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The Effect of Using an Explicit General Problem Solving Teaching Approach on Elementary Pre-Service Teachers' Ability to Solve Heat Transfer Problems

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Abstract

This study investigate the effectiveness of adding an 'explicit general problem solving teaching strategy' (EGPS) to guided inquiry (GI) on pre-service elementary school teachers' ability to solve heat transfer problems. The pre-service elementary teachers in this study were enrolled in two sections of a chemistry course for pre-service elementary teachers' at a four year university. One section of this class was taught a treatment method, the explicit general problem solving approach, while the other section was taught using guided inquiry approach. Quantitative data was obtained using a post-test while qualitative data was obtained probing questions. The scores for the two teaching approaches showed no significant difference. Further, qualitative data indicated little difference in the way participants solved their problems regardless of instructional approach. Hence, this study concludes that both EGPS and guided inquiry have comparable effectiveness of teaching problem solving.

Key words: Problem solving, Heat transfer, Quantitative, Qualitative, Guided inquiry.

Introduction

Among the lifelong learning skills that students of all ages need to acquire is problem-solving (Jonassen, 2010). According to Hayes (1980) a problem is "whenever there is a gap between where you are now and where you want to be, and you don't know how to find a way to cross that gap." Therefore, finding this 'way' is an important part of problem solving. From these assertions, Bodner (1991) grouped problems into two categories: those that we do routinely as exercises and those that are new as problems. However, Bodner does not believe that there is an "innate characteristic of a task that inevitably makes it a problem" (Bodner, 2002). What a professor can perceive as an exercise can be perceived as a problem by a freshman chemistry student. According to Bodner (2003), familiarity with an activity plays a role in deciding whether to call that activity a problem or an exercise. This implies that problems can be turned into exercises with more practice (Bodner, 1997). Heat transfer problems in our study fall into this category.

Individuals solve different types of problems of varying complexities throughout their life cycle. Some of the problems are well-structured while others are ill-structured (Jonasssen, 2010). Normally, individuals meet these problems during formal education and informally in other endeavors. Most often, during formal education, students encounter well-structured problems. These problems "engage a limited number of rules and principles that are organized in a predictive and prescriptive arrangement; possess correct, convergent answers; and have a preferred, prescribed solution process" (Johansen, 2010, p. 2). Although ill-structured problems are usually more difficult, some well-structured problems do pose a great challenge for students (Jonassen, 2010).

For students to learn the problem-solving skills, teachers need to be well equipped with necessary pedagogical strategies to effectively teach these skills. A pre-service teachers' college education that emphasizes the acquisition of problem solving skills can effectively provide necessary tools that these future teachers can later utilize. This is important for elementary and middle school teachers because they are responsible for developing problem-solving skills in young children that are a necessary prerequisite for complex problem-solving in the

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future. This paper compares the effectiveness of adding an Explicit General Problem Solving (EGPS) to the guided inquiry (GI) approach on pre-service elementary teachers' ability to solve heat transfer problems in chemistry.

Theoretical Framework

Schoenfield (2013, p. 11) believes that success in problem solving depends among other factors on the "individual's use of problem solving strategies, known as heuristic strategies." Heuristics help to "convert a non-procedural cognitive skill to a procedural one (VanLehn et al., 2004, p. 522). Metallidou (2009, p. 76) define problem solving as a "goal-directed behavior [that] requires an appropriate mental representation of the problem and the subsequent application of certain methods or strategies in order to move from an initial, current state to a desired goal state."

Successful problem solvers understand the problem by initially constructing a description of the problem to help in the search of an appropriate solution (Reif, 1981). This is done by translating the problem into an easily understandarble form. This summary must include key concepts required to describe the problems. For instance, to solve a heat transfer problem where a hot metal is immersed in water, a student may need to include key concepts such as specific heat capacity, thermal equilibrium and others in the initial description of the problem.

Furthermore, problem solving, as viewed by cognitive psychologists, encompasses self-analysis, observation, and the development of heuristics (Hardin, 2002). Cognitive psychologists have been interested in investigating the mental processes involved when individuals learn and solve problems. They stressed a need for knowledge organization in order to improve the efficiency of retrieval of this knowledge from the conceptual schemata during problem solving (Sternberg, 1981; De Jong and Ferguson-Hessler, 1986). The hope is to organize and connect knowledge in long-term memory such that it is easily recalled when needed (Johnstone, 1991). This led to the development of cognitive approaches to solving problems. A notable cognitive psychologist, Polya (Hardin, 2002), developed a stepwise model of problem solving. This included "(1) understand the problem, (2) devise a plan, (3) carry out the plan, and (4) look backward" (Hardin, 2002). These steps are not content specific hence are just referred to as general problem solving skills (Hardin, 2002). Although Polya's steps seem to follow a linear path, researchers have found that the steps are actually cyclic in nature. For instance, Carson and Bloom's (2005) study on how mathematicians approach problem solving found that they would pass through one step, remember something, go back and check before proceeding. When the solution was not acceptable during checking, the mathematicians returned to the planning phase.

In this study, we seek to investigate whether or not adding explicit problem solving techiniques to an inquiry approach improves problem solving. Our explicit problem solving strategy derives from Polya's four stages but recognizes the cyclic nature of these stages.

Research on Problem Solving

According to a 2002 official statement by the National Science Teachers Association (NSTA), "the elementary science program must provide opportunities for students to develop understandings and skills necessary to function productively as problem-solvers in a scientific and technological world". Further, according to Kahle (1991), American elementary teachers believe that science is taught to interest students and to instill problem-solving skills in them. She also noted that elementary teachers are not confident in teaching physical science because they believe that it is difficult. Perhaps these teachers need appropriate skills which can enhance their confidence in teaching physical science.

A logical opportunity for future teachers to learn scientific problem-solving skills is during their undergraduate teacher preparation. Specifically, pre-service teachers can learn problem-solving during science content courses such as chemistry. However, several studies have shown that problem-solving is difficult for students, especially in introductory chemistry classrooms (Cooper, Nammouz, & Case, 2008; Gabel, Sherwood, & Enochs, 1984). A number of studies in problem-solving investigated the differences between novice and expert problem-solvers in chemistry (Heyworth, 1998; Kumar, 1993; Sutherland, 2002). These studies found that experts think through their problems while novices lack this skill. Other studies showed that explicit teaching of problem-solving enhances students' ability to solve problems in chemistry topics such as the mole, gas laws, stoichiometry, and chemical equilibrium at different levels of education (Bunce, Gabel, & Samuel, 1991; Kumar, 1993; Schmidt, 1994).

There has been an ongoing search for alternative approaches to teaching problem-solving in chemistry (Bunce & Heikkinen, 1986; Lorenzo, 2005; McCalla, 2003). Bunce and Heikkinen (1986) investigated whether using stepwise approach as proposed by Polya improved students' scores in mathematical chemistry problems. These authors found no significant difference (F = 2.05, p = .092) in mathematical chemistry scores between the treatment and control groups. Nevertheless, they acknowledged that most students did not use the approach when solving problems, and observed that this might have led to the observed lack of significant influence from their approach. Another study (McCalla, 2003) found that when solving difficult problems, students who used a specific pathway approach significantly performed better ($p < 0.02$) than those who did not use the approach. However, there was no statistical difference between those who used the approach and those who did not use it for simple questions. She therefore concluded that students need an appropriate structure when solving difficult problems. These results agree with Lorenzo (2005) who found that students using problem-solving heuristic were more confident and had a higher ability to solve difficult chemistry problems.

VanLehn et al. (2004) found that using explicit problem solving did not improve student correct response compared to the control group but improved how much information the students presented during problem solution. They concluded that students taught using explicit problem solving had a better qualitative presentation of their problem due to the structure provided. Nevertheless, the students in the control section were able to learn problem solving implicitly to obtain correct answers similar to an explicit group.

Although different authors have studied problem solving on various topics in chemistry, very few studies have been done on pre-service elementary and middle school teachers. Furthermore, only one study (Greenbowe & Meltzer, 2003) investigated how students approach thermochemistry problems, which are related to the heat and temperature topic. In this study, the authors observed several difficulties that students faced when solving thermochemistry problems. Students did not recognize the direction of energy flow and did not properly utilize positive and negative signs when representing heat lost versus heat gained. Furthermore, students had difficulties recognizing quantities, such as mass, in the thermochemical equations. Although Greenbowe and Meltzer recognized these problems, there is scarce information on research to address the difficulty of problem solving on heat transfer.

In response to this, we decided to investigate two instructional approaches to determine their effectiveness toward problem solving within the context of heat transfer problems. The first approach involved guided inquiry (GI) while the second one involved guided inquiry with the addition of an explicit general problem solving (EGPS) approach. Our research addressed the following questions:

- How does adding explicit problem solving steps to guided inquiry affect pre-service elementary teachers' scores on heat transfer problems?
- How does adding explicit problem solving steps to guided inquiry affect pre-service elementary teachers' problem solving strategies?

From these two research questions, our hypothesis was that adding explicit steps to GI would improve students' approaches to solving problems and their scores because the added structure would convert a non procedure cognitive skill to a procedural one thereby reducing cognitive laod (VanLehn, 2004).

Methods

Design

We used a mixed method approach as espoused by Johnson and Onwuegbuze (2004), Onwuegbuze and Leech (2005), and Onwuegbuze, Slate, Leech and Collins (2007) to collect and analyze data. In this study, we used the explanatory sequential mixed method because the quantitative data provided information to the qualitative data (Chi, 1997). We compared the mean performances of the treatment and control sections using quantitative data and determined what students were thinking as they solved heat transfer problems using probing questions.

Context

Our study involved two sections of chemistry for elementary pre-service teachers at a Midwestern (USA) university. Each section was composed mainly of female (> 83% to 17% male) pre-service elementary teachers.

The 24 students in each section were divided into six groups of four each. Selection into these sections was voluntary and hence there was no random assignment.

Statistical analysis of the first exam scores indicated no difference between these two sections. One researcher taught the treatment section and a colleague taught the control section. To ensure that instructors taught similar content except the treatment, they discussed the lessons before and after teaching. They gave similar examples, homework assignments, and end of topic exams. Scores of the first exam were used to investigate similarities in performance before the heat transfer topic. Table 1 shows presents the characteristics of these two groups.

Table 1. Characteristics of Participants

Characteristics		Similarities/differences
Instructors		Different
Homework assignments		Same
Instruction time		Same
Final exam on the topic		Same
Gender	treatment	21 female 3 male
	control	20 female 4 male
First exam mean score	treatment	88.17%, p=0.28
	Control	90.75%

The Instructional Approaches

Both sections were taught using guided inquiry but additional explicit steps of problem solving (EGPS) were added to the treatment section. In our guided inquiry classrooms, students work in six groups of four each. Each group is supplied with information to read and materials to work with. Leading questions are used to help learners develop conclusions about what they are working on. Students also solve heat problems as groups and the instructor gives them some hints, such as "Have you met a problem like this before? How did you solve it? Can you use that knowledge to solve the present problem?" After discussion, different groups of students present how they think they can solve the problem, or how they have solved it. The instructor then solves the problems with the class putting emphasis on the relationship between physical principles used and equations necessary to solve the problems. However, students are not compelled to use a specific procedure to solve heat transfer problems. Then students solve the problem using equations necessary to solve it.

The EGPS has all the characteristics of the guided inquiry approach but with added written explicit steps of problem solving. We adapted the EPGS approach from Polya's method as described in "How to solve it" (1957). The instructor explicitly encouraged students to solve their heat transfer problems using a systematic stepwise approach. This approach had the following steps: *Engage, Define the problem, Devise a plan for solving the problem, Carry out the plan, and Look back*. These stages are cyclic in nature (Figure 1) because whenever there is a problem at any step, the problem solver returns to previous steps (Wilson, Fernandez, & Hadaway, 1993). For each problem, the students had to use the steps indicated on the rubric to get to their solution. Table 2 summarizes the two instructional approaches.

Table 2. A Summary of the Two Instructional Strategies

Instructional approach	EGPS	GI
Inquiry involved	Yes	Yes
Explicit steps provided	Yes	No
Instructor emphasis on the steps	Yes	No
Students compelled to use an explicit strategy	Yes	No

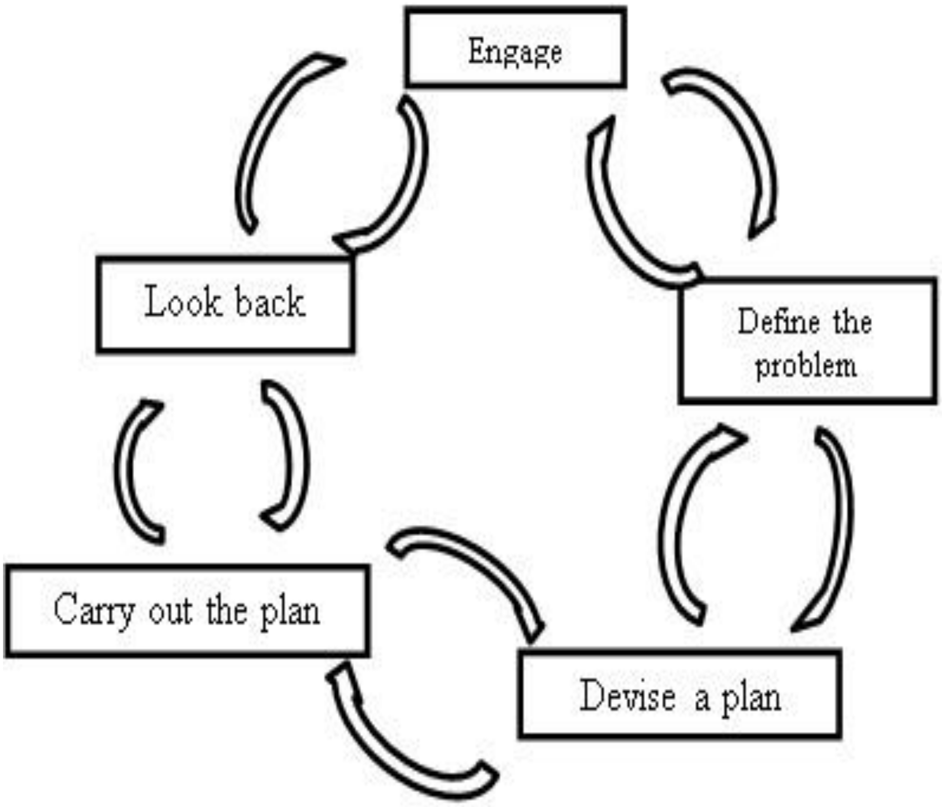

Figure 1. Cyclic Nature Of Problem Solving. Adapted from Carson and Bloom (2005)

Instruments and Data Collection

The heat transfer topic took three weeks to complete and afterwards, the students took a post-test. The problems were developed by one researcher from the heat and temperature topic. This test was validated by two science educators, both very familiar with the course, for face and content validity. The test had eight problems, some of which were easy while others were complex. The problem was regarded as easy if it could be solved in one or two steps and heat transfer is between two similar substances at different initial temperatures. Question 1 below was regarded as a simple question:

> *What will be the final temperature of water when 100 g of water at 80 ^{o}C is mixed with 200 g of water at 20^{o}C?*

Anyone with knowledge of the correct formula could easily get this question by just substituting values for letters in the equation. A difficult problem involved a number of steps, application of various chemistry principles, and heat transfer between two different objects. Question 3 below was regarded as a difficult question

> *A piece of metal weighing 25.50g is heated in boiling water for 40 minutes. Then it was removed from the boiling water and dropped into an insulated Styrofoam cup containing 150 ml of water at 22^{o}C. Assuming there was no loss of heat to the surroundings, what was the final temperature of the system? (The specific heat capacity of the metal is 0.91 J/g/^{o}C)*

Apart from knowing formulas involved, students needed to know and apply the law of conservation of energy. They also needed to know that objects assume the temperature of their environments and the conventional signs given for the heat absorbed and heat released when objects are mixed. These problems were created with regard to what students learned in their heat transfer topic.

Twenty two students consented to use of their results from the treatment section and all the 24 students in the control section agreed to participate. Of those consenting, 20 and 22 participants actually took the test from treatment and control section respectively. Four students volunteered for interviews, two from each section. Selection of the interview questions depended on students' performance on the post-test. We selected two questions, one simple (question 1) and one complex (question 3) from the tests for the probing questions. We selected these questions because they clearly demonstrated the different approaches to solving heat transfer problems. Question 1 involved heat transfer between water at different initial temperatures (same substance) and question 3 involved heat transfer between metal and water (different substances) leading to the concept of specific heat capacity. The simple question was at the knowledge and comprehension levels of Bloom's taxonomy of the cognitive domain while the complex one was at comprehension and application levels. The interviews were videotaped by one researcher and transcribed by an independent transcriber. The approximate duration of each interview was 20 minutes.

Data Analysis

After the post-test, one of the researchers collected the students' papers and gave them to an independent person who removed names and replaced them with numbers. The three researchers graded the papers independently, and the calculated Cronbach's alpha was 0.94. Both descriptive and inferential statistics were used to analyze the data. Sample means, standard deviations, and graphs were used to represent descriptive statics. For inferential statistics, we used *t*-test, Levene's test and Kolmogorov-Sminorv test to analyze quantitative data. The Kolmogorov - Sminorf test was used to establish the normality of the data. The Kolmogorov-Sminorf test statistics for treatment ($p = 0.18$) and control ($p = 0.67$) were calculated using SPSS. We carried out Levene's *F*-test to determine the equivalence of the two population variances. The calculated test statistic ($F_{1,36} = 9.38$, $p = 0.004$) was used to determine the appropriate *t*-test. Welch–Satterthwaite *t*-test was used to determine whether the explicit problem solving approach statistically improved mean percentage of the post test scores compared to the guided inquiry approach. We also carried out a question by question comparison in students' performance among the 8 post-test questions using *t*-test. For the qualitative section, two researchers analyzed data from all the interviews independently and developed codes. The codes emerged from the interview transcripts. The agreement between the coders was calculated using the recal2 online software and the Cohen's kappa was 0.83 (92% agreement). The disagreements were resolved before proceeding to report the data.

Results

To answer our research question 1 "How does adding explicit problem solving steps to guided inquiry affect pre-service elementary teachers' scores on heat transfer problems?", we used the post-test scores. Table 2 compares subjects mean performances between the treatment (EGPS) and the control (GI) groups.

After calculating the mean scores (Table 3), we found that the treatment group scored higher (52%) than the control group (47%). Levene's test statistic, $F_{1,36} = 5.71$, $p = 0.02$, indicated that there was significantly less variation in performance among the treatment group than the control group.

Table 3. Post-test Comparisons between EGPS and Guided Inquiry Approaches

Instructional approach	EGPS, n = 20	SD	GI, n = 22	SD
Post-test mean score	52	13	47	20

SD: standard deviation

Since the variances from these two different groups were unequal, a normal *t*-test was not suitable to determine the differences between means. Therefore, we utilized a Welch–Satterthwaite *t*-test to determine whether the explicit problem solving approach statistically improved mean percentage of the post test scores than the guided inquiry approach. There was no statistical difference between the two approaches, $t_{(34)} = 0.84$, $p = 0.41$. The calculated Cohen $d = 0.30$, $r = 0.16$, indicates low effect size (Hill, Bloom, Black, & Lipsey, 2007). This implies that both statistically and practically, there is no difference in performance between these two teaching approaches.

Results for students' performances for each of the 8 post-test questions are shown in Figure 2.

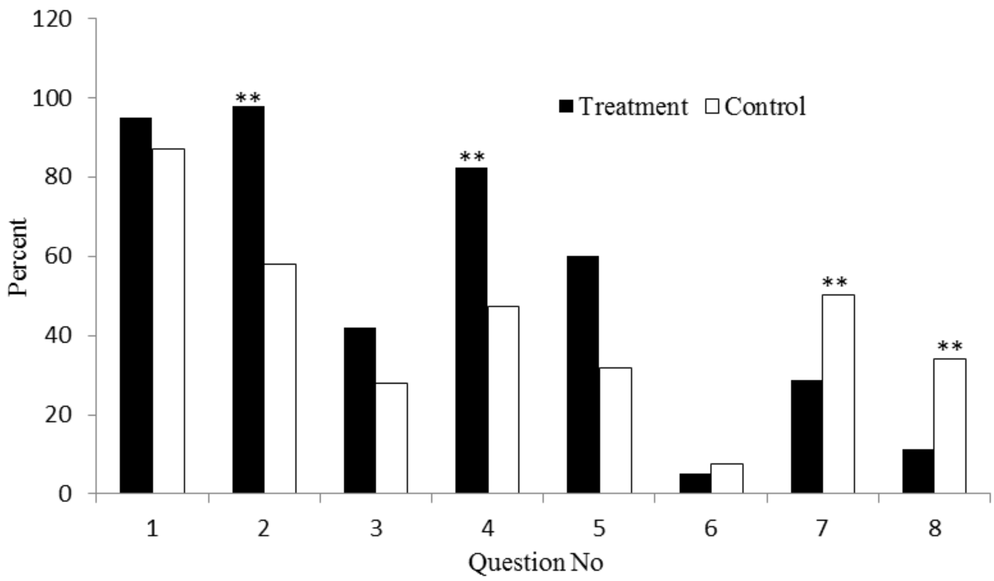

Figure 2. Comparison of Students' Performance on Individual Questions (**$p < 0.05$)

Question 1 was the easiest question followed by questions 2, 4 and 7 which were regarded as intermediate. Questions 3, 5, 6 and 8 were regarded as complex because they involved involved a number of steps, application of various chemistry principles, and heat transfer between two different objects. Questions 7 and 8 were mostly application items that required the use of heat transfer problem solving knowledge in real life situations.

The treatment section outperformed the control group on questions 2 and 4 ($p < 0.00$ and 0.01 respectively) while the control section did significantly better than the treatment group on questions 7 and 8 ($p < 0.05$ and 0.004). We observed that many students from the treatment section did not attempt questions 7 and 8 possibly due to time constraints. Although both sections had 1 hour to attempt all the eight questions, most students from the treatment section spent more time doing the first 5 questions than those from the control section.

For the qualitative part, we used questions 1 and 3 (taken from the post-test) because question 1 is solved without specific heat capacity and 3 needed the specific heat capacity to solve. To answer research question 2 "How does adding explicit problem solving steps to guided inquiry affect pre-service elementary teachers' problem solving strategies?" we used the probing questions. Four participants identified as subjects 1, 2, 3 and 4 answered the interview questions. Subjects 1 and 2 were from the treatment section and subjects 3 and 4 were from the control section. Subjects 1 and 3 were higher performers in their respective sections while subjects 2 and 4 were average performers. After the interview data analysis, three themes were developed: conceptual understanding, organization skills and confidence in solving heat transfer problems.

Our results showed that conceptual understanding was not related to the teaching approach but rather students' ability. The two lower performers from each section (subjects 2 and 4) lacked conceptual understanding of the algorithm variables in solving heat problems. Although they correctly used the formula for question 1, they did not understand the meaning and relationship between the variables in those formulas. However, the two higher performers from both sections understood the logic behind the formula in question 1. The following excerpt gives an example:

> ***Interviewer:*** *What is the logic behind that formula and behind the whole answer?*
>
> ***Student 1(EGPS higher performer)****: Ok well, I knew the equation for when you mix two masses of the same substance at different temperatures together.*
>
> ***Subject 4 (GI low performer)****: I wasn't taught the reasoning but I think…obviously you gonna multiply it by the temperature and I mean in 100 divide by 300 that's how many grams that you have out of the total of that water.*

In terms of proper use of positive and negative signs, only one subject (subject 3) from the control group understood and utilized them in his problem. Two participants (subjects 1 and 4) did not understand the meaning of signs when calculating the heat problems. Generally, students from both sections did not emphasize signs to show heat loss or heat gain although this was taught in class. Subject 4 suggested using an arrow to indicate the direction of heat during the heat transfer. The interview excerpts below show responses from the two higher performers from both sections.

> ***Interviewer:*** *So how do you know which one loses heat and which one gains heat?*
> ***Subject 3 (GI):*** *If it is a positive number it gains heat and if it's a negative, it loses heat.*

> ***Interviewer:*** *Ok what sign do we use when we lose heat?*
> ***Subject 1 (EGPS):*** *should it be positive?*

Conceptual understanding about thermal equilibrium was not linked to teaching approach but was related to performance in class. In terms of subjects, conceptual understanding about thermal equilibrium, only subjects 1 and 3 recognized that the initial temperature of the metal in question 3 is 100^{o}C because the metal was immersed in boiling water for some time. The other two participants could not recognize the initial temperature of the metal. The excerpts below show responses from subjects 1 and 2 when probed about the initial temperature of the metal in question 3.

> ***Subject 1 (EGPS):*** *I knew the temperature of the metal was 100^{o}C because when it is in boiling water for an extended amount of time it gathers that temperature…because it reaches equilibrium so it balances up.*

> ***Subject 2 (EGPS):*** *The water is at 22^{o}C but it doesn't say what the metal is. I would assume that the metal would be hotter.*

There was also no difference between the two groups on the conceptual understanding about specific heat capacity in calculating heat transfer problems students, only subject 1 and 3 clearly understood the role of specific heat capacity and used it properly in solving heat transfer problems. Subject 4 did not understand this concept although she felt that it was important in solving heat transfer problems.

> ***Interviewer:*** *What is so special about what you mentioned, the specific heat, why is it important?*

> ***Student 4 (GI):*** *Ammh, I really don't know. I mean I know it's important because it's the temperature of like of metal or water, whatever, we are using it for , I mean all of it is just like a constant.*

> ***Interviewer:*** *I agree with you we have two different substances, what is the implication when we have two different substances?*

> ***Subject 3 (GI):*** *I suppose because you have different conductors and metal has lower specific heat capacity and it transfers the heat away from it quicker while for water it takes long to heat up.*

The theme, organization of ideas, had two codes. The codes dealt with writing down the facts of the problem before beginning to solve it and breaking down a complex problem into parts for simplification purposes. In terms of organization of ideas, the EGPS group seemed more organized than the control group when solving their heat transfer problems. Only subjects 1 and 2 indicated that they organized their ideas during problem solving. Subjects 3 and 4 just talked about how they used their formula to get to the right answer. When asked how they solved problem 1, subjects 2 and 4 responded as follows:

> ***Subject 2 (EGPS):*** *First thing I did was to write down what was already stated in the problem; that is 100g of water at 80^{o}C and 200g of water at 20^{o}C…*

> ***Subject 4 (GI):*** *Well, I learned the formula for finding the temperatures like if you mix two temperatures of a certain way together and I know that it was like temperature 1 of the first thing over the total…*

In terms of splitting a complex problem into parts, all the participants realized that question 3 was complex and needed to be solved as two systems (metal and water) before merging it. Lastly, two participants lacked confidence in solving the heat transfer problems. For instance, participant 2 and 4 were unsure why they used specific heat equation although they recognized that it was the equation suitable for question 3. The excerpts below compare responses from subject 3 and 4 on how they solved problem 3.

Subject 3 (GI): *Ok, I used the formula for the specific heat capacity and the given here, the specific heat capacity of the metal; then I used that and I equaled that to the specific heat capacity of the water which is 4.2 J/g/°C and I just took the mass of the water…*

Interviewer: *Ok, so I see two sides to the equation why did you do that?*

Subject 3: *Because one is the heat lost and the heat gained from the metal because when the metal at a certain temperature goes into the water at a certain temperature, one loses heat the other one gains heat.*

Subject 4 (GI): *Aamh, just looking at this now I am not sure if I did this right, I don't know if you had to have the double sided formula because I did it wrong…*

Discussion and Conclusion

The mean posttest scores for both treatment and control groups were close to 50%. This may be due to a combination of time constraints and the level of difficulty of the problems. VanLehn et al. (2004) observed a similar trend and attributed it to what he termed a 'floor effect'. This effect occurs when the problems are too difficult regardless of the instructional approach. The quantitative results have also shown that there is no significant difference in performance between participants taught using the two approaches. These results are consistent with previous studies (Bunce & Heikkinen, 1986; Foster, 2000; VanLehn et al. 2004). All the studies found that an explicit problem solving approach did not improve students' achievement. However, we also observed that most students in the treatment section did not complete the last two problems. This was likely due to time constraints. Furthermore, the EGPS encouraged focus on applying individual principles when solving problems. This implies that students were likely to write down more information in the treatment section than the control group. This behavior was also observed by VanLehn et al. (2004). Levene's test indicated that there were higher variations in performance in the control section than in the treatment section. These results are consistent with a previous study (Foster, 2000). Foster (2000) found that higher performing students in a non-explicitly taught course skewed the results and hence increased variability. This also may mean that teaching using EGPS reduced the gap between higher performers and low performers. This is not surprising because Bunce and Heikkenen (1986) found that higher performers are not affected much by explicit problem solving teaching intervention compared to lower performers.

The qualitative data has shown that subjects 1 and 3 had fewer problems than participants 2 and 4. This is probably because the former were higher performers in their respective sections. Participants 2 and 4 had problems with conceptions and solving complex problems. The interviews have shown that participants from both the treatment and control groups used similar reasoning. They have also shown that differences emerged due to varying abilities not due to treatment versus control teaching strategies. This is not surprising because we believe that both the guided inquiry and EGPS are active approaches to solving problems. This likely enables them have similar influence on students' performance. Furthermore, the data showed that students in the treatment section were more organized than the control group. This is expected because an explicit approach to problem solving encourages this organization. VanLehn et al. (2004) reached the same conclusion when they observed that their treatment group students were more organized than the control group. They acknowledged that students will solve problems depending on the focus of instructional technique.

Though organized, the treatment group students did not sufficiently plan for the problem despite being explicitly taught to do so. This is not surprising because Huffman (1997) found similar results. In Huffman's study, the students from the group taught explicitly did not even plan the execution of their problems. This is consistent with Dalby, Tourniaire, and Linn's (1986) assertion that novices consider planning to be the most difficult step in solving problems. Our students did not have enough experience solving mathematical problems, hence are in the group of novices. However, planning is an important step for successful problem solving because it helps the solver in constructing a description of the problem in search of an appropriate solution (Reif, 1981). This may have affected the performance of participants in the treatment group. Eylon and Linn (1988) believe that inexperienced problem solvers rarely use procedures because they lack sufficient understanding of the problem.

We also observed that students from both sides never understood the proper use of signs in solving heat transfer problems. This is consistent with results found by Greenbowe and Meltzer (2003) who observed that students in their study failed to determine the direction of heat flow and correctly use positive or negative signs to indicate the direction of this flow.

In conclusion, adding an explicit general problem solving teaching strategy to GI did not significantly improve pre-service elementary teachers' ability in solving heat transfer problems compared to the guided inquiry only approach. There is also no difference on how students reasoned as they solved their problems from both treatment and control groups, apart from their ability to organize information. This may imply that either, adding EGPS to a general inquiry approach did not help this group or the participants did not properly use the approach during problem solving. Furthermore, since both strategies use inquiry, may be they are too similar to show a difference.

Limitations and implications

The study had some limitations which could affect the results. First, students' had no prior experience with the explicit general problem solving approach and the heat topic is only three weeks long. This might not give them enough time to get accustomed to the EGPS and could affect the outcomes of this study. Therefore, we believe that with more treatment time, the influence of the EGPS may be more pronounced. Second, selection of interviewees never went as planned such that we just used participants who were present. We believe that more interviews would have given us a clearer picture about what most students were thinking as they solved the problems. Furthermore, although we made an effort to ensure that the major difference was our instructional approach, we cannot rule out the influence of the instructor on the performace of students from these two sections.

In terms of instructional implications, the results have shown that the two strategies had comparable influence on problem solving. However, instructors who plan to use EGPS in their teaching must understand that some students need more time to get accustomed to this strategy because novices rarely plan and follow procedures when solving problems. Instructors must focus on teaching students how to plan when solving problems because it is a trait that is successful with expert problem solvers.

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