

MASTERY OF A PROBLEM SOLVING STRATEGY FOR IMPROVING  
HIGH SCHOOL CHEMISTRY STUDENT ACHIEVEMENT

by

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## ABSTRACT

This investigation determined the correlation between problem-solving strategies and student achievement. Problem solving is an important part of real-world application and many students have not acquired the essential skills to work through complex problems that they may encounter everywhere. Student interviews, teacher and student surveys, prelab and postlab assessments, and journal writings were analyzed to determine an improvement of student understanding through the implementation of the DRUFAS problem-solving strategy. As a result of integrating DRUFAS an increased proficiency in answering complex problems occurred in a high school chemistry classroom.

## INTRODUCTION and BACKGROUND

The past three years I have taught high school science in a small rural school district in south central Montana. As the high school science teacher, I instruct an average of eighty students in the subjects of biology, chemistry, physics, advanced biology, environmental science, and earth science. All of the nearly 200 k-12 students attending the school district speak English as their primary language with several students being fluent in Finnish, German, and Spanish as a second language. The majority of students that attend school come from low to middle-income families with very few students from high-income households. Consequently, the entire school district is homogeneous in the academic experiences students bring to the classroom resulting in a limited range of diversified skills.

Throughout my eleven years as an educator, I noticed a general decline in students' analytical abilities resulting in minimal skills for solving even simple scientific tasks such as operating a microscope, reading a graph, or calculating for percent yield. This complex problem is not due to a lack of knowledge since most students do well when asked similar questions or prompted by the instructor. However, even above average students need help in working through simple problems if it requires several steps. Applied problem solving skills and analytical skills are also lacking in many other courses, such as Mathematics, History, and English.

### Focus Question

High School students over the past decade have diminished skills in problem solving and analytical thought which led me to my problem statement and my primary focus question: How will using the DRUFAS problem solving strategy impact student

achievement for mathematic intense chemistry questions? Furthermore, I wanted to determine which step(s) of the problem solving strategy was most effective for students on scientific and mathematic oriented tasks in chemistry. Finally, I researched the transfer of these skills to other academic areas to determine if this problem-solving strategy carried over to other academic areas.

## CONCEPTUAL FRAMEWORK

The principle goal of education is to create people who are capable of doing new things, not simply of repeating what other generations have done—people who are creative, inventive, and discoverers. The second goal is to form minds, which can be critical, can verify, and not accept everything they are offered (Piaget, 1954). The challenges facing our workforce are often ill structured and most contain unclear goals, insufficient constraints, multiple alternative options, and different criteria for evaluating proposed solutions (Ogilvie, 2008). As educators we need self-thinking students that can solve many complex problems of today's world. Many of the problems our current students will encounter do not even exist today. These students cannot simply repeat the procedures of the past to accomplish this feat, thus problem-solving strategies are important skills that every student needs to be successful.

The teaching of specific problem-solving skills gives students and teachers a language with which to talk about the strategies used to solve problems (Higgins, 1997). This language allows teachers to communicate methods students need to answer real world problems within the confines of the classroom. These problem-solving skills should transfer to successful discoveries outside the classroom. As educators we want our

students to be independent thinkers for a lifetime, not just during a course, thus these skills must be transferable to other areas of the students' lives to have meaning and be effective.

Developing and enhancing problem-solving abilities of students have long been important objectives of science education. Problem-solving ability is generally viewed as the ability to think critically, to reason analytically, and to create productively, which all involves quantitative, communication, manual, and critical-response skills (American Association for the Advancement of Science, 1993). Problem solving is an integral part of science and it should permeate throughout the entire science curriculum (Russell & Chiappetta, 1981). Furthermore, teaching must involve students in inquiry-oriented investigation in which they interact with their teachers and peers...they apply science content to new questions; they engage in problem solving, planning, decision making, and group discussions (NRC 1996). These skills all lead to successful scientific intuition that guides students to ask the right questions, apply the proper knowledge, and eventually persevere with a conclusion to the problem.

Perseverance in solving problems is also important because students need to realize that some problems require a lot of time to solve (Higgins, 1997). Many problems in science, technology, engineering, and mathematics (STEM) take many complex steps that students need to recognize a pattern and formulate a method to solve. This is where understanding a large quantity of information may allow some students to solve problems faster and more accurately than others. As educators we continually attempt to expand the knowledge base and the analytical thought of our students.

Expert skill may exist because of a sizable body of knowledge (Larkin, McDermott, Simon, & Simon, 1980). Although experts in any field may have to know a large amount of information they still have to extract that information and effectively

problem-solving skills allows them to identify patterns that lead to a conclusion for the question at hand. Knowledge must be indexed by large numbers of patterns that, on recognition, guide the expert in a fraction of a second to relevant parts of the knowledge store (Larkin et al., 1980). To be successful in problem solving, it appears that students need to have some background knowledge and to possess certain science-process skill (Chang & Weng, 2002)

Most ‘experts’ have an ability to work through complex problems with ease toward the final answer. The most obvious difference between expert and novice is that the expert knows a great many things the novice does not know and can rapidly evoke the particular items relevant to the problem at hand (Larkin et al., 1980). The other skill that expert problem solvers use effectively is forward thinking to solve problems, often thought as a much easier method to solve problems than the working backward. Forward thinking uses problem solving skills to manipulate the information to reach a meaningful answer, by using multiple familiar steps throughout the question can be fully understood and solved. Meanwhile, working backwards requires multiple steps to solve the difference between the answer and the information given. Teachers, being experts and familiar with a problem, may tend to use a working forwards approach when demonstrating how to solve a problem. But for students, when a problem is unfamiliar, mean-ends analysis is the strategy employed initially (Heyworth, 1999).

Drawing on past skills or knowledge is only part of effective problem solvers. Most real-world problems are ill defined to some degree, lacking required information and not having a well-defined ending state—and therefore with neither a known correct nor best solution (Fortus, Krajcik, Dersshimer, Marx, & Naaman, 2005). Many of the scientific problems of today are lacking important information to be easily solved, for this

reason effective problem solving strategies and background knowledge of the question at hand must be established for student achievement for modern scientific questions.

Solving a problem requires students to understand the problem, make accurate observations, interpret data, formulate a valid hypothesis, and find solutions to the problem (Chang & Weng, 2002). If this looks familiar, it is the bases of the scientific method taught within most science curricula today and is effective at solving most problems in the scientific and real world.

The major reasons students find problem solving difficult is that they fail to construct meaning from the problem statements, not being able to link the meaning of the problem to their knowledge structure, or simply lacking the appropriate knowledge structure for that specific content area (Lin, Chiu, & Chou, 2004). Student must acquire the knowledge base before making sound scientific decisions. The method in which students access this knowledge is debatable, however they must educate themselves prior to problem solve effectively. Students that view science as static assert that science consists of a group of facts that are best memorized. On the other hand, those who view science as dynamic believe that scientific ideas develop and change, and that the best way to learn these ideas is to understand what they mean and how they are related (Songer & Lin, 1991).

In Chang's 2010 study of prior knowledge and reasoning skills the results suggest that more teaching emphasis should be placed on reasoning skills when developing students' divergent-thinking abilities, while stressing more domain-specific knowledge when students' convergent-thinking ability is considered (Chang, 2010). Educators should encourage students to gather as much meaningful knowledge as possible by multiple means such as textbooks, blogs, wikis, and other resources available to them. The goal is

for students to acquire more information for the specific task and future knowledge base. Chang's study also encourages Earth science teachers to include fostering students' higher order thinking skills by problem solving in their teaching (Chang, 2010).

The major movement in science curricula today is inquiry-based learning and the skill sets that accompany inquiry-based style of teaching encompass problem-solving strategies. Some educators are hesitant to make the shift toward science by inquiry for that very reason, students don't know how to ask meaningful questions and lack the information to solve the inquiry portion of the lesson. Although inquiry-based curricula and teaching practices give students experience in dealing with real-world problems, it is not yet evident whether the activities in inquiry-oriented classrooms help students construct knowledge that will help them deal with real-world problems while working in real-world settings (Fortus et al., 2005). Evidence gathered from several K-12 science programs that stress inquiry has taught us much about students' abilities and difficulties when they are required to struggle with ill-defined problems. For instance, we have learned that children tend to generate low-level factual questions rather than questions that could extend their understanding (Scardamalia & Bereiter, 1992).

From my experience teaching inquiry-based science, the students must have some prior knowledge of the procedures to ask effective questions to solve the problem, without this information students quickly become frustrated. Furthermore, the need for the correct answer(s) supersedes the path that the students travel to acquire that answer. As with some inquiry-based laboratory exercises persistence must be a factor for learning to ultimately take place. For this reason, practicing effective problem solving strategies prior to inquiry-based lab exercises provides students with the tools to work through complex real-world problems.

Consequently, many students lack the skills they need to be successful problem solvers through inquiry, the problem lies with transfer of knowledge. If students are unable to transfer what they learn in school to real-world problems then the meaning behind every science lesson is lost. The research suggests that transfer of problem solving learned in science classrooms is not easily achieved (Bransford & Schwartz, 1999). These skills must be introduced early, reinforced often, and mastered for many years to benefit students. As educators, we must provide opportunities for our students to develop these skills in introductory courses. If we wait until only later courses to challenge students with rich, complex tasks, then they will have little time to gain confidence and experience with these approaches (Ogilvie, 2009).

Instruction in science is generally aimed at achieving two goals: the acquisition of a body of organized knowledge in a particular domain and the ability to solve problems in that domain (Heyworth, 1999). Advanced problem solving skills must be applied to effectively use both branches thus, allowing success in science and reasoning. These strategies must be practiced and challenging for students to become familiar with how they are employed when difficult problems arise. There is a great deal of evidence that students who wrestle with problems and expand on their answers learn more effectively than students who simply seek the correct answer (Pazos, Micari, & Light, 2010).

## METHODOLOGY

My action research project was conducted within a high school chemistry course throughout three units between March and mid May. I employed the DRUFAS problem-solving strategy early in the study to answer my primary focus question: How will using the DRUFAS problem solving strategy impact student achievement for mathematic intense

chemistry questions? Secondly, I researched chemistry students' ability to use the DRUFAS problem-solving strategy to determine which step was most effective for them on scientific and mathematic oriented tasks in chemistry. Thirdly, I researched the transfer of these skills to other academic areas to determine if student achievement improves as a result of this problem-solving strategy.

### Participants

The students that participated required parental permission which limited my study to eight students within a class of eighteen students. Although eight students were allowed to participate in the statistical analysis of this study I chose to include the remaining ten students so they would be familiar with the steps of DRUFAS for future science courses. This student group consisted of five female and three male students. The ethnicity of this group included one female student of Hispanic descent and one male student of Native American descent, the remaining six students were Caucasian. The entire group was of middle-class social-economic standing. This group had four high achieving students, three average students, and one below average achieving student.

### Intervention

To accomplish this, I implemented a problem-solving skill called the DRUFAS method into my chemistry classroom. The acronym stands for **D**escribe and or **D**iagram what you are asked to do, **R**atios or **R**elationships needed for conversion, list the **U**nits and variables given to you, list the **F**ormulas and equations you believe you'll need, complete the **A**lgebra required to solve the problem, and write a **S**entence that contains the numeric **S**olution and what it means, this information is located on Appendix A (Graves, 2010).

The DRUFAS method of problem solving was adapted from a suggested problem solving strategy by a colleague, Jesse Graves. This strategy was introduced to me during a conversation about student achievement and she gave me some information on a method with the acronym DUFAS which was effective for her physics students. The acronym DUFAS in my opinion was not appropriate for my students nor would it fit exactly into my chemistry classroom so I added the **Ratio** step to include balance equations and proportion labels used later in the problem solving method.

As with so many of the challenging questions chemistry students work through I find that if a student does not understand what the question is asking or if they are missing details for solving these problems they simply give up without attempting. I liked using DRUFAS because it allowed me to observe students' working toward understanding. If information was missing it allowed me as a facilitator to simply interject with a missing part of the problem and they continued working toward a solution. Furthermore, teaching a specific problem-solving strategy gives students and teachers a language with which to talk about while solving problems (Higgins, 1997).

This capstone project contained two units each applied the DRUFAS strategy to complete the several tasks in each unit for better understanding. Each unit used the basis of conservation of mass and stoichiometry to solve. For this reason I could not begin my integration until the conclusion of the stoichiometry unit. Once the stoichiometry unit concluded, the next two units (solutions/molarity and gases) used these fundamental ideas to solve problems pertaining to solution concentration, freezing point depression, boiling point elevation, pressure, volume, and molar concentration in gases.

### Data Collection

The introduction of the DRUFAS strategy began during the end of the stoichiometry unit, more precisely, limiting reactants. As a baseline data collection I used a laboratory journal entry before initiating DRUFAS. I then divided the participating students into three groups to develop a case study for each achievement level. Group A contained the four high achieving students, Group B contained the average students, and Group C contained the one lower than average student. During the laboratory journal entry students were prompted the following question:

If you needed a specific amount of product (Copper) and only had limited amounts of supplies (Zinc and Copper II sulfate pentahydrate) how would you determine the right combination of reactants to mix in a chemical reaction as to limit the amount of waste material you would accumulate during the reaction?

(Appendix B)

Following the baseline data collection I introduced the concept of DRUFAS to the students and had students practice this problem solving method with several examples I worked through in cooperative group settings and before the entire class. This practice allowed students observe how DRUFAS permitted them to actively work through difficult problems of limiting reagents. Following the introduction of DRUFAS I had the participants complete a pre-intervention survey that contained the same questions as the post-intervention survey. I did this to determine student thoughts concerning the DRUFAS strategy.

Within the first unit students used the DRUFAS method more exclusively to solve some complex problems with solution molarity. There was a pre-assessment taken with a difficult problem imbedded in a quiz. The extra credit question allowed me to assess

students' problem solving skills without decreasing their evaluation grade. This assessment is located in Appendix C.

Later in the molarity unit I introduced a complex problem of mixing two solutions of different concentration to combine with a specified volume and molarity. While solving this DRUFAS problem students had to guess and check to determine which combination worked to complete the task. This problem was designed to be a post-assessment for molarity and is located in Appendix D.

During the second unit students applied DRUFAS while learning about pressure. Much of this unit had students apply the gas laws to answer several real world problems about pressure. These problems were intentionally ill structured with me as a guiding facilitator rather than a formal teacher. By this time students understood how to use the DRUFAS problem solving method and needed to utilize this method to work through these problems. This assessment was structured to simulate real world problems that may not have a well-defined ending state. These problems are included in Appendix E. This unit was followed up with a student survey, which questioned how the students adapted to the learning environment and what adjustments were done to accomplish understanding (Appendix F).

The second unit assessed the DRUFAS problem-solving technique with the Ideal Gas Law that illustrates the relationship between molar amounts, pressure, temperature, and volume. In this unit students needed to describe what they are asked to accomplish, identify the ratios needed, list the units and variables they were given and what must be solved, list the formulas they needed, complete the algebra required to solve the problem, and finally write a sentence that contained the numeric solution to the question (Appendix E).

Following the second implementation unit, I conducted my surveys to determine if the DRUFAS problem-solving technique was useful and transferred to understanding throughout all three units. From this data collected I selected a group of eight students of different abilities based on the assessment to complete the interview process. The student interviews focused on the effectiveness of this problem-solving technique and focused mostly on the gas law unit, effective graph interpretation, and gas law understanding (Appendix G). The data sources are described in Table 1 below.

Finally, following the implementation of the DRUFAS problem-solving strategy I conducted a teacher staff survey in the following curricular areas (Mathematics) to determine if there was transfer of the strategies into other classrooms (Appendix H).

Table 1

*Triangulation Matrix*

<b>Research Question</b>	<b>Source Data I</b>	<b>Source Data II</b>	<b>Source Data III</b>
<i>Primary Question</i> 1. How will using the DRUFAS problem solving strategy impact student achievement for mathematic intense chemistry questions?	Student Surveys	Pre-assessment observations	Post-assessment observations
<i>Secondary Questions</i> 2. What step in the DRUFAS problem-solving strategy did students succeed?	Student Surveys	Student Interviews	Teacher Observations
3. Did the DRUFAS problem-solving strategy transfer into other curricular areas?	Student Surveys	Staff Surveys	Grade Improvements

## DATA AND ANALYSIS

### Primary Question

To answer my primary question of the impact of the DRUFAS problem solving strategy I used laboratory responses, pre-intervention and post-intervention assessment responses, and student survey questions. The laboratory responses collected several weeks prior to the intervention units and the assessment responses during the six week intervention units were compared to determine the effectiveness of the DRUFAS problem solving method for students' critical thinking skills.

The results from the pre-treatment/post-treatment written responses taken from the laboratory report prior to intervention and questions embedded into an exam and homework questions displayed a slight increase in understanding of the question process and a greater improvement in completion of a detailed answer. Although the questions increased with difficulty throughout the intervention, students were able complete most questions with the application of the DRUFAS strategy.

The pre-intervention gauge used the laboratory summary displayed in appendix B in conjunction with an assessment question included in appendix C to determine the effectiveness of each group of students' ability to solve complex problems. The post-intervention measurement included a question displayed in appendix D and an exam question is discussed in each of the following case study groups.

Group A included four of the highest achieving student in this chemistry class and were my first group to assess the impact of DRUFAS. Three of the four members of group A answered the laboratory response thoroughly; meanwhile, one student did not complete the conclusion and observation portion of her laboratory response. I cross

referenced these responses with the pre-intervention assessment question and only two of the four members from group A attempted to answer the question with only one student from this group answering this question correctly.

The post-intervention questions resulted in all four students from group A completing the both the complex homework question observed in appendix D and the exam question. All students illustrated an improvement of their question completion skills while using the DRUFAS strategy. These results can be observed in Table 3.

The average achieving students in group B had even less success at the complex problems in the pre-intervention assessments, only one of the three students completing the laboratory response. Although this student completed the laboratory summary, his response was minimal and missed important quantitative data usually observed in a complete response. A different student from this group of three received full credit for the pre-intervention assessment question while the other two students did not attempt to answer the question due to its complexity.

The post-intervention assessment of group B presented the greatest improvement in the completion of complex problems with all of the members completing the complex problem in appendix D and answering the complex problem found in the exam. The results of one student's response in group B can be observed in Figure 1 below. This same student did not attempt the pre-assessment question and had a minimal laboratory response.

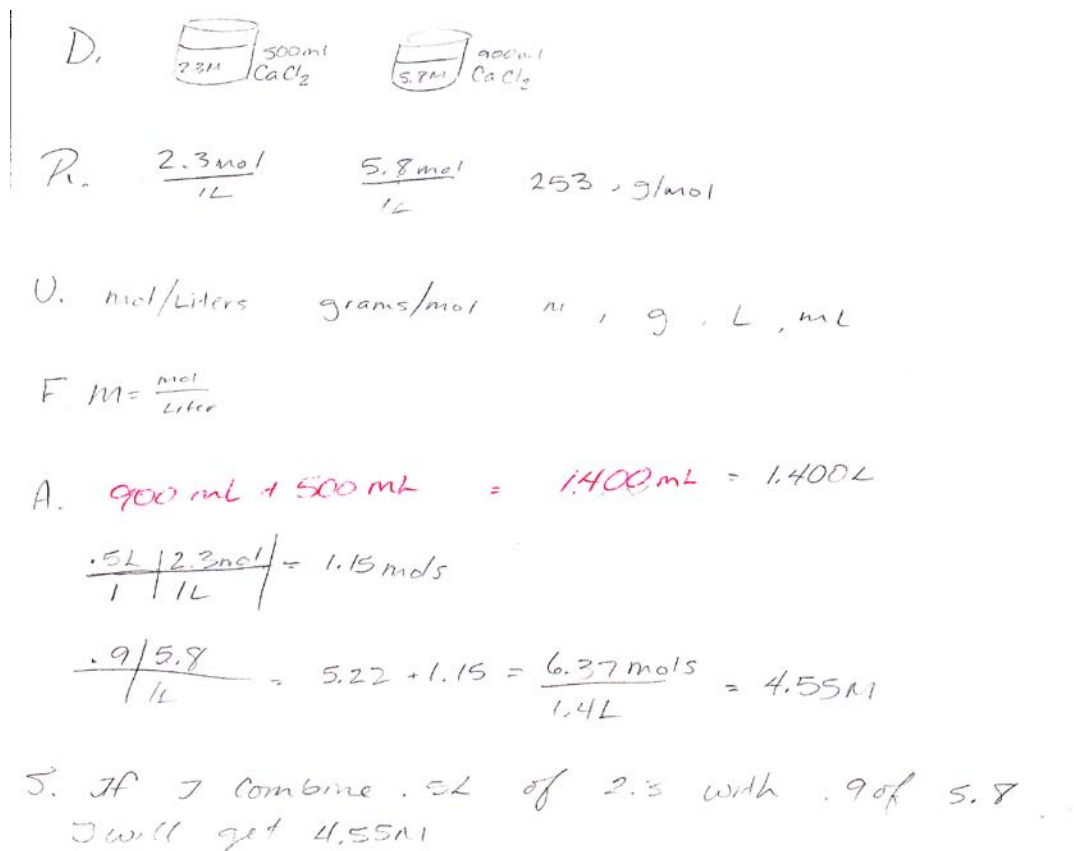


Figure 1: Student response to a DRUFAS question.

All members of group B attempted to answer this exam question while one student had difficulty with the **Algebra** and **Sentence** steps of the DRUFAS strategy she did complete the other steps of the strategy. Some analysis of this student's response allowed me to determine she misidentified the ratios needed for completion of her answer. With this information I would now be able to help this student better understand why the question was missed. However, if this question had not required the use of the DRUFAS strategy and she left the question blank I would not know what information was missing for student comprehension. These results are also displayed in Table 3.

The below average achieving student in group C did not complete the laboratory summary or attempt the pre-intervention assessment question. This result was not

surprising and was the main reason I chose to conduct this intervention. The averages of the responses can be observed in Table 2.

Table 2  
*Student Results for Pre-intervention Questions (N=8)*

Groups	Laboratory Summaries	Assessment Question
Group A	75%	50%
Group B	33%	33%
Group C	0%	0%

Meanwhile, the post-intervention response of the below average achieving in group C showed some improvement in the exam response. This student chose not to complete the DRUFAS Molarity assignment so I was unable to assess his response in this portion of the assessment. These results are also represented in Table 3.

Table 3  
*Student Results for Post-intervention Questions (N=8)*

Groups	DRUFAS Molarity Response	Exam Response
Group A	100%	100%
Group B	100%	75%
Group C	0%	66%

As a result of these assessments I acknowledged that students needed to display how they worked through the question so they could complete the task. For this reason, students may not attempt to answer difficult problems although they have the skills and the background information to because they lack a strategy to solve the problem which is discussed by Heyworth (1999) studying his study of forward versus backward thinking

problem solving. A means-end analysis is used initially when a problem is unfamiliar. From this knowledge I felt that DRUFAS would be helpful since it breaks the problem down into steps and each step must be written out.

The student surveys displayed that DRUFAS was easy to follow and allowed students to complete problems with confidence which was used to triangulate the impact of DRUFAS for student achievement. The pre and post-treatment average Likert score for this question was 2.375 which indicated students agreed with this statement (Table 3). There was a general agreement that the DRUFAS strategy was useful through the pre-intervention and post-intervention survey.

While introducing the DRUFAS method several students affirmed that their thoughts needed to be written out while discussing a problem in their group by saying, “I don’t like doing the extra work.” That same day however ended with another student saying, “He noticed how it arranged their thoughts.” This student later on during the intervention really enjoyed using DRUFAS and confirmed this during the student interviews.

#### Effectiveness of Each Step of DRUFAS

To answer the secondary question pertaining to the effectiveness of each step of DRUFAS as a problem solving strategy for student success I used student survey and interview responses and my own observations. Several students commented during the student interviews that diagramming allowed them to work through a problem since they could visualize what the question was asking and understand the concept for solving the problem. This would then allow them to picture what was needed for the ratio and unit steps of DRUFAS. One student said, “I would keep using DRUFAS because it works well.” Meanwhile another student said, “Diagramming the problem, I can work better

when I see things.” This process helped them think through problems as they solved them. One student stated the DRUFAS strategy was useful for him since it allowed him to write out what he was thinking.

From this information I concluded that students benefitted most from using the diagramming step of DRUFAS mostly for the conceptual understanding of what they are attempting to complete. Furthermore, this was supported with the survey statement: Describing and diagramming is a problem solving technique that is useful to me in other classrooms. This question averaged 2.5 out of 5 on a Likert survey response resulting in an agreement of the statement. Triangulation with this data and discussions during classroom activities revealed that students benefit from diagramming or describing what the question asks before beginning the task of answering the question. When students are allowed to diagram, draw, or either written or verbally describe what is occurring they can complete the problem with confidence. This information was useful since this skill was practiced each time students used the DRUFAS method to solve a problem. Many problems began with a simple drawing of what the question was accomplishing. From this drawing I gathered useful information as to what the student was thinking while they solved the problem. This was also useful for students to refer back to as they worked through the remaining steps of DRUFAS to gain confidence their answer was correct.

Through my observations I determined that students struggled with the **Algebra** step of the strategy. This step required students to synthesize the previous steps of the DRUFAS strategy and if any one part is missing in the **Ratio, Unit, or Formula** stages of the strategy a student may not be able to complete the complex question.

### Cross-Curricular Transfer

The other secondary question answered through this intervention was how DRUFAS transferred into other curricular areas such as mathematics. For this part of the project students answered survey and interview questions and this data were triangulated with staff survey to determine the effectiveness of transfer. Although student survey responses for the use of DRUFAS in other curricular areas were neutral, the interview questions responded that students may use it if presented with a challenging problem that required multiple steps. One student commented, “It helped me think troublesome problems over more.” Meanwhile, another student noticed slight improvement in her Pre-calculus scores while using the DRUFAS strategy. She did not use each step in her Pre-calculus course but she did begin to diagram more while working through complex mathematic problems. This information was triangulated with a staff survey (Appendix H) completed by the mathematics instructor and myself. Further triangulation was obtained through informal staff interviews and grade improvements in those areas for the students participating in this study.

The teacher survey confirmed that there is a connection between problem solving abilities and curricular area (math and science), as well as the real world application of problem solving. This survey also concluded that there was no change in grade improvement between chemistry and math students as a result of this intervention. Upon further discussion with the math instructor he was unaware of any improvement in student achievement during the integration of DRUFAS in the chemistry classroom.

## INTERPRETATION AND CONCLUSION

Data collected during the course of this intervention was analyzed to answer my primary focus question on the effects of implementing the DRUFAS problem solving strategy for high school chemistry students. Evaluation of the data collected from two units suggests that problem solving skills improved on complex, multiple step questions pertaining to concentration and gas laws. This allowed me to challenge my students with more difficult questions that I have used in an advanced chemistry curricula in past years. Similar to the Higgins (1997), perseverance was needed while solving most of these challenge problems and by breaking the question down in steps students begin to understand that it takes time to answer these complex problems.

Student surveys and interviews indicated that my students generally appreciated trying something different to work through complex problems. The interviews resulted in all students thought DRUFAS was useful and helped them throughout the end of the course. However, one student commented on its repetitive nature in the ratios, units, and formulas steps. Students seem to have confidence when working through challenge problems and this allowed me to tier to more difficult questions during class discussion or other informal assessments not included in the appendices.

As an educator, this project allowed me to ask students more challenging questions than previous years and witness how each student went about solving these questions. Throughout this intervention I was able to guide students as a facilitator rather than a leader at the front of the class. It also allowed me to differentiate my curriculum since DRUFAS was broken down into multiple steps this allowed me to meet the students' needs if they were challenged beyond their level of understanding.

As for answering the secondary question if DRUFAS transferred into other curricular areas I was unable to conclude there was any improvement. I was not surprised since Bransford and Schwartz (1999) suggested that transfer of problem solving learned in science classrooms is not easily achieved. This skill needs to be reinforced often and mastered for many years to show student improvement.

Furthermore, as an educator that uses action research during this intervention I had to adjust the project to collect data while embedding it in my curriculum. I used parts of the DRUFAS method weeks in advance during class discussion and instructor problem solving to prepare students of how to use DRUFAS. I also infused questions into past assignments and exams for students to complete so they could practice the method on nearly a daily basis.

There were some areas of the data collection that could have been improved after further review. The number of students involved with this intervention was far less than I wished to use for statistical analysis, less than half the Chemistry class had parent permission to participate in the study. I would have liked to begin the intervention earlier in the school year; however the stoichiometry unit lasted four weeks longer than predicted for the timeline of this project. This resulted in pushing the project dates back over a month later than planned. I also would have like more consistent attendance throughout the course of the project. Coincidentally, the majority of the class was absent for several weeks due to co-curricular activities.

While conducting student interviews I focused several questions exclusively on the Gas Laws and graph interpretation mostly for the ACT exam. I wanted to analyze student perception on their understanding of graphs and visualization necessary to interpret them. This is similar to the **Diagramming** step of DRUFAS which students did an excellent

completing each time they used the strategy. I would change several of the questions to the other steps in DRUFAS to determine their usefulness.

Although an effective problem solving strategy DRUFAS had some flaws, mainly when students reached the **Algebra** step most students stopped and could not connect the previous steps to solve the problem. All the students had the means to solve the question however they did not understand how to put the information together to complete this step. Suggesting that to be successful problem solvers, it appears that students need to have some background knowledge and to possess certain science-process skill (Chang & Weng, 2002).

## VALUE

Professional development is an important part of my career as an educator and this project has allowed me to establish a method of educational growth I can conduct in any of my classrooms. Action research is adjustable according to your needs as an educator for each classroom. What methods may be effective one year may not work another and this project has allowed me an opportunity to see how action research functions. This project has also allowed me to attempt new strategies in data collection and provide a more meaningful educational experience for my students.

By incorporating DRUFAS into my Chemistry curriculum I was able to challenge my students with questions I could not have attempted without it. This strategy gave students the confidence to think critically through a problem by breaking it down into steps. The steps of DRUFAS still needed to be synthesized in the **Algebra** and **Sentence** stages but each student had the materials to complete the task of completing difficult questions.

DRUFAS benefited my students by providing them with a strategy they have not used before to solve problems not only found in the Chemistry classroom but future science and mathematics classes my students enroll. I look forward to working with these same students in my Physics classroom next year and expanding on the DRUFAS strategy for another year.

As part of my future use of DRUFAS, I wish to incorporate more real world problems into investigation to evaluate students' critical thinking skills. I would also like to improve on my focus questions, as well as my survey and interview instruments to evaluate the effectiveness of DRUFAS. Finally, I would also like to make use of this strategy in my Physics classroom next year continuing to improve student problem solving abilities.

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APPENDICES

APPENDIX A

DRUFAS PROBLEM SOLVING HANDOUT

### The DRUFAS Problem Solving Method

DRUFAS is a problem solving method I am introducing for my masters thesis data collection this spring. It is an acronym that stands for the actions students need to complete in order to solve a given problem. This will be applicable for chemistry, physics, and can be adapted to any topic to help understanding.

D : **describe** and/or **diagram** what you are asked to do

R : **ratios** and/or **relationships** needed for conversion

U : list the **units** and variables given to you

F : list the **formulas** and equations you believe you'll need

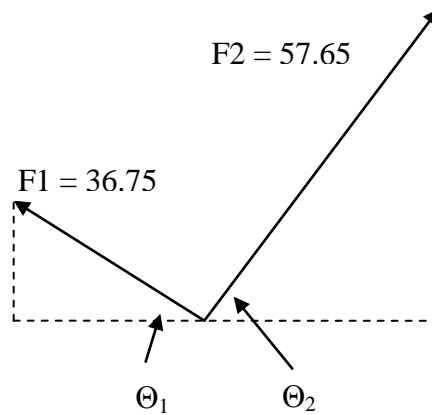
A : complete the **algebra** required to solve the problem

S : write a **sentence** that contains the numeric **solution** and what it means

Here is an example problem from an answer key I have:

An object is acted upon by two forces; F1 has a magnitude of 36.75N and is directed northwest at an angle of 25°. F2 has a magnitude of 57.65N and is directed north east at an angle of 45°. If the object has a mass of 15.25 kg, calculate the magnitude and direction of its acceleration. No friction force acts on the object.

D : (5 pts)



R : (2 pts)  $F_y = \sin \Theta \times \text{force}$   
 $F_x = \cos \Theta \times \text{force}$

U : (2 pts)  $m = 15.25$        $F_1 = 36.75\text{N}$        $\Theta_1 = 25^\circ\text{N}$   
 $F_2 = 57.65\text{N}$        $\Theta_2 = 45^\circ\text{N}$

F : (2 pts)  $F_{\text{net}} = \sqrt{(F_{x1} + F_{x2})^2 + (F_{y1} + F_{y2})^2}$        $\text{Cos}\Theta = \text{Adj/Hyp}$        $\text{Sin}\Theta = \text{Opp/Hyp}$   
 $a = F_{\text{net}}/m$

A : (6 pts)  $F_{y1} = \text{Sin}25^\circ(36.75\text{N}) = 15.531\text{N}$ , north       $F_{x1} = \text{Cos}25^\circ(36.75\text{N}) = 33.307\text{N}$ , west  
 $F_{y2} = \text{Sin}45^\circ(57.65\text{N}) = 40.765\text{N}$ , north       $F_{x2} = \text{Cos}45^\circ(57.65\text{N}) = 40.765\text{N}$ , east  
 $F_{\text{net}} = \sqrt{(40.765\text{N, east} - 33.307\text{N, west})^2 + (40.765\text{N, north} + 15.531\text{N, north})^2}$   
 $= 56.788\text{N}$ , northeast  
 $a = (56.788\text{N, NE})/15.25\text{kg}$

S : The object is accelerating at  $3.724 \text{ m/s}^2$  northeast

APPENDIX B

PRE-TREATMENT LABORATORY

## Limiting Reagents and Percent Yield.

### Introduction:

You have learned that a balanced chemical equation is like a recipe. It tells you how much of each chemical reactant is needed and how much of each chemical product is formed. However, there is more than one way to express the quantity of amount. For example you could speak of an amount of Copper and use mass. "I have 63.5 grams of Copper." Or you could speak about an amount of Copper and use a count of particles. "I have 1 mole of Copper." Since chemical amounts can be expressed in grams or moles, it is essential for a chemist to be able to convert back and forth between both units .

In this lab you will get some more practice doing just that and you will also learn about limiting reagents and percent yield.

Imagine you have a recipe that calls for 1 egg and 1 slice of bread. You have 3 eggs and 2 slices of bread. This means you have enough eggs for 3 batches of the recipe and enough bread for 2 batches. Clearly you can only make 2 batches and you will have one egg left over.

Similar situations can arise in chemistry. The reactant that you run out of first is called the *limiting reagent*. The reactant that is left over in the end is called *excess*. Often chemists do this on purpose. If a reaction needs an expensive chemical reactant, then it is usually made the *limiting reagent*. Many reactions include water, and they are done in water, so water is in *excess*.

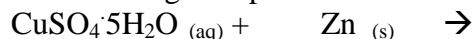
In this lab you will choose which reagent is limiting and which is in excess. You should be able to *see* that the limiting reagent is used up. It disappears! You should see that there is some left-over excess reagent.

In this lab you will also try to separate and clean your product. In both the separation steps, you will likely lose some of it, perhaps washing it down the drain. In the end, the mass of your product will be less that you expected. This happens often in chemistry. Chemists report their *percent yield* which is:

$$\text{PercentYield} = \left( \frac{\text{Actual Yield}}{\text{Expected Yield}} \right) \times 100$$

### Getting the Copper Out of Copper Sulfate Pentahydrate.

This is a single displacement reaction. Predict the products and balance the equation:



Molecular weights of the products and reactants:

$$1 \text{ mole CuSO}_4 \cdot 5\text{H}_2\text{O} = \text{_____} \text{ g CuSO}_4 \cdot 5\text{H}_2\text{O}$$

$$1 \text{ mole Zn} = \text{_____} \text{ g Zn}$$

$$1 \text{ mole _____} = \text{_____} \text{ g _____}$$

$$1 \text{ mole _____} = \text{_____} \text{ g _____}$$

Procedure

1) Obtain  $2.0 \pm 0.1$  g of  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ . Record the actual amount that you use!!!!

\_\_\_\_\_g  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$

2) Determine how much Zn will be needed to react with that much  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ .

3) Measure out that much aluminum plus about .05 grams. Record the **actual** amount that you use.

4) Measure out that much aluminum minus about .05 grams. Record the **actual** amount that you use.

---Starting with your limiting reagent, determine how many grams of copper should be formed in the reaction.

5) Do not use zinc powder.

6) Put the zinc into the  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$  (aq) and observe the reaction.

7) If necessary, use a stir rod to stir the zinc or add heat to the  $\text{CuSO}_4$  (aq).

8) When it is finished carefully observe the appearance. Can you tell which reagent is the limiting reagent, and which is the excess reagent? Does this match what you did in step 3 or 4?

9) Stir *gently* and allow the Copper to settle to the bottom. Strain out any excess zinc and discard. Carefully pour as much of the water off the copper as possible without losing any.

10) Write your name on a piece of filter paper and weigh it. Record this number.

11) Set up a filter flask. Put the filter paper into a funnel. Wet the paper. Turn on the water to make a vacuum.

12) Pour in your copper. Use a wash bottle to rinse any clinging copper into the funnel.

13) Rinse the copper in the funnel a few times to wash away any remaining  $\text{CuSO}_4$ .

14) Set the filter paper onto a paper towel to dry until tomorrow.

15) Weigh the filter paper containing the copper and subtract the weight of the filter paper. This is your actual yield. Include this in your lab report.

16) Determine your percent yield and include this in your lab report.

Format of Lab report:

Title: Descriptive

Introduction: A sentence or two of background information.

Purpose: What do you want to find out by doing this experiment or activity?

Hypothesis: Make an educated guess and back it up with a sentence or two.

Procedure: Cite lab handout and mention any exceptions.

Data: Include all tables, graphs, observations and measurements, and calculations that may apply

Conclusion: What happened, did you get "the answer?"

Discussion: A few sentences to let me know that you know what's going on.

APPENDIX C

MOLARITY QUIZ WITH WITHOUT DRUFAS QUESTION

\_\_\_\_\_/24

**Molarity Quiz****Name:** \_\_\_\_\_

1. What is the mass of NaOH in 2.4L of 5.0M of the solution?
2. What is the concentration of Mg(OH)<sub>2</sub> if you dilute 178g in 0.8L of solution?
3. What is the volume of 7 M NaHCO<sub>3</sub> is needed to contain 189g of NaHCO<sub>3</sub>?
4. Determine the number of moles of solute to prepare 2.35L of 2.0M Cu(NO<sub>3</sub>)<sub>2</sub> solution?
5. You are preparing 3.00L of a 0.750M MgCO<sub>3</sub> solution, what is the mass of MgCO<sub>3</sub> needed?
6. What is the final volume of 4.67 mol in Li<sub>2</sub>SO<sub>3</sub> dissolved to make a 3.89M solution?
7. If you add 48.00g of PbCl<sub>2</sub> to form a 5M solution, how many mL will you have?
8. You need to make 2.1L of 1.2M solution from a stock solution of 10M NaOH, how many mL of stock solution do you need?

**EXTRA CREDIT**

You mix 2.0L of 5M LiOH with 6.0L of 8.0M of LiOH. What is the final concentration?

APPENDIX D

COMPLEX, MULTI-STEP PROBLEM WITH DRUFAS

**Solve the following problem using DRUFAS:**

One beaker has 0.600L of 1.5M HCl and another beaker has 1.500L of 5M HCl, what combination is needed for exactly 1L of 3M HCl?

APPENDIX E

GAS LAW QUESTIONS WITH DRUFAS QUESTION

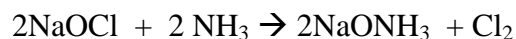
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## Gas Law II

Name: \_\_\_\_\_

**Show your work on all questions to receive full credit.**

1. How many moles of argon gas are in a 50.0L container at 18.4 atm and 127°C? (2 points)
2. A 274.8 sample of an unknown binary gas has a volume of 30L at 3.2 atm and 27°C. What is the unknown gas and should we be concerned what is in the container? (3 points)
3. If a sample of fluorine gas is confined to 3.0L and kept at 27°C with an initial pressure of 47psi, what is the final pressure if the temperature is raised to 77°C? (2 points)
4. A sample of helium was compressed at 35°C from a volume of 0.5L to 0.25L. The final pressure was 3.8atm, what was the initial pressure? (2 points)
5. A hot air balloonist puts 125,000 L of air into their balloon at 27°C and atmospheric pressure (1 atm). When they heat up the air to 200°C, what is the final volume of the air in the balloon? (2 points)
6. Using the following reaction if you react 38g of ammonia (NH<sub>3</sub>) with a bucket of bleach (NaOCl) how much volume of space will the chlorine gas occupy at room temp (298K) and 1 atm? Use DRUFAS to explain your solution. (6 points)



7. Find the volume, in liters, of each of the following at STP: (3 points)
  - a. 8.00g O<sub>2</sub>
  - b. 3.50g CO<sub>2</sub>
  - c. 3.0mol H<sub>2</sub>S
8. What is the pressure in atmospheres exerted by a 0.500mol sample of nitrogen in a 10.0L container at 298K? (2 points)

APPENDIX F

STUDENT SURVEY QUESTIONS

### Student Survey for Problem Solving Technique

Please choose what best describes your answer for each statement using the following scale:

Strongly Agree (**SA**)

Agree (**A**)

Neutral (**N**)

Disagree (**D**)

Strongly Disagree (**SD**)

	<b>SA</b>	<b>A</b>	<b>N</b>	<b>D</b>	<b>SD</b>
1. This problem solving activity was easy to follow and allowed me to complete problems with confidence.	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>
2. Describing and diagramming a problem solving technique that is useful to me in other classrooms.	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>
3. I am proficient at graph interpretation as an example, gas laws.	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>
4. The gas laws and other conversion factors have a direct connection with my math class.	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>
5. Learning with the teacher facilitating is much more challenging than with more guidance.	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>
6. I wish I had more experiences like this laboratory to prepare me for the real world.	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>
7. You should always get some background information from your instructor prior to any activity for it to be a good learning environment.	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>
8. I had to adjust my learning style to use DRUFAS.	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>
9. I will use this problem-solving technique in my other classrooms.	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>
10. I wish I had more laboratory experiences to apply more problem-solving strategies.	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>

APPENDIX G

STUDENT INTERVIEW QUESTIONS

### **Student Interview Questions**

The following is a list of interview questions I discussed with a group of ten students of varying abilities from the postlab assessment.

1. Did you like the DRUFAS problem solving strategy implemented in this Chemistry course?
2. Do you think problem solving is a strong point for your abilities as a student?
3. Did you notice an improvement in scores in any other classes as a result of improving your problem solving skills?
4. What other problem solving strategy would you use for similar labs? Why?
5. How often do you work with graphs in your other classes, name which class and give an example?
6. Do you believe graph interpretation is an important skill needed to be successful in the real world?
7. Which gas law are you the most familiar with and why?

APPENDIX H

TEACHER STAFF SURVEY QUESTIONS

### Teacher Survey for Problem Solving Techniques

Please choose what best describes your answer for each statement using the following scale:

Strongly Agree (**SA**)

Agree (**A**)

Neutral (**N**)

Disagree (**D**)

Strongly Disagree (**SD**)

	<b>SA</b>	<b>A</b>	<b>N</b>	<b>D</b>	<b>SD</b>
1. I have notice an improvement in the way students work through difficult problems.	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>
2. Grades have improved in my classroom since the intervention of problem solving techniques in the Chemistry classroom.	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>
3. I see a direct connection between problem-solving and my curricular area.	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>
4. Students generally struggle with complex, multi-step problems in my curricular area.	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>
5. I often feel like students could not accomplish a task without me there to guide them.	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>
6. Problem-solving is important for real world application.	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>
7. In your curricular area students are often let go to research and explore material on their own.	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>
8. Students use their time wisely when working through complex problems.	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>
9. Students here are “self-thinker” in that they can find information and apply what they understand.	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>
10. I wish I had more students that could solve complex problems with little guidance from the facilitator (teacher).	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>