

THE EFFECTS OF A TEACHER PRESCRIBED PROBLEM-SOLVING PATHWAY
ON NOVICE PROBLEM-SOLVERS IN A CHEMISTRY CLASSROOM

by

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ABSTRACT

Many high school chemistry students struggle developing the skill of problem solving. When faced with novel problems they often do not even know where to begin. This leads them to leave problems blank or partially completed and prevents them from spending the necessary time and effort wrestling with the problem. This study investigated a teacher prescribed problem solving pathway and its effect on the strategies that students used to solve problems. It also looked at the impact on the students' attitudes and confidence with problem solving. Documented Problem Solutions, confidence surveys, and a survey of strategies called I Do Not Understand Survey were used in conjunction with student work and reflections to determine if the treatment had any effect on the students' approach to problem solving. The results indicate that students incorporated most of the strategies used in the prescribed pathway and continued to use these strategies one-month post-treatment. Unfortunately, the study did not translate to improved attitudes and confidence toward problem solving. The students' reflections shed light on the number of students who feel some level of stress when confronted with a challenging problem.

CHAPTER ONE

INTRODUCTION AND BACKGROUND

Context of the Study

Holderness School is an independent boarding school in central New Hampshire. The school was founded in 1879 as an Episcopal high school for boys. Holderness went co-educational in the 1970's but still maintains a connection to its Episcopal roots. The school educates students in grades nine through twelve and also has three to five post graduate students each year. The overall student population is 280, 85% of which are boarding students and 15 % are day students. Forty five percent of the student body is female and 15 % are international students from eleven different countries. The average class size is 12 with a maximum class size of 16. The student to faculty ratio is six to one. The tuition for boarding students is \$64,800. Financial Aid is available and approximately one-third of the students receive aid, totaling more than \$3.5 million annually (Holderness.org). All of the students matriculate to a four-year college or university. Holderness school places a priority on the school community. This includes family style dinners where each faculty shares a meal with six or seven students. Family style dinners occur at least two times a week. Each student and faculty are also expected to know the name of each member of the community and as part of the Jobs Program each student on campus has a job ranging from cleaning a classroom to raking leaves.

In the MSSE 504, Formative Assessment in Science Education I conducted a Documented Problem Solutions assessment with an honors physics class. This classroom

assessment technique had the students document all the steps that they use to solve a given problem. Many of the students in this class were former students of my chemistry class. This group of students had strong problem-solving skills and were able to produce the correct response on most of the problems that were presented with the assessment. Given their success on solving the problems I thought that they would have little difficulty describing the important steps that they took to reach their solution. This was not the case. The majority of the students failed to mention a step that was common to all of the problems on the assignment. This apparent struggle with metacognition lead me to consider Documented Problems Solutions with my younger less experienced chemistry students. Even when offered partial credit on all problems many of my chemistry students will leave difficult problems blank or show little to no work. I spoke with a colleague who had her AP statistics students document the steps to their solutions on each problem they were assigned. This was met with great resistance from her students. They argued that it more than doubled the time it took to complete each assignment and it often overwhelmed those students who were struggling in the class. Again, these students were, as a group, more advanced students with better problem-solving skills than my chemistry students. I was looking for a way to help my novice problem solvers and to get all of my students to begin to reflect on their thinking.

Focus Question

My focus question was, Will a clear and manageable problem-solving pathway provided to the students with the appropriate scaffolding help more students implement problem-solving strategies in high school chemistry?

My sub-question was as follows:

1. What impact will this process have on student attitudes and confidence with problem-solving?

CHAPTER 2

CONCEPTUAL FRAMEWORK

Problem Versus Exercise

Researchers studying problem solving must first start with a working definition of the word problem. One definition of a problem is a gap or divide between where a learner is and where they want to be and not knowing how to build a bridge to cross the gap (Hayes, 1980). Another way to view a problem is characterized by a learner who is faced with a question and does not have an immediate solution or pathway to reach a solution (Bloom & Niss, 1991). A problem has also been defined as a difficulty that a learner needs to clear away but lacks any groundwork to do so (Ince, 2018).

To aid their students, educators have set out to establish a defined set of steps or a pathway that a learner must undergo in order to solve a problem. One early and often referenced pathway contains four steps to solve all mathematical problems. The first step is to understand the problem. In this step the known(s) and unknown(s) are identified. The second step is to devise a plan by first asking if the problem is similar to other problems that have already been solved. The third step is to carry out a plan. Included in this step is checking all work performed. In the final step, the question “does the solution make sense” needs to be answered (Polya, 1957).

Many science educators have developed their own process to help students solve problems. Goldilocks Help was established to assist novice chemistry students by providing them with a five-step problem-solving guide. In the first step, titled

Understand, the problem is defined and or deconstructed. The second step, Analyze, the known(s) and the unknown(s) are extracted from the problem. The third step, Plan, involves establishing a relationship between the known(s) and the unknown(s). The fourth step, Implement, includes all the calculations. The final step, Evaluate, is determining the sensibility of the solution (Yuriev, Naidu, Schembri & Short, 2017).

Research suggests that it is important to distinguish the difference between problems and exercises. The steps taken to solve a problem are significantly different from a path used to find a solution to an exercise. Algorithms are often used in science and math education and can be described as a defined set of rules that can be followed to obtain a solution. Therefore, algorithms are important in solving exercises (Bodner, 1987). Bodner (1987) used the factor label method as an example of an algorithm being used to solve an exercise. The factor label method is used to convert one unit into another. He believes that algorithms alone, however, cannot be used to solve a problem. Certain parts of a problem might be solved using an algorithm but by definition the problem as a whole cannot be solved with a series of known steps. However, if a student has not built appropriate algorithms to solve specific parts of a problem then it is unlikely that they will be able produce a solution to the overall problem (Bodner, 1987).

Research concludes that problems are solved in a cyclical and seemingly irrational manner. Steps may include try something, try something else, read the problem again, and start over if you have to. A method like this is clearly not linear and again points to the difference between problems and exercises. This cyclical approach emphasizes that no single problem-solving method can incorporate all of the nuances of

problem solving because of the complexity of the process and the variability of the learner (Bodner & Herron, 2003).

The complexity of the problem-solving process has led many educators in other directions. Instead of trying to provide a problem-solving guide or pathway for students some educators want students to focus on the reasoning they have used to arrive at a solution. Show-That is a method that provides students with the final answer to problems in the form of an equation. The students are then required to document how that final answer was derived. This shifts the focus of the student from trying to find a numerical answer to showing their reasoning behind the answer provided. This method may also help the students' understanding of the underlying concepts (Hewitt, 2008). Another approach is the cross-proportion method that was developed as a concept-based process. This differs from the algorithm approach commonly used to solve problems in chemistry and starts with students pointing out the underlying principles that they have learned and that are needed in the solution (Cook & Cook, 2005).

Difficulty of A Problem

Research has focused on factors leading to varying problem difficulty. One study determined that as the amount of information that has to be processed increases so does the difficulty. Based on this idea, researchers believe that at some point the volume of information will exceed the working memory and overwhelm the learner. Therefore, they determined that the number of steps required to solve a problem determines its difficulty (Johnstone & El-Bana, 1989). Another study pointed out some of the limitations of using volume as the sole indicator of difficulty. In the study it was

noted that each step to a problem cannot be assumed to be of equal difficulty, some steps are more difficult than others (Tsaparlis, 1998). A more recent study did not limit the focus of the research to the final answer that the students obtained. Instead, this study looked at the process of problem-solving. This study reported that a problem with only a few steps can be difficult if the process is branched as opposed to linear. One example is when students start with a single number in a problem and need to use it in two separate calculations before they can obtain a final answer. This is a different path than a series of conversions from one unit to the next which many students are familiar with. It also noted that students often have algorithms that are context bound. Consequently, if the context changes, they are no longer able to appropriately apply the algorithm. Similarly, other problems are difficult because a student's knowledge is often tied to the context in which it was learned. In this case students may not have the ability to transfer their knowledge of the subject to an unfamiliar problem. Lastly, some problems are difficult simply because students have failed to memorize important information needed to succeed in the subject. This could be due in part to the focus in education on higher order thinking skills leading to the neglect of simple but important content (Gulacar & Fynewever, 2010).

Behaviors of Successful Problem Solvers

The difficulty of any single problem is dependent on the problem solver. Novice and expert are terms sometimes used to categorized problem solvers. It is, however, better to look at problem solving performance on a continuum. As someone gains more knowledge in a field they are less dependent on general strategies to solve a problem. In this way a problem can become an exercise due to an increase in field

specific knowledge. The behaviors of successful problem solvers can be compared to the behaviors of unsuccessful problem solvers. Successful problem solvers read and reread a question throughout the process of solving a problem (Bodner & Herron 2002).

The idea that there are certain behaviors that promote successful problem-solving has led to the study of these behaviors. One study compiled a list of the behaviors of successful physics problem solvers that are found in the reviewed research. It was found that successful problem solvers first try to comprehend the underlying physics concepts and then work on a solution to the problem. It was also noted that they tend to follow a series of steps to get to the final answer, including making a plan and evaluating the outcome. On the other hand, unsuccessful problem solvers started by trying to plug numbers into mathematical equations. The successful problem solvers' up-front preparation time to understand the concepts and deconstruct the problem was longer than the unsuccessful problem solver. This time was spent making appropriate connections between all of the data provided in the problem. The unsuccessful problem solver was unable to make these connections (Ince, 2018). Eliminating numbers from questions and forcing students to let the symbols of the equations guide them may force unsuccessful problem solvers to focus on making these important connections (Hewitt, 2006).

Another study was conducted to determine if student use of a teacher supplied problem solving method increased after a period of behavioral modification. The research was a response, in part, to the frequent refrain from students that they understood it in class but can't do it on their own. Many students reported not knowing how to get started. The research provided the test group with a fairly regimented method to solve physics

problems. Rewards were given to the students who followed the pathway provided. At the end of the research period more students were using the pathway or parts of the pathway. While the students' behaviors were successfully changed, the students' attitude remained unchanged. Most of the students reported that the formulaic method provided by the instructors was too time consuming and cumbersome. It was also noted that the increase in use of the pathway did not seem to have a measurable impact on student performance (DiLisi, Eulberg, Lanese & Padovan, 2005).

CHAPTER 3

METHODOLOGY

Treatment

The purpose of this study was to determine the impact of a teacher prescribed problem-solving method on the strategies students use to work through challenging problems and their confidence when facing a novel problem in chemistry. The treatment period for the research was during the third and fourth quarters. Most of the work done during this time was quantitative with students solving multi-step problems including but not limited to stoichiometry, solution stoichiometry, gas laws, and colligative properties. A total of 31 students in two classes of Honors Chemistry, an introductory chemistry class, participated in this study. Seven of the students were international students. The research methodology for this project received an exemption by Montana State University's Institutional Review Board, and compliance for working with human subjects was maintained (Appendix A).

Prior to any treatment, Student Work Checklists were used to determine what students were including in their solutions to problems (Appendix B). These checklists included the following categories: left blank, answer only, work included, formula included, correct response, time spent and name of the student. Student Work Checklists were used on homework, classwork, and assessment problems. Just prior to treatment the Documented Problem Solutions Trial formative assessment was conducted. This first Documented Problem Solution was used to familiarize the students with the expectations

of this classroom assessment technique and to get them to think about the steps they use to solve problems. The Documented Problem Solution Pretreatment was conducted on a 1-value given stoichiometry problem just prior to treatment. In January a teacher prescribe problem-solving pathway was presented to the students, explained, and modeled by the teacher (Figure 1). This pathway prompted the students to write down all the knowns, unknowns, and equations. Students also had to write a concise description of the process they would use to get from the knows to the unknown. Finally, students were asked to check their answer.

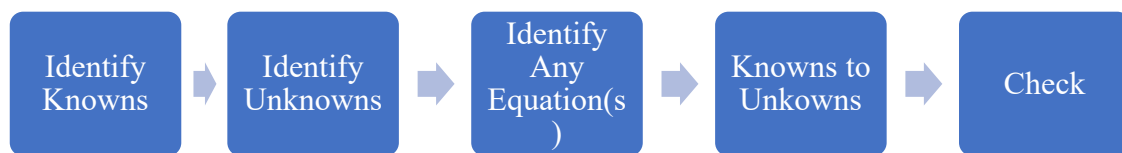


Figure 1. An overview of Teacher Prescribed Pathway.

Each of these steps was deconstructed and explained by the teacher. For example, students were shown how they should write down the basic equation first and then manipulate this equation for the desired variable before any numbers were added. Students were also shown ways that they could check their answers by looking at both the magnitude of the number and the unit attached. The students were required to use the pathway during the treatment period which lasted four weeks. With each new type of problem, the students were first asked to try to apply the pathway without assistance and then the pathway was deconstructed by the teacher. The pathway was first used on 1-value given stoichiometry problems. Most of these problems had a five-step linear pathway. Next, students were asked to apply the pathway to more complex stoichiometry problems with a limiting reactant. These problems generally had eight or more steps. The

increased volume of steps had the potential to increase the difficulty (Johnstone & El-Bana, 1989). Eventually the students were asked to apply the pathway to colligative property problems. These problems combined many of the steps of the stoichiometry problems with multiple new equations. Some of these problems could also be described as having a branched solving process as opposed to the linear process used in most of the previous stoichiometry problems. This had the potential to make the colligative property problems even more complex (Gulacar & Fynewever, 2010). Students were reminded daily to include their pathway with all problems. After the treatment period students were free to use the pathway or not use the pathway. The post-treatment student work was examined to see what parts of the pathway, if any, the students were still using. Assessments one week and one month post treatment were used to observe any behavioral changes in the students.

Data Collection and Analysis Strategies

Two pre-treatment assignments were analyzed using data compiled on the Student Work Checklist. The first pre-treatment assignment was an introductory homework problem that students were asked to complete without an in-class explanation. This problem required a simple two step solution. The question, What is the mass in grams of a billion billion (10^{18}) atoms of ^{24}Mg ?, was analyzed to determine if there was a relationship between a student showing work and answering the problem correctly.

The second pretreatment assignment dealt with wavelength, frequency and energy problems and was the first assignment that required the students to use multiple formulas ($c = \lambda \nu$ and $E = h \nu$) and, on some problems, combine the formulas. Again, using the

Student Work Checklist, the data was analyzed to see if there was a relationship between the gender of the student and whether or not a formula was included in their solution. The analysis of these two assignments was performed before any treatment began and helped guide the rest of the study.

The Pre and Post-Treatment Documented Problem Solutions were used to determine the steps students used to solve problems (Appendix D). Documented Problem Solutions were used to develop problem solving skills and to develop the ability to apply previously learned principles to new problems (Angelo & Cross, 1993). The teacher determined the fundamental steps needed to correctly solve the problem. The number of each of these steps that a student correctly identified was recorded. A boxplot was used to represent the average scores. The median difference between the pre and post-treatment numbers was compared for each student using the Wilcoxon Signed Rank Test.

The Pre- and Post-Treatment Confidence Survey was used to determine students' confidence and comfort solving new and different problems (Appendix G). The questions ask students to strongly disagree, disagree, agree or strongly agree to questions about their confidence working through problems that they had not seen before or were unlikely to arrive at a correct response. The percent of positive responses on the pretreatment survey were compared to the positive responses post treatment. Bar graphs were used to represent this data.

The Pre and Post-Treatment I Do Not Understand Likert Survey was used to determine what strategies students use when faced with a problem they do not understand and therefore can not solve. The students were asked to respond strongly agree, agree,

disagree, strongly disagree to the five questions. The percent of positive responses on the pretreatment survey were compared to the positive responses post treatment. Bar graphs were used to represent this data.

A post-treatment reflection was conducted. The students were asked to respond to five questions. The questions, What are your strengths as a problem solver? What are your weaknesses as a problem solver? How will you improve on these weaknesses? How do you feel about working on a type of problem that you have never seen before? What are some strategies you could use to work on a type of problem that you have never seen before? The qualitative data was grouped according to like responses and plotted using pie charts.

The data collection instruments used to answer the primary and secondary questions are outlined in the triangulation matrix below (Table 1).

Table 1. Data Triangulation Matrix.

Focus Questions	Data Source 1	Data Source 2	Data Source 3
<p>Primary Question:</p> <p>Will a clear and manageable problem-solving pathway provided to the students with the appropriate scaffolding help more students implement problem-solving strategies in high school chemistry.</p>	Pre and Post-treatment Checklists	Documented Problem Solutions	I Do Not Understand Survey
<p>Secondary Question:</p> <p>What impact will this process have on student attitudes and confidence with problem-solving?</p>	I Do Not Understand Survey	Student Reflection	Student Confidence Survey

CHAPTER 4

DATA AND ANALYSIS

Results

The data obtained from the first Student Work Checklist indicated that 58 percent of the students did not include any work in their solution ($N=31$). One student included work but did not have a final calculation. Forty two percent of the students successfully answered the question correctly. The data was analyzed using a Pearson's Chi-Squared Test. The null hypothesis was showing work is independent of answering the question correctly. The p-value for the test was 2.473×10^{-5} with a Pearson's correlation coefficient of 0.823. This extremely small p-value demonstrates that the null hypothesis should be rejected. The evidence indicated that showing work on this problem was not independent of obtaining the correct answer. The Pearson's correlation coefficient of 0.823 show a strong relationship between showing work and answering the problem correctly.

The data from the second Pretreatment Student Checklist indicated that 42 % of the male students and 68% of the female students included formulas in their work ($N=31$). A Chi-Squared Test for Independence was used to analyze the data. Including formulas with their work was independent of the student's gender was the null hypothesis. The p-value of the test was 0.2727 suggesting that the null hypothesis should not be rejected. Gender and showing work were independent on this assignment. Neither females or males were more likely to include work.

Student Checklists were also used to look at two post-treatment assessments. The first was administered one week post treatment and the second was administered one month post treatment. The first quiz was a solution stoichiometry quiz that included two problems on colligative properties. Figure 2 shows a student's response to the first question on the post treatment assessment. Included in the response was the knowns, unknowns, equations, and pathway.

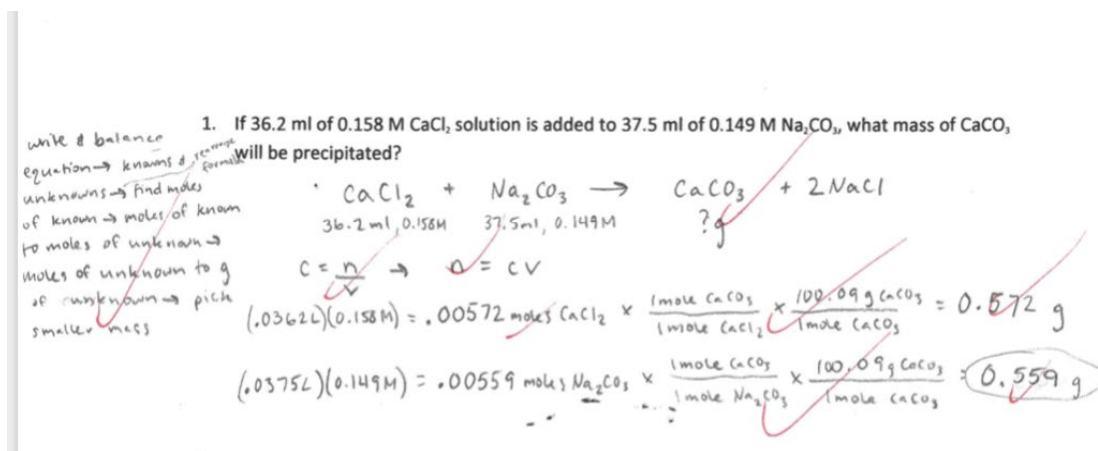


Figure 2. Student work on first post-treatment assessment.

Ninety three percent of the students who took the assessment included all of the steps of the teacher prescribed pathway in their solutions. Two students did not include a descriptive pathway on how to go from knowns to unknowns and one student also did not include equations. The second quiz was a gas law quiz. Ninety six percent of the students who took the quiz included knowns, unknowns, and equations in their solutions but only one student also included a descriptive pathway on how to go from knowns to unknowns (Figure 3).

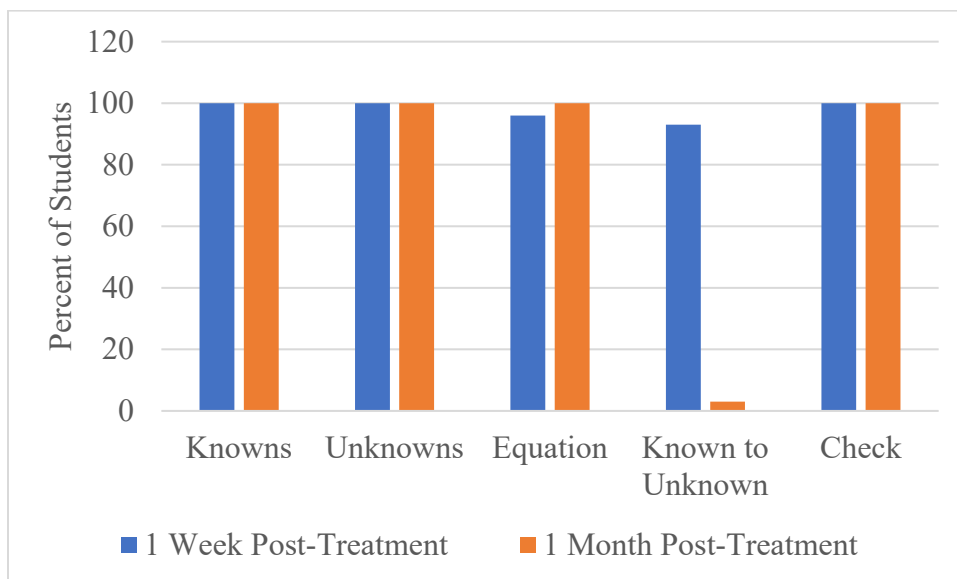


Figure 3. Post-treatment assessments pathway steps included, ($N=30$).

The pre and post-treatment Documented Problem Solutions used similar 1-value given stoichiometry problems. Each of these problems was solved by the instructor and nine steps were included in the solutions. The students' responses were compared to the instructors and the number of correct steps counted. The pretreatment mean for the number of steps was 3.7 compared to 6.9 steps post-treatment. The means of the pre and post-treatment Documented Problem Solutions were plotted using a boxplot (Figure 4).

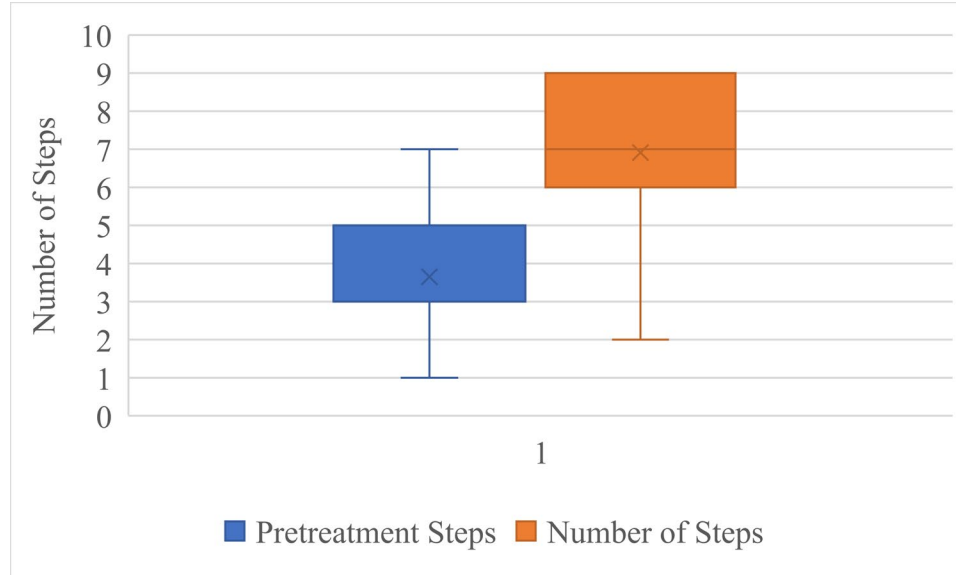


Figure 4. Numbers of steps included in documented problem solutions.

Due to the small sample size and the outliers identified by the boxplot a Wilcoxon Signed Rank Test was used to analyze the median difference between the Pre and Post-Documented Problem Solutions. The null hypothesis for this test was the median difference between the pairs was zero. The p-value for the test was 5.905×10^{-5} indicating that there is an extremely small chance to see these differences if the null hypothesis was accepted. The increased number of steps that students included on the post-treatment documented problem solution was significant.

A Pre and Post-Treatment I Do Not Understand Survey was administered to better understand the strategies that students used when faced with a problem that they did not fully understand. The first three questions dealt with the student using outside resources as a strategy to help understand the problem. The first question was, “If I do not understand a problem, I look back in my notes or the book to see if there are similar problems.” The second question was ““If I do not understand a problem, I look on-line

for help” and the third question was “If I do not understand a problem, I talk to a classmate or friend.” On the pretreatment survey ninety three percent of the students responded with strongly agree or agree to the first three questions combined (Figure 5). On the post-treatment survey this percentage changed to ninety percent.

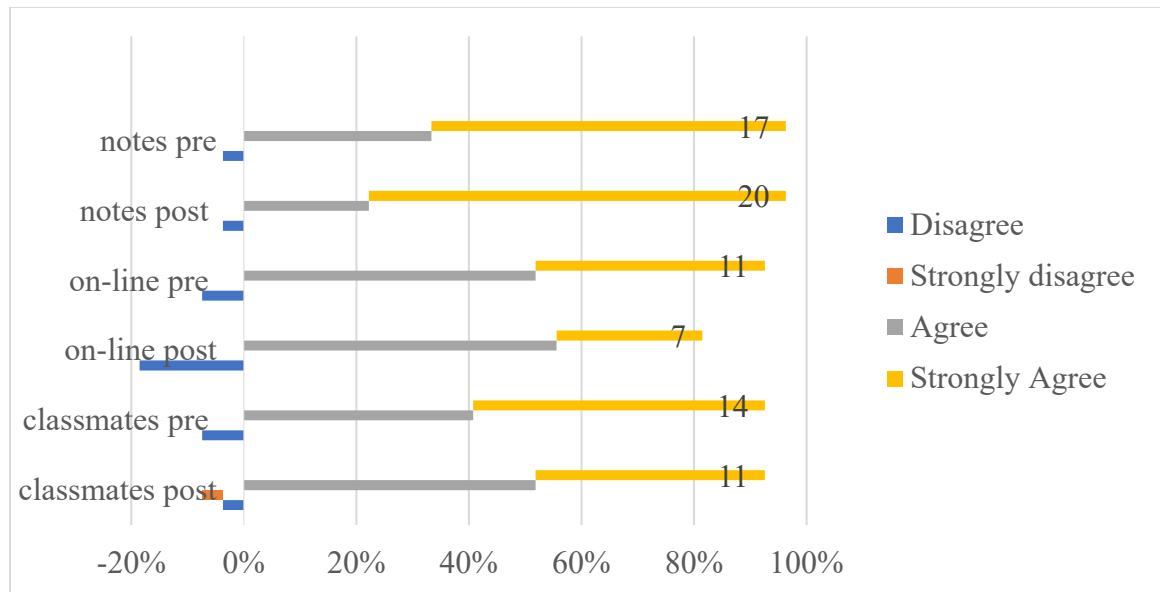


Figure 5. Responses to first three questions on I Don't Understand Survey, (N=27).

The last two questions of the survey dealt with strategies that were part of the teacher prescribed problem solving pathway. These questions were “If I do not understand a problem, I write down all the knowns or givens” and “If I do not understand a problem, I write out a plan that could help me solve the problem.” On the pretreatment survey thirty three percent of the students responded with strongly agree or agree to these questions. On the post treatment survey this percentage increased to eighty three percent (Figures 6).

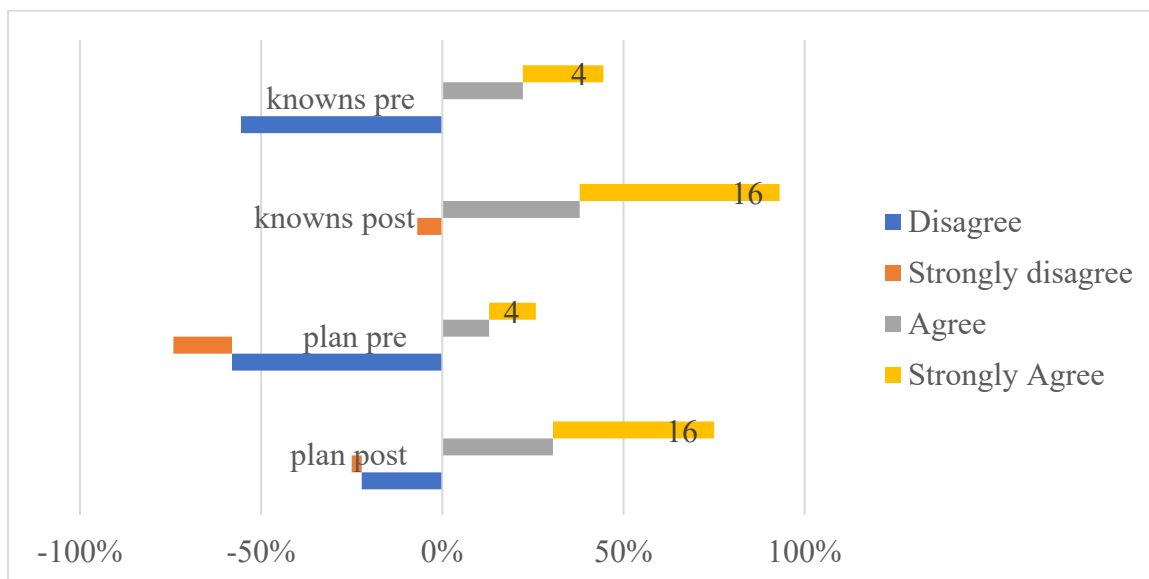


Figure 6. Responses to last two questions on I Don't Understand Survey, ($N=27$).

Three students wrote in a response on the pretreatment survey about “sometimes” including the knowns and unknowns in their solution. One student wrote, “Sometimes, depends on the problem and how it is worded.” On the post-treatment survey two students wrote in a response to the same question. Including the knowns and unknowns for these students had become a habit. A student wrote, “Writing the knowns and unknowns has become a habit, no matter if I understand the problem or not”

Responses to a Post-Treatment Student Reflection were used to understand students' attitude, confidence and strategies used when solving problems in chemistry. The responses to each of the four questions were grouped by the same or similar replies. Twenty-two students responded to the question asking their strengths when solving problems in chemistry(Figure 7). Forty one percent of the students said that they were good with using and manipulating equations. One student responded “I can find the right equation to use in order to solve the problem.” Thirty two percent of the students

mentioned that they were willing to spend as much time as needed to solve a problem. One student wrote, “I spend a lot of time on problems before giving up.” Eighteen percent of the students mentioned that they are able to fully understand the problem before they try to solve it. A student responded, “I can easily understand what the problem requires me to do.” Finally, nine percent of the students reported being good with numbers as a strength in their problem solving.

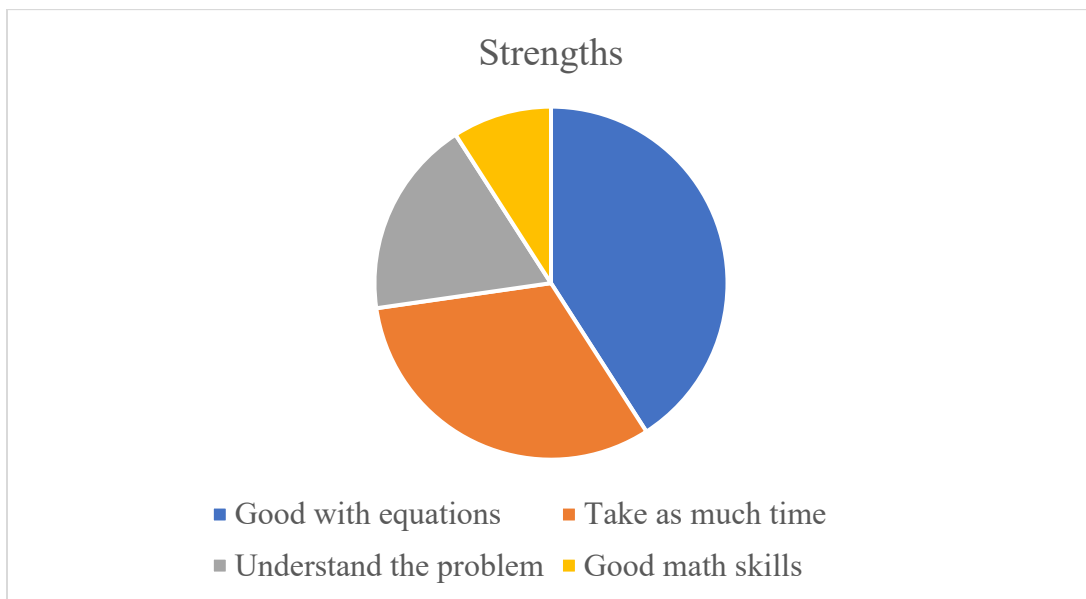


Figure 7. Student post-treatment reflections on strengths in problem solving.

Twenty five students wrote about their weakness as a problem solver (Figure 8). Twenty eight percent of the students mentioned that they were susceptible to making small or careless mistakes. One student responded, “Paying attention to the details and when I check the answer just being careful on the small details...” Twenty percent of the students mentioned not being able to fully comprehend what the question is asking. “The majority of my mistakes come from reading the physical problem wrong or reading something that is not there or missing something that is.” Twenty percent of the students

replied that they tended to give up too easily. One student wrote, “When I don’t understand something I usually give up a little too quickly and don’t try out new methods when struggling.” Another twenty percent of the students responded that they jump into the solution too quickly. A student wrote, “A weakness I have as a problem solver may be the fact that I like to go straight into answering the question.” Finally eight percent of the students reported that their struggles with math was their weakness in problem solving.

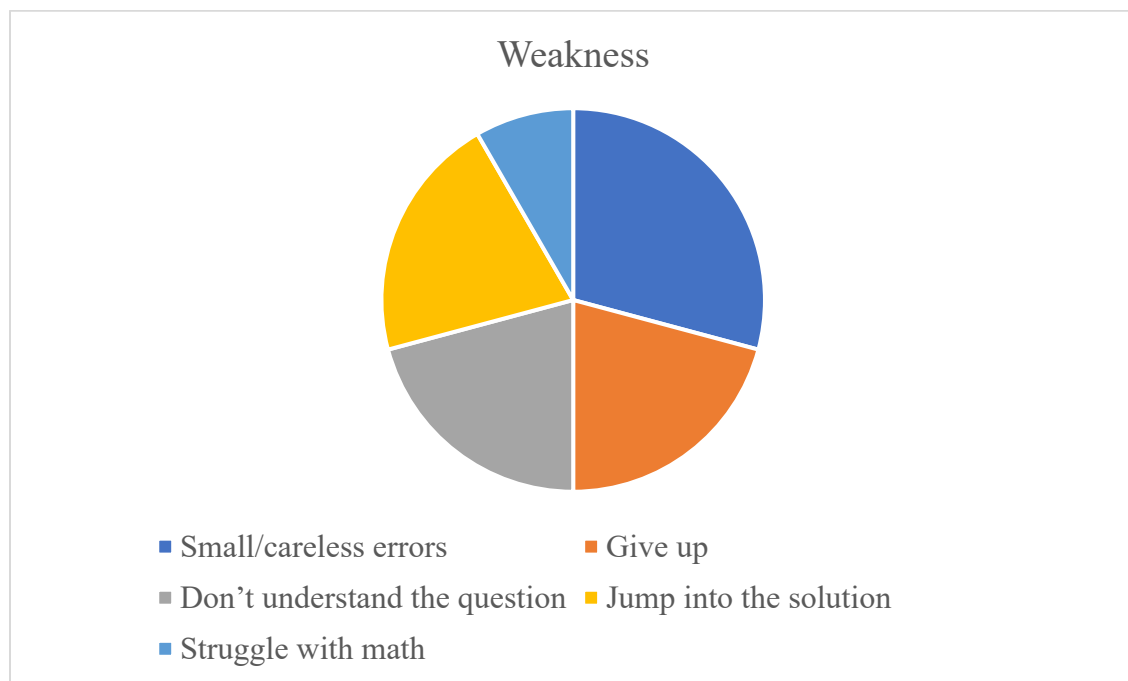


Figure 8. Student post-treatment reflections on weakness in problem solving.

When asked what strategies they use when facing a type of problem that they have never encountered before forty three percent of the student responses mentioned that they tried to connect the new problem with past problems that they have solved (Figure 9). One student wrote “I think this helps me when I am working on a problem I

have never seen before because I understand past problems we have done and am able to incorporate those methods into the new problem.” Twenty seven percent of the student responses said that reading and rereading the problem carefully was a strategy that they employ. A student wrote “ I will make sure to read and reread each problem so that I can fully understand the problem. ” Seventeen percent of the student responses said that they used other resources like on-line videos when they do not understand a problem. One student responded “ I use my resources (reference papers, text book, online, etc.) if I am stuck or have been struggling on a problem for a while.” Thirteen percent of the students said that writing out the knowns, unknowns and a pathway was a strategy that they now used. “ I think writing out the knowns, unknowns, pathway and equation helps me a lot to combat this because it gives me a clearer idea of the steps necessary to complete the problem.”



Figure 9. Student post-treatment reflections on strategies used in problem solving.

Only sixteen of the thirty students responded to the question asking them how they felt working on a problem that they had never seen before (Figure 10). Fifty percent of the students responded that working on these problems caused them some level of stress. One student wrote “I get kind of freaked out when I see a problem that I never have seen before.” Twenty five percent of the students mention that they take on these new problems as a challenge. “When I work on new problems I see it as a challenge, I try to use previous knowledge to piece together the problem and find an answer.” Twelve and a half percent of the students reported being comfortable solving this type of problem and another twelve and a half percent said that they felt frustrated.

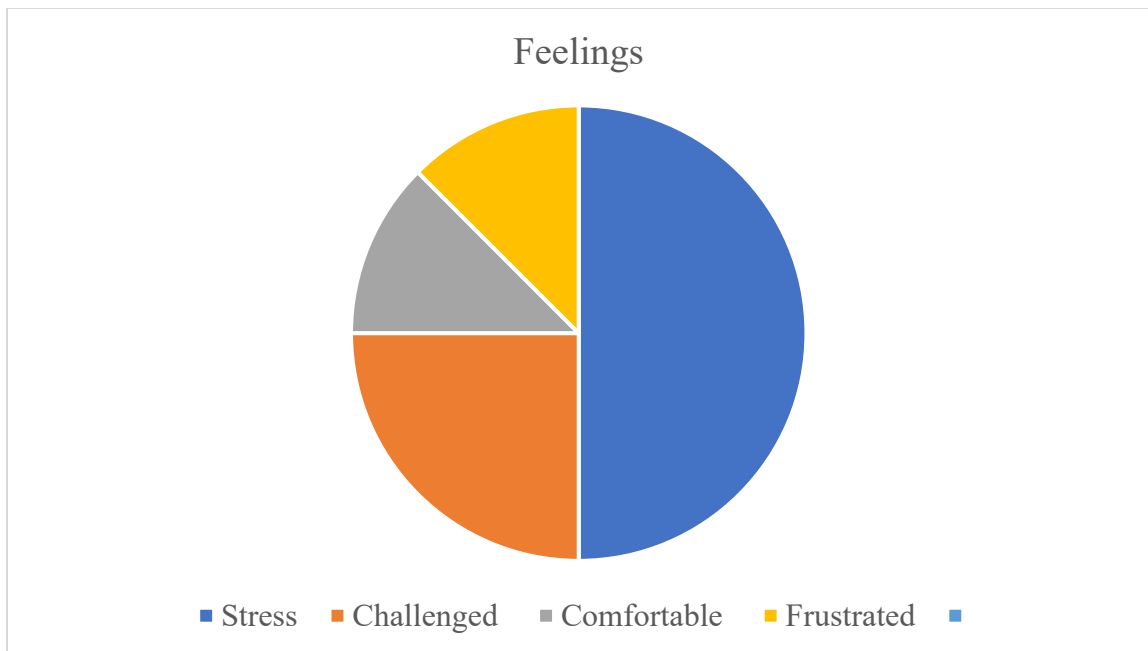


Figure 10. Student post-treatment reflections on feelings in problem solving.

The Confidence Survey was conducted both pre and post-treatment. Twenty nine students completed the pretreatment survey but only twenty five completed the post treatment survey. The percentage of positive responses, strongly agree or agree, was

compared. On the first question “I feel confident and comfortable working through problems I am unfamiliar with,” sixty two percent of the students responded positively pretreatment and sixty percent responded positively post-treatment. This same comparison was sixty eight percent pretreatment to eighty four percent post-treatment for the second question, “I feel confident and comfortable working through a problem even knowing that there is a likelihood that I am not going to arrive at the correct response.” The third question “I feel confident and comfortable working through a homework problem on material that was not covered in class,” had a forty five percent positive response pretreatment and fifty two positive responses post-treatment. Finally, sixty two percent of the responses were positive to the fourth question “I feel confident and comfortable when my teacher gives a problem on an assessment that is worded different than the problems presented in class” on the pretreatment survey. On the post treatment survey 60 percent of the responses were positive for this question.

CHAPTER 5

CLAIM, EVIDENCE, REASONING

Claims from the Study

The two pretreatment assignments were analyzed as baseline data before implementation of the intervention and helped direct the focus of the study. The first assignment helped assess the importance of continuing with the study. If there was not a clear connection between the amount of work a student showed and their ability to answer a question correctly the value of the study would have been in question. The analysis of the first pretreatment assignment showed a clear connection between the amount of work shown by the students and whether or not they arrived at the correct answer. Students who did not show work were less likely to arrive at the correct answer. This data gave me confidence that the study was in fact worth pursuing. The second pretreatment assignment was used to address a common refrain heard in teachers' meetings about students and in particular male students. The typical teenage male student has been described in teachers' meetings as not being as attentive to details as their female classmates. This could account for the lack of work shown by male students. The analysis of the second pretreatment assignment showed that neither male or female student in my classes were less likely to show work. This indicated that the same intervention for both male and female students could be effective.

The use of the teacher prescribed problem solving pathway did provide useful strategies to help students solve challenging problems. This was shown by an increase in

the number of steps that students identified as important when solving stoichiometry problems. Pre and Post-treatment Documented Problem Solutions were used to get students to think about their thinking and document each step of solving a problem. Both the mean and median steps, pre and post -treatment, that students documented were used to show this increase. The results indicated that students were thinking about the problem-solving process more in-depth after the treatment. Question four and five on the Pre and Post- Treatment I Don't Understand survey show that students were using two of the strategies outlined in the teacher prescribed problem solving pathway much more frequently post-treatment. Students responding with a strongly agree or agree to question eight, identifying and writing down all the knowns and unknowns, increased by 49 percent from pre-treatment to post-treatment. Question nine, about writing a pathway or plan to show how to get from the knowns to unknowns, also showed a large increase. Only 15 percent of the students identified this as a strategy that they used pre-treatment whereas sixty seven percent of the students responded strongly agree or agree post-treatment ($n=27$). Finally, the two post-treatment assessments also show that students continued to use the strategies outlined in the teacher prescribed pathway even after the treatment period had ended. Ninety seven percent of the students continued to write down the knowns, unknowns and any formulas on a gas law assessment one month post-treatment.

As for the students' confidence and attitudes regarding problem solving there was no indication that this intervention had any impact. The percent of positive results on the Confidence Survey for the pre-treatment questions was fifty nine and only increased to

sixty four post-treatment. The post-treatment reflection told a similar story. Sixty three percent of students that wrote about their feelings when facing a problem that they had never seen before responded in a negative way. These students reported feeling stressed and frustrated.

Reflection on Methodology

It needs to be noted that the impact of Covid-19, the resulting long break (March 7th – April 13th) and the move to on-line learning had an impact on this capstone project. This included a need to adjust the focus question and sub-questions. Initially I had planned on determining if the teacher prescribed problem solving pathway would improve student results. This was to be determined using the same pre and post-treatment assessment. The plan was to administer a stoichiometry test pre-treatment and then again one month post-treatment. The time gap had a twofold purpose. First, the post-treatment assessment was going to be presented to the students as a review for their final exam. Second, the time between assessments was hopefully going to give a more accurate measure of the impact of the treatment. Unfortunately, once we went to on-line learning all our assessments became open note/ open book assessments. Comparing a post-treatment open note assessment to a pre-treatment assessment had little value. One of my sub-questions originally was about the use of the teacher prescribed problem solving pathway increasing the time students worked on problems. On the pre-treatment assessment, students recorded the time that it took them to solve each problem. Unfortunately, the time it took for students on pre-treatment questions could not be

compared to the post-treatment time because students had the opportunity to look through their resources before solving each question.

Another factor that I did not account for was the constantly changing size of my class. One of my students left after the first semester on a medical leave. More importantly, I taught seven high level skiers who were gone on and off throughout the winter, some of these students were not in class for weeks at a time. This made it difficult to collect and compare data and often put in question the statistical test that I had hoped to use to analyze the data.

Finally, I tried to collect too much data initially. I was collecting many pre-treatment assignments and filling out Student Work Checklist. This became tedious work and most of this data was not used in the study. This data overload could have negatively impacted important data that I needed to collect later in the study.

Value of the Study and Consideration for Future Research

In the MSSE 504 course, Formative Assessment in Science Education the importance of closing the loop with students was emphasized. After each classroom assessment technique was administered teachers were encouraged to share their findings with their students. The greatest value of conducting this study was the sharing of information with my students. Early in the school year I explained the basic ideas behind my study. This led to many conversations about the research that I had found on problem solving. As a class we talked about how a successful problem solver spends more up-front time understanding the problem than a novice problem solver. We also talked about how the typical pathway to a solution is not always linear. A conversation about cyclical

pathways encouraged the students to try an approach to a problem and when it did not work to return to the foundational concepts and try another approach. Before the first Documented Problem Solutions was administered, we talked about metacognition. Most of the students had never heard the word or understood the concept. Students began to better understand what I was asking when I would say “what were you thinking here.” Their responses became more thoughtful. When the teacher prescribed pathway was finally introduced each part was broken down and scaffolded. For example, one step, writing the formula, the importance of manipulating the formula without numbers was emphasized. The power of graphing calculators allows students to skip this step but then they often miss out on a better understanding of the relationships between the variables and therefore some of the underlying concepts. On an assignment post treatment, I had the students manipulate the ideal gas law to solve for density. I do not think they would have been able to do this without the many discussions about manipulating formulas. Finally, the students were interested to hear the results of the surveys and the themes that developed in their reflections. All of this sharing of information took time but this time was time well spent.

Another important value of this study was that it revealed the stress that many of my students feel on a daily basis. In the post-treatment reflection, many students expressed some level of stress when presented with a problem that they had never seen before or they felt unprepared to answer. A few of the students openly wear that stress in class but for many others it came as a complete surprise to me. Certainly, this has reminded me to be empathetic to all learners. I am aware that until this stress is managed

it will be difficult to make the improvements in problem solving that I am aiming for. In the future an increase in formative assessments may help ease some of the stress by taking away some of the pressure to perform.

Future Research

Next year I would like to continue with this study and collect some of the data I was unable to this year. Ultimately, I would like this process to help students become better problems solvers. To analyze this would require pre and post-treatment assessment data. The only information that I have on post-treatment performance was on the assessment one-week post-treatment. The students were presented with four questions, three of the four were similar to questions that we went over in class but the other question was slightly different. Sixteen of the thirty students made the same mistake on this problem. They tried to make the information in the problem fit into a type of problem that they were familiar with leading them to use an incorrect formula. From my research this is a common mistake made by novice problem solvers. The information from this one question, even though it is a small data point, indicates that many of my students still need work improving their problem-solving skills. I do think that measures of improvement will need to be more long term. I, therefore, would like to check in with these students next year when most of them are taking some level of physics and see how many of them are still using all or part of the problem-solving pathway. I would also encourage their physics teachers to use a Documented Problem Solutions assessment and with the students' permission I would like to analyze the data from these formative assessments. This information would help determine a longer-term impact of the study.

Impact of Action Research on Author

As a teacher at a small boarding school I pride myself in knowing my students well. Unfortunately, this can cause me to make assumptions about my students. This study, for me, showed the importance of making decisions on information not assumptions. I had no idea how many of my students felt some level of stress when faced with a question they did not immediately know how to solve. As honors chemistry students these students were some of the best in the 10th grade. I assumed that more of these students would see novel problems as a challenge worth tackling not as a source of stress. When students left a homework problem blank I assumed that it was because they were being lackadaisical and saying that they didn't understand was an easy excuse. The data from the post treatment reflection and follow up conversations gave me this important information. Now I am tasked with how to best make changes based on this information.

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APPENDICES

APPENDIX A

INSTITUTIONAL REVIEW BOARD EXEMPTION



**INSTITUTIONAL REVIEW BOARD
For the Protection of Human Subjects
FWA 0000165**

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MEMORANDUM

TO: Randal Houseman and John Graves

FROM: Mark Quinn *Mark Quinn CJ*
Chair, Institutional Review Board for the Protection of Human Subjects

DATE: November 25, 2019

RE: "The Effect of a Teacher Prescribed Problem-Solving Method on the Amount of Time Students Spend Working on Problems" [RH112519-EX]

The above research, described in your submission of November 25, 2019, is exempt from the requirement of review by the Institutional Review Board in accordance with the Code of Federal regulations, Part 46, section 101. The specific paragraph which applies to your research is:

- X (b) (1) Research conducted in established or commonly accepted educational settings, involving normal educational practices such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.
- X (b) (2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation; and (iii) the information obtained is recorded by the investigator in such a manner that the identity of the human subjects can readily be ascertained, directly or through identifiers linked to the subjects, and an IRB conducts a limited IRB review to make the determination required by section 16.111(a)(7).
- _____ (b) (3) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under paragraph (b)(2) of this section, if: (i) the human subjects are elected or appointed public officials or candidates for public office; or (ii) federal statute(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.
- _____ (b) (4) Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available, or if the information is recorded by the investigator in such a manner that the subjects cannot be identified, directly or through identifiers linked to the subjects.
- _____ (b) (5) Research and demonstration projects, which are conducted by or subject to the approval of department or agency heads, and which are designed to study, evaluate, or otherwise examine: (i) public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs; (iii) possible changes in or alternatives to those programs or procedures; or (iv) possible changes in methods or levels of payment for benefits or services under those programs.
- _____ (b) (6) Taste and food quality evaluation and consumer acceptance studies, (i) if wholesome foods without additives are consumed, or (ii) if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the FDA, or approved by the EPA, or the Food Safety and Inspection Service of the USDA.

Although review by the Institutional Review Board is not required for the above research, the Committee will be glad to review it. If you wish a review and committee approval, please submit 3 copies of the usual application form and it will be processed by expedited review.

APPENDIX B

BLANK STUDENT WORK CHECKLIST

APPENDIX C

CONFIDENCE SURVEY

Post-Treatment Survey – Confidence

Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

⋮

1. I feel confident and comfortable working through problems I am unfamiliar with. *

- strongly agree
- agree
- disagree
- strongly Disagree

:::

2. I feel confident and comfortable working through a problem even knowing that there is a likelihood that I am not going to arrive at the correct response. *

- strongly agree
 - agree
 - disagree
 - strongly Disagree
-

3. I feel confident and comfortable working through a homework problem on material that was not covered in class. *

- strongly agree
- agree
- disagree
- strongly disagree

4. I feel confident and comfortable when my teacher gives a problem on an assessment that is *
worded different than the problems presented in class.

- strongly agree
 - agree
 - disagree
 - strongly disagree
-

APPENDIX D

I DO NOT UNDERSTAND SURVEY

Pre Treatment Survey – “I Do Not Understand”

Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

Each question will have four possible responses, strongly agree, agree, disagree and strongly disagree.

1. If I do not understand a problem, I look back in my notes or the book to see if there are similar problems? *

- strongly agree
- agree
- disagree
- strongly disagree



2. If I do not understand a problem, I look on-line for help? *

- strongly agree
- agree
- disagree
- strongly disagree

3. If I do not understand a problem, I talk to a classmate or friend? *

- strongly agree
- agree
- disagree
- strongly disagree

⋮

4. If I do not understand a problem, I write down all the knowns or givens? *

- strongly agree
 - agree
 - disagree
 - strongly disagree
 - Other...
-

5. If I do not understand a problem, I write out a plan that could help me solve the problem? *

- strongly agree
 - agree
 - disagree
 - strongly disagree
-

APPENDIX E

POST-TREATMENT STUDENT REFLECTION QUESTIONS

Please respond to the following prompts.

What are your strengths as a (chemistry) problem solver?

What are your weaknesses as a (chemistry) problem solver?

How will you improve on these weaknesses?

How do you feel about working on a type of problem that you have never seen before?

What are some strategies you could use to work on a type of problem that you have never seen before?