y=\frac{1}{x+1}$
(D) $y=10^{-x}$ (E) $y=10^x$

25. If $T_n=1+2+3+\cdots+n$ and

$$P_n=\frac{T_2}{T_2-1}\cdot\frac{T_3}{T_3-1}\cdot\frac{T_4}{T_4-1}\cdot\cdots\cdot\frac{T_n}{T_n-1} \quad \text{for } n=2,3,4,\ldots,$$

then P_{1991} is closest to which of the following numbers?
(A) 2.0 (B) 2.3 (C) 2.6 (D) 2.9 (E) 3.2

26. An n-digit positive integer is *cute* if its n digits are an arrangement of the set $\{1,2,\ldots,n\}$ and its first k digits form an integer that is divisible by k, for $k=1,2,\ldots,n$. For example, 321 is a cute 3-digit integer because 1 divides 3, 2 divides 32, and 3 divides 321. How many cute 6-digit integers are there?
(A) 0 (B) 1 (C) 2 (D) 3 (E) 4

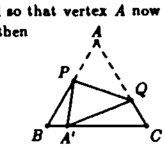
27. If $x+\sqrt{x^2-1}+\frac{1}{x-\sqrt{x^2-1}}=20$ then $x^2+\sqrt{x^4-1}+\frac{1}{x^2+\sqrt{x^4-1}}=$
(A) 5.05 (B) 20 (C) 51.005 (D) 61.25 (E) 400

28. Initially an urn contains 100 black marbles and 100 white marbles. Repeatedly, three marbles are removed from the urn and replaced from a pile outside the urn as follows:

MARBLES REMOVED	REPLACED WITH
3 black	1 black
2 black, 1 white	1 black, 1 white
1 black, 2 white	2 white
3 white	1 black, 1 white.

Which of the following sets of marbles could be the contents of the urn after repeated applications of this procedure?
(A) 2 black marbles (B) 2 white marbles (C) 1 black marble
(D) 1 black and 1 white marble (E) 1 white marble

29. Equilateral triangle ABC has been creased and folded so that vertex A now rests at A' on $\overline{BC}$ as shown. If $BA'=1$ and $A'C=2$ then the length of crease $\overline{PQ}$ is



(A) $\frac{8}{5}$ (B) $\frac{7}{20}\sqrt{21}$ (C) $\frac{1+\sqrt{5}}{2}$ (D) $\frac{13}{8}$
(E) $\sqrt{3}$

30. For any set S, let $|S|$ denote the number of elements in S, and let $n(S)$ be the number of subsets of S, including the empty set and the set S itself. If A, B and C are sets for which

$$n(A)+n(B)+n(C)=n(A\cup B\cup C) \quad \text{and} \quad |A|=|B|=100,$$

then what is the minimum possible value of $|A\cap B\cap C|$?
(A) 96 (B) 97 (C) 98 (D) 99 (E) 100

Appendix D
Pretest B

SCIENCE REASONING/PROBLEM SOLVING PRETEST 25 MINUTES-26 QUESTIONS

DIRECTIONS: There are four passages in this test. Each passage is followed by several questions. After reading a passage, choose the best answer to each question and fill in the corresponding oval on your answer sheet. You may refer to the passages as often as necessary.

Passage I

Matter can exist in various forms, called *phases*. The surrounding temperature is one of the factors that determines whether the phase is *solid, liquid,* or *gas*. Matter can change from one phase to another when the surrounding temperature changes. For example, ice changes phase to liquid water when heated. To better understand phase changes, two experiments were performed using p-dichlorobenzene, an organic compound.

In each experiment, a sample of five grams of p-dichlorobenzene was placed in a test tube. The sample was heated in a beaker of water placed on an electric hot plate. While in the liquid phase, the p-dichlorobenzene was slowly and continuously stirred to ensure an equal temperature throughout the sample. The temperature of the compound was measured every 30 seconds in degrees Celsius (^{o} C).

Experiment 1

A test tube containing p-dichlorobenzene was heated to 95^{o} C and then removed from the beaker of water and cooled at a constant rate. The temperature of p-dichlorobenzene was observed until it cooled to room temperature (22^{o} C). As the compound changed from a liquid to a solid, a depression formed on the top of the compound. The results are recorded in Figure 1.

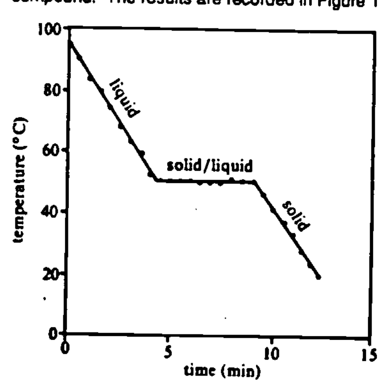


Figure 1

Experiment 2

A test tube containing solid p-dichlorobenzene was placed in a beaker of water at 30^{o} C and heated at a constant rate until the water began to boil (100^{o} C). The temperature was recorded and the results are shown in Figure 2.

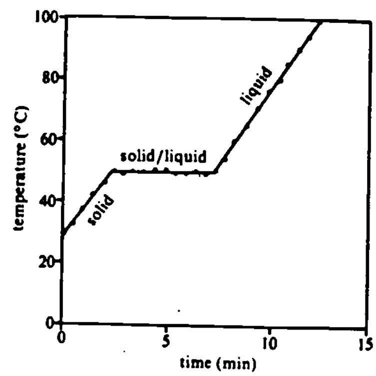


Figure 2

1. Which of the following phase changes is most similar to the one in Experiment 2?
   - A. iodine solid to iodine gas
   - B. liquid water to ice
   - C. ice to liquid water
   - D. liquid water to steam

2. The basic difference between the designs of Experiments 1 and 2 was the
   - A. amount of p-dichlorobenzene used.
   - B. direction of the temperature changes.
   - C. temperature of the phase changes.
   - D. length of time needed to complete the phase changes.

3. What phase change took place in Experiment 2?
   - A. The water changed from solid to liquid.
   - B. The water changed from liquid to solid.
   - C. The p-dichlorobenzene changed from solid to liquid.
   - D. The p-dichlorobenzene changed from liquid to solid.

4. If a similar organic compound were substituted for p-dichlorobenzene in Experiment 1, which phase(s) would be expected to be present in the sample at the temperature where the graph of the results for the sample becomes horizontal?
   - A. solid only
   - B. liquid only
   - C. gas only
   - D. solid and liquid only

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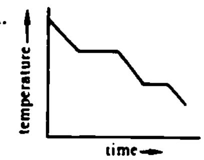
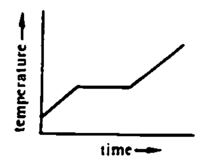
5. In another experiment, sulfur was heated until it changed phase from solid to liquid and then from liquid to gas. Which of the following sketches best represents the temperature-versus-time results of this experiment?

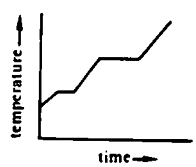
A.



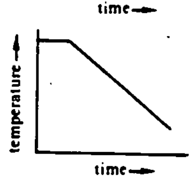
B.



C.



D.



6. Which of the following modifications in experimental design would provide new information about phase changes?
   - A. starting Experiment 1 at 70° C
   - B. extending Experiment 2 to the melting point of p-dichlorobenzene
   - C. repeating Experiment 2 with the temperature held constant at 51° C
   - D. extending Experiment 2 to the boiling temperature of p-dichlorobenzene

7. Which of the following assumptions was made in designing these experiments?
   - A. Both water and p-dichlorobenzene would begin to boil at 95° C.
   - B. Both water and p-dichlorobenzene would begin to melt at 30° C.
   - C. The exact amount of water in the beaker would be critical to the results.
   - D. The p-dichlorobenzene would change phase within the physical parameters of both experiments.

Passage II

A chemist used the following methods to determine the solubility of a soluble salt, KNO_3, in water at various temperatures.

Method 1

Twenty grams of KNO_3 was added to a large calibrated test tube containing 15.0 mL of water. The water was heated until the KNO_3 dissolved. The test tube was cooled slowly, and when crystals just began to appear, the temperature was recorded. Then 5.0 mL of water was added to the test tube, and the solution was reheated until the KNO_3 dissolved. It was then cooled again until crystals were just visible. This process was repeated three more times and the following data were obtained:

Trial	Water volume (mL)	Temperature (°C)	Solubility (g KNO_3/100 mL H_2O)
1	15.0	67	133
2	20.0	56	100
3	25.0	47	80
4	30.0	40	67
5	35.0	37	57

Method 2

A second method to determine solubility involves evaporating the water from a saturated solution and weighing the salt left. Initially, the salt is added to a container of water until no more will dissolve (some undissolved salt will be left on the bottom of the container). A portion of the solution is poured off, its volume and temperature measured, and it is carefully heated until the water is completely evaporated. The remaining salt is weighed. The mass of the salt per 100 mL of solution is the solubility. At 40° C the solubility for KNO_3 was 54 g/100 ml solution.

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8. When choosing between the two methods of solubility determination, which of the following properties of the materials is LEAST important to consider?
   A. the approximate solubility of the compound
   B. the reactivity of the compound with water
   C. the shape of the crystals that form
   D. the rate at which crystals form in solution

9. Based on the data presented for KNO_3, what can be one generalize for the solubility of salts?
   A. Volume is directly proportional to temperature.
   B. Temperature has no relationship to volume.
   C. Solubility has no relationship to temperature.
   D. Solubility is dependent on temperature.

10. Assuming the measurements were completed accurately for both methods, which of the following best explains why the resulting solubilities are different for the two methods?
   A. Less water was used in Method 1.
   B. Method 1 measured the volume of water, but Method 2 measured the volume of solution.
   C. Some of the KNO_3 boiled off during the completion of Method 2.
   D. There was a portion of KNO_3 undissolved before the sample was taken for measurement and evaporation.

11. Suppose the chemist decided to try a third method to determine solubility. In this method, water was added to a known amount of solid until the solid just dissolved. Then the temperature was measured. When the method was tried, the resulting solubility was lower than those obtained using the other two methods. Which of the following is the most likely explanation for this result?
   A. The rate of dissolving was so slow that more water than necessary was added.
   B. It was too difficult to control the temperature of the water added.
   C. The sample was contaminated with a small amount of very soluble material.
   D. The chemist spilled a small amount of the sample after it had been weighed out.

12. Suppose that during Method 2, as the water was almost boiled off, severe splattering of the last few drops of liquid and crystals occurred. Some of this material splattered out of the container and was lost. What effect will this have on the result of the experiment?
   A. Since most of the water was boiled off, there will be no change in the solubility data.
   B. The mass of the remaining salt will be too low and the calculated solubility will be too low.
   C. Since mostly salt rather than water was lost, the solubility is unaffected.
   D. The solubility will appear to be too high due to a decreased volume of water.

13. Under what conditions would Method 2 be more useful to use than Method 1?
   A. when the solubility must be found for a specific temperature
   B. when there is only a limited amount of pure water available
   C. when the temperature cannot be accurately measured
   D. when the salt is very soluble

14. When using Method 1 for solubility determinations, which of the following is NOT an important consideration?
   A. the weight of the KNO_3 increments
   B. the temperature of the solution when crystals appear
   C. the volume of the water increments
   D. the temperature at which the KNO_3 first dissolves.

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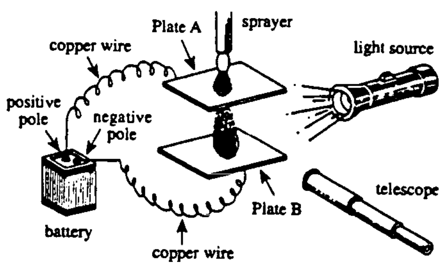
Passage III

Charged particles exert electrical *forces* on one another, causing the particles to change speed and/or direction. A particle moving at a constant velocity has no total force acting on it. Oppositely charged particles (one positive and one negative) will attract each other; two positively charged particles or two negatively charged particles will repel each other. To study the motions of charged particles, students used a variation of Robert Millikan's famous experiments.

One horizontal metal plate, Plate A, was placed above an identical plate, Plate B, as shown in the figure below. Each plate could be connected by a copper wire to one *pole* of a battery. Water was mixed with tiny, uniformly sized plastic spheres. When the mixture was sprayed through a pinhole in Plate A, some spheres became electrically charged. Light was shone on the spray, and a small telescope was used to observe the movements of the spheres.



Experiment 1

Before the plates were connected to the battery, all the spheres fell at approximately the same, constant speed.

Experiment 2

A few seconds after spraying had begun, Plate A was connected to the positive (+) pole of the battery and became positively charged; Plate B was connected to the negative (-) pole and became negatively charged. Subsequently, the students observed that some of the spheres reversed their direction of motion. Of spheres that continued to fall, some sped up or slowed down.

Experiment 3

Plates A and B were initially connected to the battery as in Experiment 2. While a certain sphere was observed falling toward Plate B, the students reversed the connections between the plates and the battery. As a result, the observed sphere slowed down, reversed its direction, and sped up.

15. The purpose of the copper wires was most likely to
    A. conduct charges between the poles of the battery and the plates.
    B. prevent the battery from becoming discharged.
    C. maintain the correct spacing between Plates A and B.
    D. support Plates A and B.

16. According to the information presented in the passage and the figure, when Plates A and B were first connected to the battery, what charges were produced on the plates?
    A. Plate A became positively charged and Plate B became negatively charged.
    B. Plate A became negatively charged and Plate B became positively charged.
    C. Both plates became positively charged.
    D. Both plates became negatively charged.

17. Atoms contain particles in a central core, or *nucleus*. Other particles travel around the nucleus in *orbits* (closed paths, like circles). Based on the information in the passage, the particles in the orbits are attracted to the particles in the nucleus, most likely because the particles in the nucleus and in the orbits
    A. have the same mass.
    B. have the same radius.
    C. are both positively charged.
    D. are oppositely charged.

18. In Experiment 2, after the plates were connected to the poles of the battery, some of the falling spheres fell faster. Those spheres that sped up more were probably
    A. lighter than the other spheres.
    B. larger than the other spheres.
    C. more positively charged than the other spheres.
    D. uncharged.

19. In Experiment 2, when the plates were connected to poles of the battery, the motions of some of the falling plastic spheres did not change. The spheres whose motions did not change were probably
    A. much smaller than the spheres whose motions changed.
    B. positively charged.
    C. negatively charged.
    D. uncharged.

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20. Consider two spheres that are identical, but with opposite charges. If the students placed the spheres near each other, initially at rest, and if the only forces were those between the spheres, the students would most likely observe the spheres moving in which of the following ways?
    A. The two spheres would move toward each other with equal speeds.
    B. The two spheres would move toward each other with different speeds.
    C. The two spheres would move away from each other with equal speeds.
    D. The two spheres would move away from each other with different speeds.

21. An *electron* is a tiny particle having a single negative charge. When the mixture was sprayed through the pinhole, some electrons were knocked loose from the plastic spheres. In Experiment 3, when the connections between the battery and the plates were reversed, those electrons between Plates A and B would most likely have been attracted toward
    A. Plate A.
    B. Plate B.
    C. both Plates A and B.
    D. neither Plate A nor Plate B.

Passage IV

The *heating rate* is defined as the amount of heat absorbed by a material in a given time period. When a material absorbs heat, its temperature may rise.

For 50 g each of various liquids, initially at 20° C, Table 1 lists the temperature change, when each liquid absorbs heat for 10 sec at a heating rate of 60 watts (W).

Table 1

Liquid	Mass (g)	Heating rate (W)	Time (sec)	Temperature change (°C)
Benzene	50	60	10	6.9
Ethylene glycol	50	60	10	5.0
Methanol	50	60	10	4.7
Mercury	50	60	10	86.3

For 50 g or 100 g of water, initially at 20° C, Figure 1 shows the temperature changes that occur when the water is heated for 10 sec at various heating rates, and Figure 2 shows the temperature changes that result for water at a heating rate of 60 W for various amounts of time.

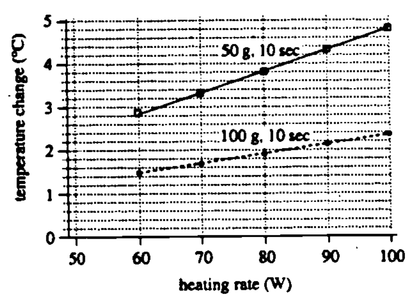

Figure 1

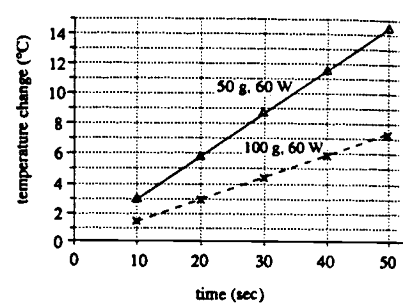

Figure 2

22. According to Table 1, how much benzene was being heated?
    A. 6.9 g
    B. 10 g
    C. 50 g
    D. 60 g

23. For both sets of observations graphed in Figure 2, water absorbed heat at a rate of
    A. 10 W.
    B. 50 W.
    C. 60 W.
    D. 100 W.

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24. According to the data in Table 1, which of the following lists ranks the four liquids in order of *decreasing* temperature change?
    A. Benzene, Ethylene glycol, Methanol, Mercury
    B. Ethylene glycol, Benzene, Mercury, Methanol
    C. Methanol, Ethylene glycol, Benzene, Mercury
    D. Mercury, Benzene, Ethylene glycol, Methanol

25. Do Figures 1 and 2 contain graphs of the same relationship?
    A. No; Figure 1 contains a graph of temperature change versus time, whereas Figure 2 contains a graph of temperature change versus heating rate.
    B. No; Figure 1 contains a graph of temperature change versus heating rate, whereas Figure 2 contains a graph of temperature change versus time.
    C. Yes; both figures contain graphs of temperature change versus heating rate.
    D. Yes; both figures contain graphs of temperature change versus time.

26. According to the data in Figure 1, if 25 g of water were heated at a rate of 60 W for 10 sec, the temperature change of the water would be closest to which of the following values?
    A. 0.7° C
    B. 1.5° C
    C. 2.2° C
    D. 5.7° C

*Adapted from the PLAN Test: Forms 09B, 10A, 24A, and 25A.

Appendix E
Students Interview

STUDENT INTERVIEW

1.) How do you feel in class when you are given a problem that makes you think?

2.) Why?

3.) What types of questions make you think the most?

4.) What types of things do you do in class that require problem solving?

5.) How do you approach solving a word problem?

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Appendix F
Similarity Project

In Jules Verne's *The Mysterious Island*, Cyrus Harding, one of several travelers stranded on an island, uses similar right triangles to estimate the height of a cliff.

> Cyrus Harding had provided himself with a straight stick, twelve feet long. . .Having reached a spot. . .nearly five hundred feet from the cliff, which rose perpendicularly, Harding thrust the pole two feet into the sand. . . perpendicularly. . .
>
> That done, he retired to necessary distance, when, lying in the sand, his eye glanced at the same time at the top of the pole and the crest of the cliff. He carefully marked the place with a little stick. . .
>
> The first distance was fifteen feet between the stick and the place where the pole was thrust into the sand.
>
> The second distance between the stick and the bottom of the cliff was five hundred feet.

Complete all work on a <u>separate sheet of paper</u> !!!!!!!!!!

1.) Draw and label a diagram that models the situation described in the passage.

2.) Identify the similar triangles in the diagram you drew.

3.) Find the height of the cliff.

Appendix G
Sample Problem

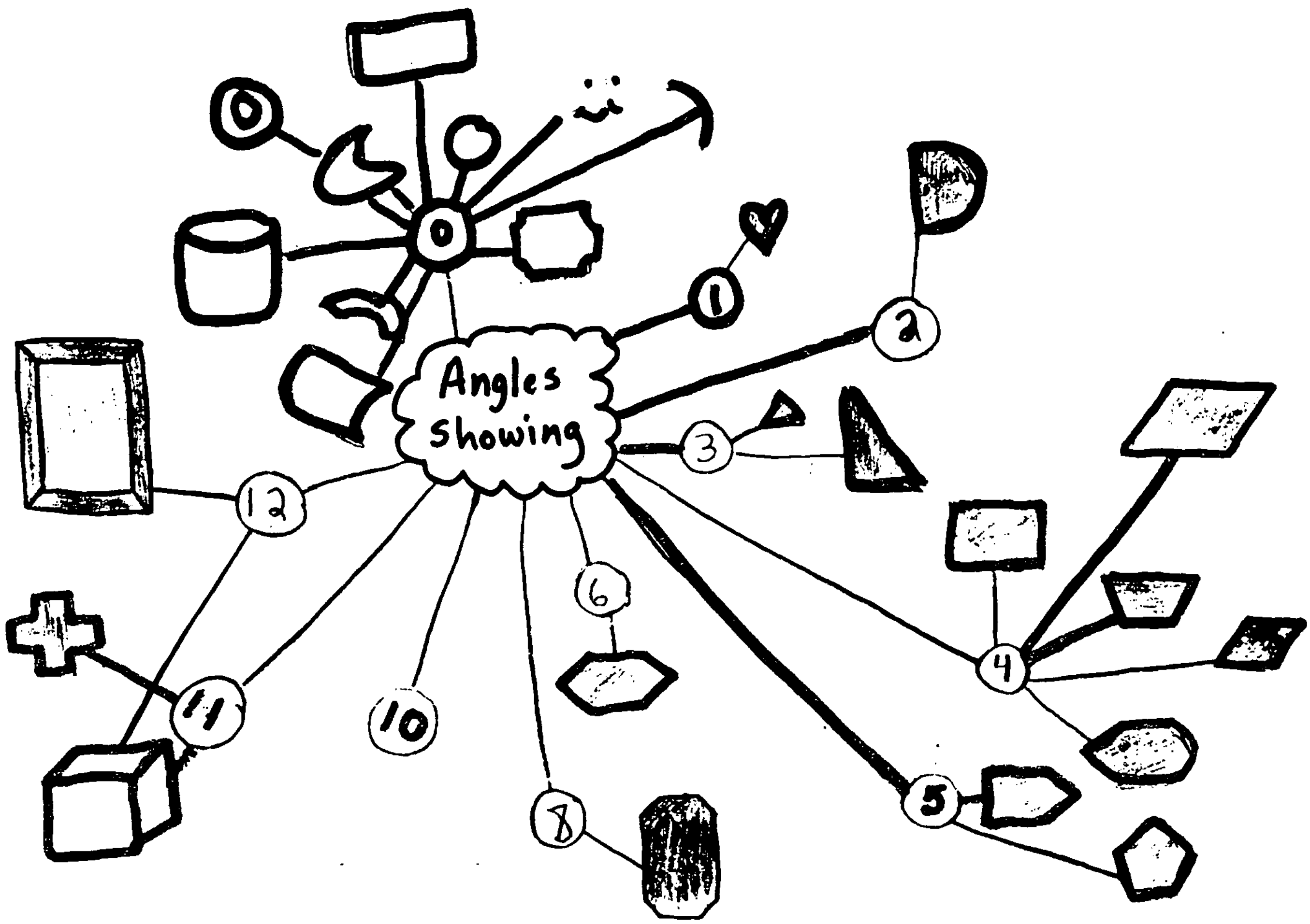
1) Can the cosine of an acute angle ever be greater than 1? If so, give the measure of such an angle. If not, explain why.

2) To the nearest degree, give the measure of the angle formed by a diagonal of a cube and the diagonal of one of its faces.

3) To avoid a steep descent, a plane flying at 25,000 feet starts descending 150 miles from the airport. At what constant angle of descent should the plane descend?

4) Find the height, PB, of a mountain whose base and peak are inaccessible. At point A, the angle of elevation of the peak is 30 degrees. One kilometer closer to the mountain, at point C, the angle of elevation is 35 degrees. (Draw a diagram)

Appendix H
Web



Appendix I
Multiple Intelligences Experiment

Scaling the Planets

Project Goal: Create a model of our solar system

Data:

1.) Find the diameter of the sun and each of the nine planets in our solar system. Be sure to record the source of your data.

2.) Organize your data in a spreadsheet or table. Label everything clearly. Include units of measure. Include columns for the dimensions of the scale model and the actual dimensions of the solar system.

3.) Choose a convenient size for Earth's scale diameter. Use this size to calculate the scale for the model. Your scale must use the same units for Earth's actual diameter and its scale diameter.

Model:

1.) Use the scale you found to calculate the size of the sun and each planet in a model. If the sizes of the models will be unreasonable, choose a new scale for the diameters.

2.) Choose a scale to show the distances of the planets from the sun. Can you use the same scale that you chose for the diameters?

3.) Create scale models of the sun and each planet in the solar system. Your models may be two- or three- dimensional. Place these models at their scale distance from the sun.

Appendix J
Student Reflection

Results:

1.) Write a summary of the project that includes the source of your data, your spreadsheet or table with an explanation of each formula that you used, and why the scale you chose is the best one for this project.

2.) You can extend your results by investigating some of these topics:

- Find information about the planets and photos of them to include.
- Find the scale distance between our sun and another star.
- Write a short piece discussing the size of the scale model of the solar system if the diameter of each planet and the distance between each planet and the sun are at the same scale.

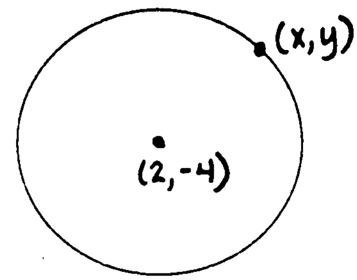
3.) Write a reflection answering the following questions:

a.) How did making this model change your understanding of the size of the solar system?
b.) What did you do to determine your scale for your model?
c.) What was the most interesting part of the project?
d.) Explain what you think a ratio is.

Appendix K
Portfolio Sample

Given: radius = 7
center (2, -4)

Task: Write an equation that may help find the missing coordinates x, y



Things to think about:

1.) What do you already know?

2.) What other information would make this easier?

3.) Can you find that other information from #2?

4.) What mathematical ideas/concepts/formulas can help you with the solution?

Appendix L
Challenge Problem

Given the larger of two circles with center P and radius p and the smaller of the two circles with center Q and radius q. Draw PQ. Which of the following statements is false?

a.) p - q can be equal to PQ

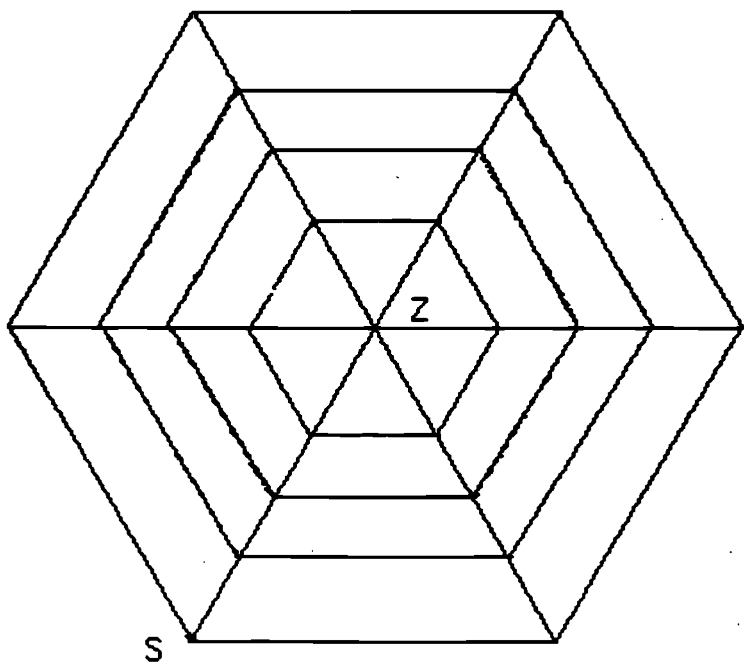
b.) p + q can be equal to PQ

c.) p + q can be less than PQ

d.) p - q can be less than PQ

e.) none of the above

Appendix M
Student Problems



The perimeters of each regular hexagon that share a common center point are reduced by 24 and the polygons go inward.

SZ=16

Find three non-sharing side polygons who's perimeters added together equal 152.

Appendix N
Trip to Mars

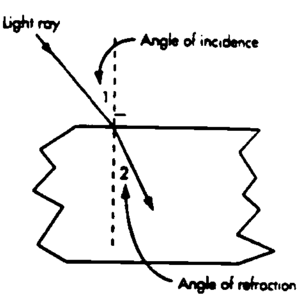
You and your CPS team have been taken by lunar shuttle to the Mare Imbrium Recreational Facility (MIRF). Mare Imbrium is the largest flat region of the lunar surface and has been used for decades as a location for school field trips. MIRF is located equidistant (350 km) from the four craters Plato, Aristillus, Archimedes, and Timocharis. Your math and astronomy instructors have given you four days to complete four problems. After four days, you must return to the lunar colony Galileo. You should be able to complete the problems within a day and a half. For the rest of your stay, you and your CPS team may take advantage of the moon's largest and most complete recreational facility.

1.* Your first task is to determine the area of Mare Imbrium bounded by centers of the four craters. Moving counterclockwise with a lunar transit, your CPS team sweeps the angles between the crater centers. The angle from Plato to MIRF to Aristillus measures 115°. The angle from Aristillus to MIRF to Archimedes measures 45°. The angle from Archimedes to MIRF to Timocharis measures 60°. The angle from Timocharis to MIRF to Plato measures 140°. What is the area of the quadrilateral connecting the centers of the four craters?

2.* Your second task is to determine the length of a tunnel to be drilled through a lunar peak at the center of a crater. From a point on the crater floor, you and your CPS team run ropes to the two ends of the proposed tunnel. Measuring the ropes, you find that the distance along the first rope is 24.5 m and along the second is 21.2 m. The two ropes meet at a 68° angle. What will be the length of the tunnel? At what angle with the first rope should the tunnel be drilled so that it comes out at the correct exit point?

3. Your third task is to determine the thickness of a vein of bauxite located 30 km southeast of MIRF. On the surface, the vein appears as a 36-m-wide strip that is over 100 m long. The distance across the vein at the surface, however, is not the thickness of the vein. Lunar geologists know that the vein recedes from the surface at an angle. It is your task to determine that angle and from it calculate the actual thickness of the vein.

4. Your fourth task is to determine the identity of a piece of clear, hard material uncovered by lunar historians near one of the early moon landing sites. Geologists have narrowed your search down to four possiblities: quartz, glass, zircon, or diamond. Use Snell's law to determine the identity of the material. Snell's law expresses the relationship between the angles formed by a light ray moving from one medium to another. Light bends as it passes into more dense material because it slows down. By measuring the angles formed by light bending as it moves from the vacuum of the lunar surface through the clear, hard material, you can determine the material's identity.



The figure at right shows the angles formed by a light ray moving from one medium to another. The angle of incidence is $\angle 1$. The angle of refraction is $\angle 2$. These angles are related by the following formula (Snell's law):

$$\sin \angle 1 = k \sin \angle 2.$$

The constant k depends on the nature of the two mediums. The table below gives the value of Snell's constant for light going from a vacuum or air into quartz, glass, zircon, and diamond.

Substance entered from vacuum or air	Quartz	Glass	Zircon	Diamond
Snell's index of refraction	1.46	1.5	1.9	2.42

You and your CPS team find several measurements of different angles of incidence and the corresponding angles of refraction for the glass-like material. Your results are shown in the table below. Use Snell's law to identify the mysterious material. (Unfortunately, you suspect that one of the measurements was found incorrectly. Therefore you may have to test more than one pair of angles.)

Angle of incidence ($\angle 1$)	15°	20°	25°	30°	40°	50°	60°
Angle of refraction ($\angle 2$)	6.1°	10.4°	12.9°	15.3°	19.8°	23.8°	27.1°

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Appendix O
Experiment

Please show all work. Make sure every step is included in your solution of each task.

Station #1: Water displacement

Find the radius of the ball dropped in the water.
Do not try to measure the ball with a ruler!!!

Station #2: Cone Construction

Construct a cone with a radius = 2 inches.

Station #3: Water in a Cylinder

Find the depth of the water if the cylinder was turned upright.
Do not tip the cylinder upright!!!!

Station #4: Tennis Balls

Assuming that the can is cylindrical, find the volume of the air inside the can. Do not open it !!!!!

Station #5: Comparing Boxes

Which box can hold more, box A or box B?

Station #6: Pyramid

What fraction of the large pyramid is filled with water?

Appendix P
Student Reflection

Member Names:

1.) What were we supposed to do?

2.) What did we do well?

3.) What would we do differently?

4.) Do we need any help?

Appendix Q
Sample Lab

High School CHEMISTRY

The ACS is developing microscale versions of *ChemCom* laboratory activities. This issue of *Chemunity News* presents the fourth of these *ChemCom* Microscale Labs.

Voltaic Cells

In this laboratory activity, students are asked to study several voltaic cells. The voltages of the electrochemical cells can be measured by connecting the two appropriate half-cells to the voltmeter. Each half-cell is contained in one dropper assembly (see Fig. 1). A half-cell is immersed in a solution containing ions of the same metal. The half-cells make electrical contact through the conducting agar at the bottom of the beaker. This conducting agar serves as the salt bridge and at the same time prevents the metal ion solutions from mixing (see Fig. 2).

Procedure

Put on your goggles.

Zinc–Copper Electrochemical Cell

1. Connect one alligator clip from the voltmeter to the Cu*(R)* electrode. Cu*(R)* means the regular-sized copper electrode.

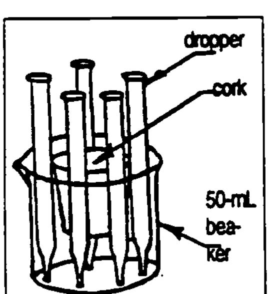


Fig. 1.

ChemCom LABNOTES

2. Connect the other alligator clip from the voltmeter to the Zn electrode. If the needle is deflected in the positive direction, secure the wire. If the needle is deflected in the negative direction, reverse the alligator clips.
3. Record the reading on the voltmeter.
4. Disconnect the alligator clips.

Magnesium–Copper Electrochemical Cell

1. Connect one alligator clip from the voltmeter to the Cu*(R)* electrode.
2. Connect the other alligator clip from the voltmeter to the Mg electrode. Reverse the clips if needed.
3. Record the reading on the voltmeter and disconnect.

Iron–Copper Electrochemical Cell

1. Connect the alligator clip from the voltmeter to the Cu*(R)* electrode.
2. Connect the other alligator clip from the voltmeter to the Fe electrode. Reverse the clips if needed.
3. Record the reading on the voltmeter and disconnect.

Studying Electrode Size

1. Connect one alligator clip from the voltmeter to the Zn electrode.

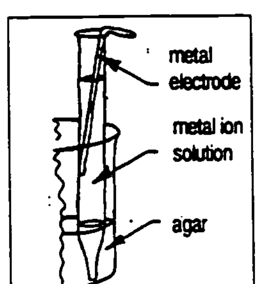


Fig. 2.

2. Connect the other alligator clip from the voltmeter to the Cu*(R)* electrode. Reverse the clips if needed.
3. Record the reading on the voltmeter and disconnect the Cu*(R)* clip.
4. Connect the free alligator clip from the voltmeter to the Cu(1/2) electrode. Cu(1/2) means the half-sized copper electrode. Record the reading on the voltmeter and disconnect the Cu(1/2) clip.
5. Connect the free alligator clip from the voltmeter to the Cu(1/4) electrode. Cu(1/4) means the one-quarter-sized copper electrode. Record the reading on the voltmeter, and disconnect both alligator clips.

Teacher Preparation

To assemble the half-cells in the beaker, obtain six droppers and a 50-mL beaker. Clean the droppers thoroughly, and rinse with distilled water. Hold the droppers in place around the perimeter of the beaker using a cork (see Fig. 1).

Carefully add hot agar solution to the beaker to a depth of 1 cm. The agar solution contains 1% agar and 1.5% ammonium nitrate. Allow the agar to cool undisturbed.

Clean each of the electrodes with steel wool. For the Cu*(R)*, Zn, and Fe electrodes use a fairly low gauge of wire. For the Mg electrode, use magnesium ribbon. For the Cu(1/2) and Cu(1/4), use higher gauge copper wire.

After the agar has solidified, fill each dropper two thirds full with the appropriate metal ion solution. For the copper electrodes, use 0.5 *M* copper(II) chloride solution; for the zinc electrode, use 0.5 *M* zinc sulfate solution; for the magnesium electrode, use 0.5 *M* magnesium chloride solution; and for the iron electrode, use iron(III) chloride solution. Be careful to label the droppers appropriately. Put each polished electrode into the solution of its own metal ion. Bend over a small part of the electrode to keep it from falling below the tip of the dropper (see Fig. 2).

Appendix R
Nuclear Chemistry Research Project

Nuclear Chemistry Poster/Exhibit: Living with Benefits and Risks

TOPIC: ______________________

Assignment: to create a poster/exhibit which includes all of the following about your topic:

- a clear explanation of the nuclear chemistry involved (nuclear equations) - min. 1 paragraph
- a description of why/how it is a benefit or a risk (depends on topic) - min. 2 paragraphs
- a description of the opposite side of the issue [benefits (positives)/risks (negatives)] - min. 1 paragraph
- color
- creativity ! (BONUS POINTS)
- neatness - your information does not have to be typed or word-processed, however other students, and the teacher, must be able to read it
- a minimum of one visual aid
- a bibliography (no particular format) that includes a minimum of four sources (only one source may be an encyclopedia)
- ➔ no plagiarism! If you print something off of a computer, you must put it into your own words before adding it to your exhibit.

****

- 5 multiple choice test questions with a key - not part of the exhibit (students must be able to answer these questions by using information at your exhibit)

Important Dates: Library Research: 2/16 - 2/18
Test Questions due: 2/18 (beginning of class)
Exhibits: 2/19 & 2/22
Unit Test: 2/26

Grade: teacher evaluation = 26 points
8 points (test ques. & bibliography)
34 points total

Appendix S
Sample Problem

W.S. 12-5

NAME. ____________________

GROUP: __________ DATE: __________

5-GAS LAW PROBLEMS (MIXED)

Remember: Temp. must be in Kelvin.

SHOW ALL WORK!!

1. A sample of gas occupies a volume of 240 mL when its temperature is 20.0°C. What volume will the sample of gas occupy if the temperature is changed to 40.0°C at constant pressure?

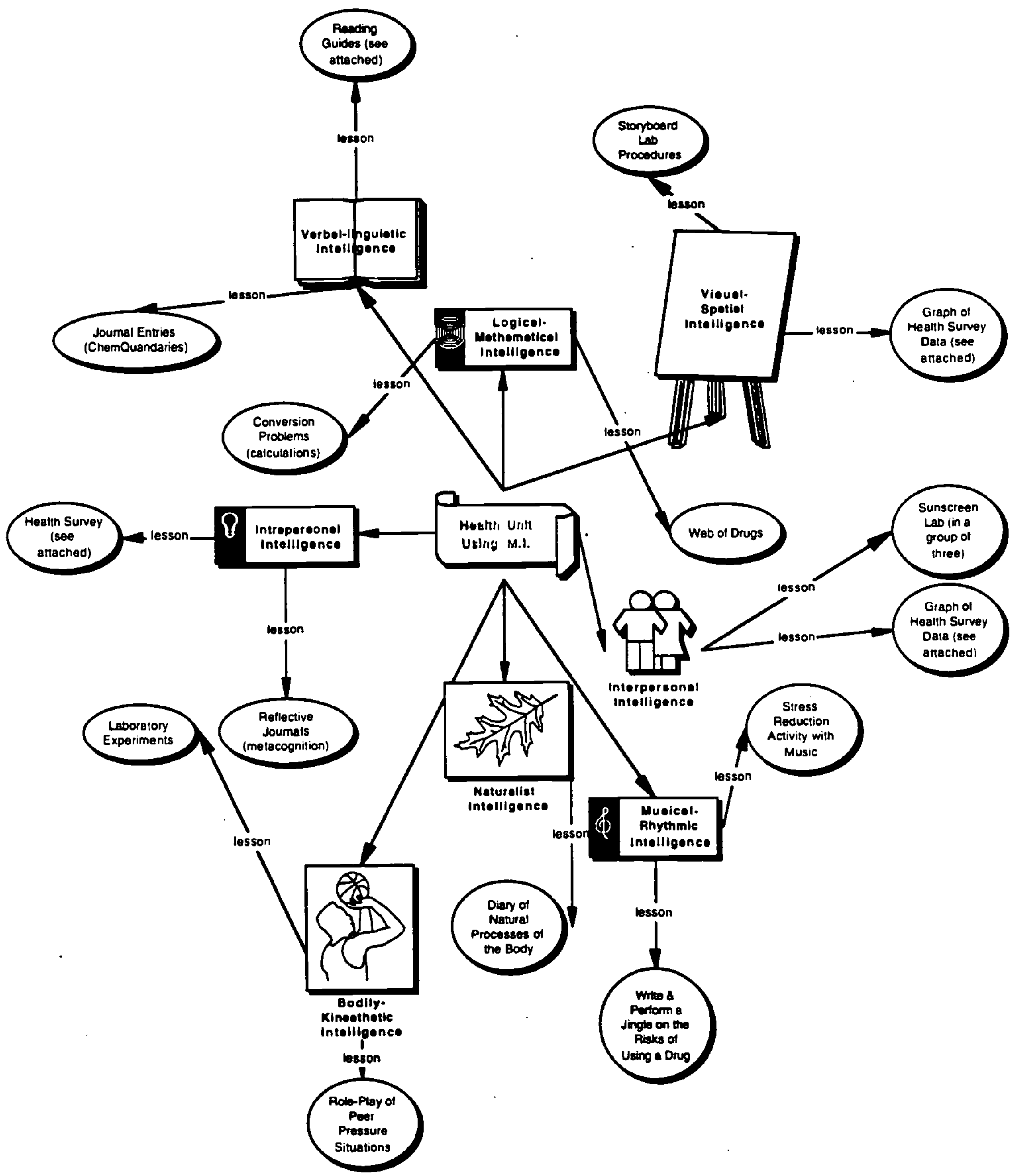
2. A sample of gas has a volume of 180 mL when the pressure is 740 mm Hg. What volume will the gas occupy if the pressure is increased to 800 mm Hg at constant temperature?

3. A sample of gas occupies a volume of 800 mL when the pressure is 680 mm Hg. What pressure will cause the gas to occupy a volume of 700 mL, assuming that there is no change in the temperature?

4. A sample of gas occupies a volume of 400 mL when the temperature is 10.0°C. What must the temperature be changed to in order to make the volume of the gas become 250 mL, assuming that there is no change in the pressure?

5. A sample of gas occupies a volume of 200 mL when the temperature is 27.0°C and the pressure is 700 mm Hg. What volume will the gas occupy if the temperature is changed to 127°C and the pressure is changed to 800 mm Hg?

Appendix T
Concept Map



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