Metacognitive Strategies in a Web-Enhanced Environment: The Effects on Achievement in Problem-Solving for Engineering Undergraduates

by

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Dedication

To my loved ones, family, friends, and colleagues.
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Metacognitive Strategies in a Web-Enhanced Environment: The Effects on Achievement in Problem-Solving for Engineering Undergraduates

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ABSTRACT

This study focused on the effects of using metacognitive strategy cuing integrated into problem-solving activities in a web-based learning environment. Purposes of the study were to investigate: (a) differences in posttest achievement between students who received metacognitive strategies embedded as cues in engineering problem sets and students who did not receive the treatment; (b) differences in perceptions of problem-solving skills between students who received metacognitive strategies embedded as cues in engineering problem set and students who did not receive the treatment; (c) differences in thermodynamics knowledge; (d) problem-solving steps students reported using across problem sets; (e) characteristics of sampled students, and (f) students’ perceptions of web-based problem sets.

The sample consisted of 81 students enrolled in an undergraduate thermodynamics course. In-class lectures were scheduled twice weekly, and web-based problem sets were assigned as homework. Two groups, the treatment group using embedded metacognitive cuing and the control group not using the embedded metacognitive cuing, practiced with problem-solving activities over a fifteen-week-semester.
Two-thirds through the semester, comprehensive posttest achievement scores were compared between groups. Analyses showed no significant differences between groups when metacognitive strategies were incorporated into web-based problem sets.

An instrument was developed and validated to measure students’ perceptions of their abilities to plan, monitor, and evaluate problems. Pre- and post testing of students’ self-reported perceptions were measured. The results indicated no significant differences between groups.

When differences in thermodynamics knowledge and skills between students were measured, pretest to posttest results showed equal improvement for both groups, contradicting the hypothesis those students in the treatment group would improve in skills and knowledge more than the control group.

A frequency analysis revealed differences in the amount of times students’ reported using engineering problem-solving steps while working through exercises. Most frequently chosen was **Step Two - List Variables (91 %)** and **Step Seven - Solved Equations (91%)**. The least chosen response was **Step Four – Made/stated Assumptions** which was selected only three percent of the time.

Implications from this investigation, along with previous research, facilitate definition of boundary conditions when employing metacognitive cuing in web-based learning.
Chapter One Introduction and Background

Introduction

Statement of problem. The ability to solve problems is an essential life skill, especially for students entering the field of engineering. Core courses that emphasize problem-solving in undergraduate engineering education are difficult for most students and impossible for some. In order for students to become better problem solvers, they need to possess a general understanding of problem-solving and, in particular, they need to understand their own intellectual abilities (Davidson & Sternberg, 1998).

Livingston (1997) suggests faculty can help students understanding problem-solving and cognitive goal setting by having them use metacognitive strategies to control their cognitive activities. The term metacognitive is defined as the learner’s ability to be conscious of and manage one’s own learning processes (Peters, 2000). Innumerable opportunities exist to improve students’ metacognitive proficiency through guided classroom instructional practices, and students should have the opportunity to use their newly acquired skills to improve performance (Flavell, 1987; Gourgey, 2001; Schraw, 2001).

Recently, researchers have investigated the use of computer-mediated programs as a means to encourage learners’ thinking and reflection on instructional content, resulting in positive support of further study (Lin & Lehman, 1999; Watson & Allen, 2002; White & Frederiksen, 1998). Consequently, the present study explored the effects
of using metacognitive strategies when problem-solving in a web-based learning environment.

Over the last decade, technology has tremendously changed the dissemination of education. “Emerging technologies are leading to the development of many new opportunities to guide and enhance learning that were unimagined even a few years ago” according to Bransford, Brown, & Cocking (1999, p.4). The Internet, and specifically web-based instruction, has become widely accepted at many educational institutions in the United States and Canada. According to The Sloan Consortium Report (2003), over 90% of all public post-secondary schools offer at least one fully online or blended learning course.

Web-based instruction offers options not available in the traditional classroom. Some advantages of how web-based instruction shapes the learning process include the ability to: (a) present students with immediate feedback, (b) expose learners to real-world data, (c) provide deeper learning experiences, (d) facilitate critical thinking skills, (e) allow learner reflection before responding, and (f) grant equal treatment to learners (Horton, 2000). Technology and media expand the ability of a student’s perception, listening, manual dexterity, and speech (Ryder & Wilson, 1996).

Technology makes possible some types of learning activities (e.g., discovery learning) and supports others (e.g., cooperative learning) that otherwise would be more difficult or impossible to achieve without technology (Smith, 2002). “Hypermedia helps to focus a student’s attention on relationships rather than discrete facts, which assists learners in building accurate mental representations” stated by Jacques, Nonnecke, McKerlie, & Preece (1993, p. 225). As a student becomes more proficient in the use of
technology, less attention is needed to focus on mundane activities and affords more time to contemplate higher order thinking. To that end, some researchers propose that hypermedia supports higher order thinking, such as calculating the suitability of information (Dede, 1987). The application of metacognitive strategies in learning can be addressed through development of an online environment of homework problems in which students receive immediate feedback and are guided, when needed, through the process of problem-solving. Integration of metacognitive strategies into web-based homework activities provides a unique mechanism to steer students towards the development of problem-solving skills necessary in engineering.

Purpose of Study. This research studied the effect of using metacognitive strategies when problem-solving in a web-based learning environment. Problem-solving is an integral requirement of the learning process for engineers. Traditionally, the learning situation created by the teacher is a predetermined curriculum outlining course objectives and activities. In this type of environment, assignments, homework and testing are all evaluated by the instructor. In many cases, students request more opportunities from faculty to work through problem solutions than time permits in any given class period.

Although homework problems have customarily been assigned from the textbook, there are several reasons why this strategy impedes the learning process. The primary obstacle is that undergraduate core courses have sizeable enrollments making it difficult for instructors to interact on an individual basis with students. Sometimes students who encounter difficulty solving a problem cannot proceed without assistance from the instructor or teaching assistant and often students work together in groups to support each
other; however, this can lead to an uneven distribution of effort within the group. Proper assessment of contributions to homework assignments is difficult since often more than one student has taken part in the work. This makes it challenging for the instructor to grade an individual’s work appropriately. Without a structure or a set of strategies in which to frame problems, students are left to devise their own methods of problem-solving (Buck, 2004). When immediate feedback is absent, students are unaware if they have solved the problem correctly and, by the time they do receive feedback, new material has been covered. In courses with large enrollments, it is more difficult for the faculty to address an individual student’s concerns through one-to-one interactions, thus making it necessary for students to take more responsibility for their own learning. One way to assist independent learning is to teach students to use metacognitive strategies so they can plan and monitor their own performance and decide whether it is appropriate to use a specific strategy at a particular time (Ashman & Conway, 2002).

While there is a significant amount of research in the literature regarding metacognition and its benefits, there is a sparse amount of literature discussing metacognitive prompts embedded in web-based instruction on learning outcomes and student self-perception of problem-solving ability. Because there has been a heavy emphasis on metacognition in classroom settings as it relates to learning over the past thirty years, it seems a natural evolution to investigate metacognition within web-based education. Therefore, this study evaluated the effect of implementing student self-evaluation in the learning environment through metacognitive reflection. Specifically, this study examined whether there was a difference in student performance, when reflective-assessment was introduced, and if change in undergraduate students’
perceptions of self-efficacy in problem-solving were affected through a self-reflection intervention.

**Research Questions**

The study design utilized mixed-method research. According to Johnson and Turner, 2003) Mixed methods are used to obtain corroboration of findings, minimize alternative explanations for conclusions, and to elucidate divergent aspects of the research. “Methods should be mixed so that they have complementary strengths and non-overlapping weaknesses” (316). The focus of this research centered around the effect of using metacognitive strategies on problem-solving in an on-line learning environment. Differing types of web-based lessons in an undergraduate engineering course were compared. All of the students solved problem sets for a thermodynamics course. Two types of instruction were administered: (1) web-based homework problem sets with embedded metacognitive strategy cuing and self-reflection, and (2) web-based homework problem sets without the embedded metacognitive strategy cuing and self-reflection.

This research concentrated on the learning outcomes and perceptions of students who used metacognitive strategies included within problem-solving instruction and practice. The overall research question was: What is the effect on students’ problem-solving ability when direct instruction on embedded cues for using specific metacognitive strategies is included in web-based instruction? Two outcomes were anticipated from this research: (1) improved performance outcomes on a posttest measure of comprehension and (2) increased student self-perception of problem-solving practices. Six questions were considered:

1. Was there a difference in posttest achievement between students who received
direct instruction using metacognitive strategies and embedded cues in their thermodynamics problem sets and students who did not receive instruction in metacognitive strategies information and cuing?

2. Was there a difference in perceptions of their thermodynamics problem-solving abilities between students who received direct instruction in using metacognitive strategies and embedded cues in their problem sets and students who did not receive instruction on metacognitive strategies information and cuing?

3. Were there differences in thermodynamics knowledge between students who received direct instruction using metacognitive strategies and embedded cues in their thermodynamics problem sets and students who did not receive instruction in metacognitive strategies information and cuing?

4. Which of the problem-solving steps did students report using across the problem sets?

5. What are the characteristics of the students in the sample?

6. What were the participants’ perceptions of the web-based problem sets?

Significance of Study. Colleges of engineering experience a significant rate of attrition during the first two years of study (Rutz et al., 2003), and as many as 25% of students enrolled in thermodynamics classes at this university do not complete the necessary requirements for a passing grade in the course (Joseph, 2004). They either drop out of the program or subsequently retake the course in another semester. The ability to comprehend higher-order thinking when problem-solving is essential for success in thermodynamics courses and engineering in general. The current evaluation criteria outlined by the Accreditation Board for Engineering and Technology (ABET, 2003) states program graduates must demonstrate competency to identify, formulate, and solve engineering problems.

Common practice in courses such as thermodynamics is for the teacher to prepare and deliver the lectures, assign and grade homework assignments, and evaluate students
through objective testing procedures, in short, a teacher-centered approach. Limitations placed upon adult learners strongly conflicts with their inherent need to be self-directing and can lead to disagreement, indifference or estrangement (deLeon, 1996). Rather than control the act of learning, the teacher can improve the likelihood of certain behaviors by encouraging and supporting the student in various activities (Gagne, 1985). Nielson (2004) found that students with high levels of self-efficacy were more prone to be cognitively engaged when trying to learn the material than students with low self-efficacy. It is hoped the findings from this study would add to the body of literature on integration of metacognitive strategies into the curriculum. Outcomes from this research could lead to a change in the nature of student-teacher interactions in the learning environment, where students assume more responsibility for their own learning (a power shift) through the evaluative process. This in turn may lead to more use of web-based support materials to facilitate students’ skills for lifelong learning.

Definition of Terms. The following terms are defined to assist with the understanding within the context of this study.

1. Andragogy: applying the process of learning to adults (Knowles, 1968).

2. Construct validity: the extent inferences can be made from theoretical constructs to operationalizations within a study (Trochim, 2005).

3. Embedded cues: using written or verbal prompts to stimulate thinking.

4. Executive control: regulating the processes that take place during learning.

5. Human agency: having the capability of being conscious of and control over one’s own actions.

6. Instructional fading: deliberately diminishing the amount of instructor support by reallocating more and more control to the learner (Wilson, Jonassen, & Cole, 1993).
7. Metacognition: managing subordinate thought processes by higher order thought processes (Broadbent, 1977). Further, according to Hacker (1998), fundamental to the construct of metacognition is the idea of thinking about one’s own thoughts. The process can be what one knows (i.e. metacognitive knowledge), what one is performing (i.e., metacognitive skill), or what is one’s existing cognitive affective state (i.e., metacognitive experience).

8. Metacognitive strategies: are the higher level thought processes used to control or modify lower level (or cognitive) thought processes (Hacker, 1998).

9. Metacognitive cuing: promoting thinking about one’s thinking processes through written or verbal prompting (Condor, 2001).

10. Problem-Solving: attaining a desired outcome through the application of knowledge.

11. Reflective assessment: employing an activity in which students reflect upon their own learning inquiry.

12. Scaffolding: providing support (models, cues, prompts, hints, or partial solutions) to students to bridge the gap between what students can do on their own and what they can do with guidance from others” (Hartman, 2001, p. 167). Additionally, it “is a form of coaching or tutoring which helps learners accomplish tasks that they cannot do without assistance, therefore aiding in the construction of expertise in the tasks, engendering autonomous performance aptitude” (McNeill, 2002, p. 3).

13. Self-efficacy: the concept that people have the ability to obtain desired results through self-motivated acts (Bandura, 2001; Onwuegbuzie, 2001).


15. Web-based instruction: any intentional use of web technologies in order to aid in the educational process (Horton, 2000).

Limitations and Delimitations of the Study

Potentially, the internal validity of the findings may be threatened due to the experimental design which lacks random assignment through differential selection of participants (Wiersma, 1995). Participants in this study were chosen from a pre-existing
group of students who registered for a course section offered in the engineering undergraduate curriculum. Because the group was intact, it was important to compare ability levels of the students when checking for group equivalence. Consequently, the ability to generalize the results to the larger population could be impaired by selection bias (Wiersma, 1995).

A second threat to internal validity results from mortality or the loss of participants over the course of the experiment. Taking into account the drop/add period which occurs during the first week of classes, the study began after this period was completed. Although this threat is likely to occur during the remainder of the semester, a robust sample size has been chosen to account for further loss of participants. Other threats under consideration included the amount of time participant’s in the experimental group spent on the treatment (i.e., reading the material and reflecting upon strategic choices) and the possibility of the participants from the two groups discussing the differences in the instructional format.

Again, because of insufficient sample randomness, it is imperative to take into account external validity threats when attempting to interpret results. Ecological validity is threatened due to demographic constraints (i.e. limited geographic region) while the population validity is restricted by selection of only engineering students as participants. There is insufficient evidence to disregard the potential threat of temporal validity.

Chapter Summary

Problem-solving is a necessary skill for engineers. The core courses, which define the engineering curriculum, are challenging to most students and require the ability to problem solve effectively. A priority in engineering education is to provide
students with skills and competencies that permit them to progress easily into professional life (Hadjileontidou, 2004).

When students actively think about the processes involved in problem-solving, they are utilizing metacognitive strategies. Since these strategies have been shown to be important to the student for self-regulation of learning activities, they should play an essential role in instructional activities. According to Flavell (1987), metacognitive experiences play a significant role in daily cognitive lives. Through the incorporation of metacognitive strategies into problem-solving homework, students will have the opportunity to become more aware of the strategies and have the opportunity to practice with them.

Organization of Remaining Chapters. The remaining chapters include a comprehensive review of the literature in Chapter Two, the experimental design and analyses in Chapter Three, followed by the results in Chapter Four and conclusions in Chapter Five. Several theoretical frameworks (i.e. Information Processing Theory, Social Cognitive Theory, and Self-Regulated Learning) form the basis of discussion relating to the research questions and subsequent hypotheses. Following the evaluation of literature in Chapter Two, Chapter Three is a presentation of the research design used in the study. A mixed-methodology approach to the research was employed because the nature of the study investigated both quantitative and qualitative dimensions. Participant selection, ethical considerations, instruments, procedures, variables, research design, and data analyses are discussed followed by a brief summary of the methods section. Chapter Four is a discussion of the study results, ending with conclusions, implications, and recommendations for further study in Chapter Five.
Chapter Two Literature Review

Overview

Chapter Two is a review of literature focusing on the role metacognition plays in a web-based, problem-solving environment as it relates to students’ academic performance and perceived problem-solving ability. Beginning with an introduction to the theoretical framework of the study through a discussion on Information Processing Theory, Social Cognitive Theory, and Self-Regulated Learning Theory, a further exploration delves into the research on metacognitive awareness and performance, problem-solving, and self-monitoring. Included in the chapter is a discussion of the research surrounding metacognitive strategies in instruction and its association to the research questions. This chapter will wrap up with a summary of instruments designed to measure metacognitive awareness.

Introduction

Leading educators consider, “the really important, central point of education is to teach people to think, to use their rational powers, to become better problem solvers” (Gagne, 1989, p. 458). The demonstration of successful problem-solving is indicated when the learner is able to change from one strategy to another, to choose or discard a strategy, or to quickly deliberate upon a problem solution (Gagne, 1989). Such activities employ metacognitive knowledge, engaging learners in higher order thinking skills which have a significant part in cognition and problem-solving (Bransford, Sherwood, Vye, &
Reiser, 1986; Jonassen, 2004). “Metacognition is especially important because it affects acquisition, comprehension, retention and application of what is learned, in addition to affective learning, efficiency, critical thinking and problem-solving” (Hartman, 2001, preface). Students, who take part in metacognitive activities such as self-evaluation, monitoring, and revising, enhance their learning (Gourgey, 2001; King, 1991; Lin, 2001; Schoenfeld, 1985).

Recent research has found positive relationships between learning outcomes and a student’s use of effective learning strategies (Covington, 2000; Zimmerman, 1989). An examination of literature for this study revealed conditions under which metacognitive interventions have particular success. In the studies, (Everson & Tobias, 1998; Hong, McGee, & Howard, 2001; Kapa, 2001; Schoenfeld, 1985), results point to increased performance among both high and lower achieving students. Lower achieving students showed the most dramatic improvements, thereby closing the gap with their more capable peers. Condor (2001) and Kramarski & Zeichner (2001) found implementation of metacognitive strategies into learning situations increased awareness of metacognition demonstrating significant differences for the treatment groups. Watson & Allen (2002), however, discovered no measurable differences in posttest achievement scores citing a possible interaction effect.

Theoretical Basis of Study

Information Processing Theory. It is not enough for students to know what to do; they must also be aware of how and when to do it. The heuristics a learner uses to internalize habitual behaviors of self-monitoring and self-guiding activities are called cognitive strategies (Bullmaster & Alcock, 2003; Gagne & Driscoll, 1988; Rosenshine,
Simply phrased, cognitive strategies are the basic methods to guide students in “attending, learning, remembering and thinking” (Gagne & Driscoll, 1988, p. 55).

Information-processing theory was developed through the work of those in the field of cognitive psychology. It is concerned with the explanation of how information is managed by the human brain. Changes to cognition occur, as attention, memory and metacognitive functions mature. The theory as it applies to human thinking has been compared metaphorically to the flow of data input and output within a computer. (Flavell, 1985; McCown & Roop, 1992). The fundamental aspect of this theory is focused on how cognitive information is coded, stored and retrieved. Learning occurs when neural impulses of taste, touch, smell, hearing and sight (stimuli) from the environment enter the nervous system through a sensory register. The learner perceives the incoming information selectively, coding it in a conceptual form kept for a brief time in short-term memory. The information is then transformed into meaningful representations for long-term storage. The ability to then retrieve information from either long or short-term memory is evidence learning has taken place (Gagne, 1989).

There is a limited capacity within the brain to process stimuli, and it can easily be overloaded when the “processing demand … [exceeds] its processing capacity”. (Flavell, 1985, p. 76). In order to deal with incoming information, four elements of attention are required. The first is the ability to control the length of time for concentration. This is often referred to as “attention span”. Secondly, a person must be able to appropriately associate task demands. For example, when two variables of a problem are presented, the learner is capable of forming relationships. The third aspect requires proficiency to plan attention, having the means to choose what is important for the task at hand. And finally,
the monitoring of attention is to know when and how to modulate concentration. Initially, the limited capacity can impede the speed at which processing takes place, however as strategies are developed, memory capabilities are liberated and can be extended (Flavell, Miller & Miller, 1993). Strategies exercised to sort retrieved information stored in memory are, according to Brown (1987), essential to intelligent problem-solving.

Memory plays a key role in Information-Processing Theory. Input of data is transferred among three structures within memory. Short-term memory, also known as “working memory” is where information is processed or worked-on as it resides in a person’s consciousness. How the space is used becomes important due to a threshold of how much information can be managed at a given time. Two types of space exist within memory; 1) operating space and, 2) storage space. The former is where operations are performed and the latter is where supplementary information is kept. Inexperience with problems requires the use of much of this space to undertake the operations. Through practice and biological maturation, automaticity, or the relief of conscious effort, leads to more efficient problem-solving.

The information-processing model of learning and memory is a fundamental structure for a number of cognitive learning theories (Gagne & Driscoll, 1988). The model, as shown in Figure 1, is a representation of how a stimulus moves from the environment at large, through sensory perception and is transformed into information stored in short and long-term memory for later recall. Transformation actions, known as
learning processes, occur when the information is retrieved to elicit responses such as speech and movement.

Figure 1. The Basic Model of Learning and Memory


The manner in which learning occurs is significantly affected by the executive control and expectancies structures. When faced with a learning situation, an expectancy about the outcome of the learning is anticipated which influences how the information is coded into memory. Similarly, the learner has the ability to control the coding and retrieval processes. The activation and modification of information flow directed through these processes are referred to as cognitive strategies (Gagne & Driscoll, 1988). They make possible the ability to perform higher order operations (e.g. reading comprehension, writing or mathematical problem-solving) and to exert executive control.
Executive control is more general in the regulation of the processes that take place during learning. Thinking about one’s own thinking is a simplified definition of metacognition. Flavell (1987) used this term to mean the learner’s ability to be conscious of and manage their own learning processes. Metacognitive processes are central to planning, problem-solving, and evaluation of a student’s own learning. When knowledge is used to meet a goal through strategic planning, it is said to be a metacognitive process. For example, a student prepares to solve a homework problem, first by determining the complexity of the task, then recognizing what they do or do not know about the problem, planning approximately how long the task will take, checking successfulness as they work, applying all relevant resources, and finally reviewing their conclusions to verify the answer is reasonable given the problem (Hartman, 2001).

Flavell (1979, 1981, & 1987) furthered his definition of metacognition by distinguishing between its two aspects; metacognitive knowledge and metacognitive experiences or regulation. Metacognitive knowledge is comprised of three dimensions: 1) the student; 2) the task; and 3) the strategy. In order for a student to become a better problem solver, he/she needs to possess “knowledge about problem-solving, in general, and about their own mental processes, in particular” (Davidson & Sternberg, 1998). A student may, for example, use a metacognitive knowledge process when planning how to proceed with a reading assignment: What do I (person variable) know about this topic (task variable), so I will be able to understand both the content and vocabulary in the passage (strategy variable)? (Livingston, 1997).
Metacognitive experiences are concerned with the sequential processes of cognitive activities and the attainment of a cognitive goal for example, understanding a problem (Brown, 1987; Livingston, 1997). Table 1 (Ferrer, 2001) is an example of what occurs when a student activates metacognitive strategies compared to when they do not. Students who are actively engaging in thinking about the process of problem-solving are using metacognitive strategies.

Table 1

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<tr>
<th>Metacognitive Checklist</th>
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<tr>
<td>Active Metacognitive Strategies</td>
<td>Inactive Metacognitive Strategies</td>
</tr>
<tr>
<td>Reflect on what was read</td>
<td>Stop reading and thinking</td>
</tr>
<tr>
<td>Summarize major ideas</td>
<td>Do nothing extra</td>
</tr>
<tr>
<td>Seek additional information from outside sources</td>
<td>Feel satisfied that reading is enough</td>
</tr>
<tr>
<td>Feel success is a result of effort</td>
<td>Attribute success to luck</td>
</tr>
</tbody>
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*Note. From Metacognition, by Ferrer, 2001, p.2.*

“Research as well as personal experience have demonstrated that students who use metacognitive strategies, notably identifying goals, self-monitoring, self-questioning, reasoned choice of behaviors, and self-assessment, are more academically successful than students who do not use these strategies” (Gourgey, 2001, p. 30). There are several reasons why an emphasis should be placed on the teaching of metacognitive skills:

1. Long term, students need to learn general skills of planning and how they apply to a wide variety of tasks and domains, rather than learning a specific skill or task.
2. Effective cognitive performance depends upon the ability to utilize metacognition.

3. Students generally are not in the habit of questioning themselves, rather, they blindly follow instructions.

4. Students who are deficient in metacognitive skills are unaware of the specifics in performing a task.

5. Metacognitive skills are important for students to: estimate task difficulty, monitor their understanding of the task, plan ahead, oversee their performance (knowing when they have reached mastery of a topic), apply all germane information, and avoid incorrect conclusions or representations. (Hartman, 2001, Wagner & Sternberg, 1984).

The use of general strategies and metacognitive knowledge as well as domain specific knowledge has been linked significantly to thinking and problem-solving (Bransford et al., 1986).

*Problem-Solving.* The dissimilarity between being a good or a poor problem solver is often in the learner’s ability to think about one’s problem-solving activities (Gardner, 1991; Schraw, 2001). “Poor problem solvers lack spontaneity and flexibility in both pre-planning and monitoring” (Brown, 1987, p. 86). Research in problem-solving for mathematics assumes those considered experts initiate a three-stage process of metacognitive and cognitive activity when working on problems. Figure 2, graphically depicts the preactive (or planning) phase, the interactive (or monitoring) phase and the post active (or evaluating phase). Each phase is an interconnected process integrating into the learning activity.
Figure 2. Components of Metacognition


Higher order cognitive skills are required to solve problems effectively. Novices are not generally able to recognize the distinction of problem types, so they must rely on general strategies for problem-solving, which do not provide strong strategies for problem solutions (Jonassen, nd). Because experts have the ability to recognize similarities in solving particular types of problems and spend more time in the planning stage, they tend to be better problem solvers (Brown, 1987; Davidson & Sternberg, 1998; Sweller, 1988). According to Everson and Tobias (1998):

Learning in complex domains such as science and engineering, or making
diagnosis in medicine or other fields, often requires that students bring substantial amounts of prior learning to bear in order to understand and acquire new knowledge or solve problems. Some prior learning may be recalled imperfectly, or may never have been completely mastered during initial acquisition. Students who can accurately distinguish between what they know and do not know should be at an advantage while working in such domains, since they are more likely to review and try to relearn imperfectly mastered materials needed for particular tasks, compared with those who are less accurate in estimating their own knowledge (p. 76).

Metacognitive awareness allows the learner to discern and select a suitable strategy to solve the problem. When a problem solver chooses to use a correct strategy from one related problem to another, it signifies metacognitive ability and demonstrates he/she has the ability to know how and when to use it (Jackson & Butterfield, 1986). Proficiency in three areas seems to be present in productive thinking and problem-solving: “intellectual skill (concept and rules), verbal knowledge, and cognitive strategies” (Gagne, 1989, p. 464). While cognitive strategies facilitate the construction of knowledge, metacognition aids “science learners to develop and use effective and efficient strategies for acquiring, understanding, applying and retaining extensive and difficult concepts and skills” (Hartman, 2001, p. 198). Research on expert versus novice behavior reports, experts have the ability to set clear goals, comprehend concepts and the relationships of concepts, keep track of their understanding, and make decisions on whether their actions are leading towards defined goals (Gourgey, 2001).
The following two study descriptions illustrate metacognitive strategies are more efficiently used by experts than novices and especially when employed in complex problem-solving situations. Schoenfeld (1985) conducted a study which investigated the relationship between a student’s proficiency at problem-solving and their perceptions of the problem-solving process. The research illustrated when metacognitive skills were employed by experts more efficient performance resulted. The findings supported the three hypotheses within the study. First, novices perceive problem-solving differently than experts whereby they look only at surface characteristics which could result in incorrect conclusions. Secondly, experts perceive problem-solving with an eye for deep structure, which allows them to recognize, categorize and select efficient solutions to problems, thereby eliminating protracted experiences. And finally, as students became more adept at problem-solving, their perceptions of the process and their performances became more expert-like.

In two related studies by Hong, McGee, and Howard (2001), 9th-grade students and 6-8th-grade students participated in research to look at four mental components (cognition, metacognition, non-cognitive variables and justification skills) deemed important for successful problem-solving. Both studies were investigated separately over a 4-week period. The first study used an open-ended response format for presentation of both the well-structured and ill-structured problems. The second study used a multiple-choice format for similar well-structure and ill-structured problems. Students were given an inventory measuring both knowledge of metacognition and regulation of cognition. The researchers concluded “regulation of cognition was strong predictor in solving only open-ended ill-structured problems. The results suggest that
problems have to be complicated enough to challenge students to use regulation of
cognition for researching successful solution. In other words, students may not need to
use regulation of cognition if the problem lacks conceptual and structural complexity,
even though they have those skills” (p. 4).

“Metacognitive knowledge may also compensate for low ability or lack of
relevant prior knowledge (Schraw, 2001, p. 7). Swanson’s (1990) investigation found
high levels of metacognitive knowledge about problem-solving compensated for lower
aptitudes in children from grades 4 and 5. Two pre-tests of aptitudes were administered
to participants with diverse academic aptitudes. A metacognitive questionnaire was first
administered followed by problem-solving tasks. Significant results from this study
indicated problem-solving performance is positively influenced by high-metacognitive
ability regardless of aptitude. Additionally, high aptitude is only important when
metacognitive ability is low.

Social Cognitive Theory. The facility to have the power over the conditions of
one’s existence is the “quintessence” of being human (Bandura, 2001). He believed
people possess a self system which allows a degree of control over their thoughts,
feelings and actions; and facilitates the perceiving, regulating and evaluating of one’s
own behavior within an external environmental context (Marzano, 1998; Pajares, 1996).
A role of the self system is to self-regulate both control and agency. The concept of
agency is the ability to be aware of and in command of one’s own actions. Three types of
agency are distinguished within this theory: direct personal agency, proxy agency, and
collective agency.
Direct personal agency refers to people’s ability to imagine innovative ideas intentionally while considering unique ways to implement them. The concept of proxy agency suggests authorizing someone to act on one’s behalf to gain preferred effects, while collective agency is based on collaborative efforts for desired outcomes (Bandura, 2001). Self-efficacy, a core feature of agency, is a concept that individuals have the capacity to produce desired effects from self-motivated activities to meet goals and expected outcomes. (Bandura, 2001; Onwuegbuzie, 2001).

Self-Regulated Learning (SRL). Many adults learn best when they feel empowered, autonomous, goal-orientated and responsible for their own learning (Cranton, 1994; Hiemstra, 1998; Knowles, 1980; Lieb, 1991; Mezirow, 1997). According to Merriam & Caffarella (2001), adults are adept at managing the many facets of their lives and are able to take responsibility for, or at the least take part in the process of, planning their own learning. An approach to directing and planning one’s own learning can be found in the research on self-regulated learning (SRL) theory. The self-directive method of learning is defined as a process of instruction based upon such activities as needs assessment, procuring learning resources, employing learning activities and the evaluation of learning (Hiemstra, 1998).

Intentionality and forethought, self-reactiveness, and self-reflectiveness, core elements of human agency are underlying constructs of Social Cognitive Theory which allow people a role in self-development, self-renewal and adaptation over time (Bandura, 2001). The concept of intentionality within this theory, describes humans actively participating within their environments through mindful decisions when faced with changes rather than passively reacting to them. Manifestation of agency describes
forethought and self-reactiveness, allowing people to move beyond immediate boundaries while molding and controlling their present state to a preferred future state (Bandura, 2001). Additionally, self-reflectiveness is the belief one has to maintain a certain amount of influence over managing themselves and environmental events surrounding them (Bandura, 1997; Pajares and Schunk, 2001).

Self-efficacy is a fundamental tenant of human agency. Bandura (2001) states the construct of efficacy is key to self-regulating motivation through setting challenging goals and outcome expectancies. Through metacognitive activities of self-efficacy, decisions are made on “what challenges to undertake, how much effort to expend in the endeavor, how long to persevere” (Bandura, 2001; Strauser, Ketz, & Keim, 2002; Wongsri, Cantwell, & Archer, 2002). Components of self-efficacy include: 1) expectations about the future; 2) influence the way we behave in specific situations; 3) beliefs about yourself – control personal agency; 4) mastery experiences – self-efficacy beliefs; and 5) evaluate experiences through self-reflection (Hannibal & Gymnasium, 2003).

An essential skill to successful learning in the sciences is problem-solving and requires students who demonstrate metacognitive proficiency by generating questions to achieve solutions (McLoughlin & Hollingworth, 2001). Table 2 represents the phases of cognitive tasks in problem-solving and the associated metacognitive regulation of such tasks.
Table 2

Metacognitive Functions Classified According to the Process Phases

<table>
<thead>
<tr>
<th>Solving-phase</th>
<th>The metacognitive function</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Problem identification</td>
<td>Collecting data, coding and remembering</td>
</tr>
<tr>
<td>b) Problem representation</td>
<td>Analogy, inference, imaginativeness, selective comparison and combination</td>
</tr>
<tr>
<td>c) Planning how to solve</td>
<td>Integration, conceptualization, heuristic choosing and formulating</td>
</tr>
<tr>
<td>d) Planning performance</td>
<td>Controlling and monitoring performance components of algorithmic mathematical knowledge and appropriate rules</td>
</tr>
<tr>
<td>e) Evaluation</td>
<td>Adjusting and contradicting a few possible solutions or suggesting alternative solution methods</td>
</tr>
</tbody>
</table>


Results from research in the literature demonstrate that learners competent in metacognitive self-assessment, those cognizant of their abilities, are more intentional and outperform those who are unaware (Rivers, 2001; Schraw & Dennison, 1994; Swanson, 1990).

Cognitive strategies are not specific procedures to be followed rather; the learner develops internal processes to enable comprehension. Wren (2004) lists five reasons why higher order cognition is of importance: “(a) enables students to grapple with intellectually sophisticated challenges, (b) enables students to integrate multiple ideas and facts, (c) enables students to undertake difficult problems, (d) enables students to find
effective and creative solutions to dilemmas, and (e) reduces the burden on memory and attention to detail” (p. 1). Information processing theory explains the manner in which executive control (metacognitive) processes manage and regulate cognition, providing an explanation as to why some students are better than others at learning and remembering (Woolfolk, 1998 in Hartman, 2001, p. 33). Because metacognitive strategies facilitate the evaluation and application of knowledge to novel situations, “metacognition is critical to cognitive effectiveness” (Gourgey, 2001, p.18).

Efficacy can be impacted through self-regulated practices as well as a student’s ability and past experiences. Students who actively engaged in their learning while applying control over goal setting and goal attainment are reported to be self-regulated learners (Schunk, 1989). When students experience acceptable results as they monitor progress towards learning goals, they are encouraged to further improve their skills (Brown, 1999; Schunk, 1989).

Three important regulatory skills appear in the literature regarding control over one’s cognitive activities: planning, monitoring, and evaluating (Jacobs & Paris, 1987; NCREL, 1995; Schraw, 2001). Planning refers to the selection of appropriate strategies and allocation of resources that affect performance. An example would be apportioning time or attention selectively before beginning a task. Monitoring is defined as a person’s awareness of comprehension and task performance. An example is the ability to engage in periodic self-testing while learning. Evaluation entails judging the outcomes and efficiency of one’s learning. The re-examination of one’s goals and conclusions is a typical example (Schraw, 2001). Table 3 is an illustration of the phase structure and sub-processes of self-regulation.
Table 3

*Phase Structure and Sub-Processes of Self-Regulation*

<table>
<thead>
<tr>
<th>Cyclical Self-Regulatory Phases</th>
<th>Forethought</th>
<th>Performance</th>
<th>Self-Reflection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task Analysis</td>
<td>Self-Control</td>
<td>Self-Judgment</td>
<td></td>
</tr>
<tr>
<td>Goal Setting</td>
<td>Self Instruction</td>
<td>Self Evaluation</td>
<td></td>
</tr>
<tr>
<td>Strategic Planning</td>
<td>Imagery</td>
<td>Causal Attribution</td>
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</tr>
<tr>
<td></td>
<td>Attention Focusing</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Task Strategies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-Motivation Beliefs</td>
<td>Self Observation</td>
<td>Self-Satisfaction/Affect</td>
<td></td>
</tr>
<tr>
<td>Self-Efficacy</td>
<td>Self Monitoring</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outcome Expectations</td>
<td>Self Observation</td>
<td>Adaptive-Defensive</td>
<td></td>
</tr>
<tr>
<td>Goal Orientation</td>
<td>Self Observation</td>
<td>Self-Satisfaction/Affect</td>
<td></td>
</tr>
<tr>
<td>Intrinsic Interest</td>
<td>Self Observation</td>
<td>Self-Satisfaction/Affect</td>
<td></td>
</tr>
</tbody>
</table>


Self-regulated behavior, like metacognitive strategies, can improve students’ success and ability to transfer learned skills to new situations through familiarity of problem meanings and strategic examination (Gourgey, 2001).

Research by Wolters & Pintrich (2001), studied the difference of motivation, self-regulated learning and classroom performance across subject matter areas and gender. The investigation concluded a relationship existed between knowledge of strategies to self-reported strategy use. Findings of the study revealed that, as a group, both genders reported similar use of regulatory strategies in the varying subject areas, although
cognitive strategies were employed more often in social studies. Females responded with more favorable usage of cognitive strategies across subjects than their male counterparts. Regarding self-efficacy, students who indicated confidence in comprehension of course materials were more apt to also indicate they employed cognitive and self-regulatory strategies.

Everson and Tobias (1998) conducted two separate studies in order to develop an evaluation instrument of students’ knowledge monitoring ability (KMA). The measure compared the differences between students’ perception of their own knowledge within a specific domain and students’ actual knowledge based upon outcomes of an objective performance measure. Summarizing the results of both studies, the conclusion sustained the KMA’s validity related to metacognitive knowledge monitoring and predictive ability in assessment. The findings reveal that while all students demonstrated an increase in vocabulary knowledge from pre- to post testing, the more capable students showed greater increase in monitoring ability.

*Self-Monitoring.* If the responsibility for learning lies with the student, so too, should the responsibility for critical evaluation (Baron, 2003; Mitrovic, 2001). According to Baron (2003) from the University of Las Vegas Teaching and Learning Center, there are several reasons for using student self-assessments: (a) it promotes an attitude of inquiry in that students have an active relationship to the material; (b) it provides opportunities for students to demonstrate relationships between course material and other experiences such as work, travel, and reading; (c) it promotes consideration of the meaning and relevance of the material learned and tasks accomplished; (d) it empowers students to add their voices to the feedback they receive from their teachers; (e) it teaches
students to engage in a self-directed process; (f) it encourages reflective learning; (g) it provides students with an opportunity to combine quantitative and qualitative assessment of their learning; (h) it creates a shift in the dynamics of teacher-student relationship (i.e. a power shift); and (i) it helps develop skills for life-long learning.

Engaging students in self-directed activities also implies the involvement of the instructor. There are a number of benefits and challenges for both the learner and teacher. From the student perspective, they take control of and responsibility for their own learning with critical intention, while the evaluation process is obvious for both parties. However, because students lack routine involvement in analyzing their own work with a critical eye, they may lack the confidence to do so. It may also be difficult for students to discuss academic problems or issues and they may be uncomfortable communicating their successes. For faculty, they will have to prepare differently by becoming familiar with the self-directed evaluative processes, defining their roles regarding feedback, and organizing their curricula accordingly (Baron, 2003).

In order to integrate self-monitoring into the curriculum, the evaluative procedure must initiate with the learner. Zimmerman (1989) illustrated the process of self-regulation in a triadic feedback loop in which self-monitoring of information is regularly processed among person, behavior and environment (Figure 3).
During the process of behavioral self-regulation, self-monitoring activities correct performance while monitoring environmental conditions. Covert self-regulation refers to revising cognitive and affective states, as necessary. Self-monitoring of these conditions directly affects desired outcomes of learning strategies (Ellis & Zimmerman, 2001; Paris & Winograd, 1990). The growing body of evidence demonstrates that students, who take responsibility for their own learning, develop deeper and more permanent knowledge and skills (Brockett & Hiemstra, 1991).

In a study by Ellis (1994), 80 undergraduate students enrolled in a remediated speech class participated in an investigation of self-monitoring training. Initially students were requested to use a standard pronunciation of a word while reading a story aloud. Later, they listened to their voice recordings to evaluate if, indeed, they had used the

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**Figure 3. Triadic Form of Self-Regulation**

standard pronunciation. This data was used as a baseline measure of self-evaluative accuracy. Participants subsequently were assigned to one of four experimental groups or the control group. Assignment included: Discrimination with Self-monitoring training, Discrimination Only training, Self-monitoring Only training, and Practice only (no training in either self-monitoring or discrimination).

After training, students were given three times to practice sentences and then report responses of self-efficacy to the question “how sure they were that they could say the word” exercising the standard pronunciation. At the end of post testing, students reported if they felt they “had” used the standard pronunciation. Students were then tested on other words containing similar sounds to check for near and far transfer. Results clearly indicated the Discrimination plus Self-monitoring group ($M = 35.88, SD = 5.71$) performed substantially better on the posttest scores at the $p < .01$ level. The Discrimination Only group ($M=14.63, SD=17.20$), the Self-monitoring Only ($M = 13.06, SD = 16.28$), the Practice Only ($M = 1.38, SD = 2.75$) and the control group with no treatment ($M = .98, SD = 1.18$) indicated significantly lower results.

The researcher reported students trained in only self-monitoring rated themselves lower on self-efficacy and self-evaluation than the control and practice groups while students who received training on both discrimination and self-monitoring ranked themselves much higher in these areas. Three important conclusions resulted from this study: 1) self-monitoring improved learning outcomes, 2) this group of college students lacked adequate self-regulatory skills to improve on their own, and 3) practice alone, by students, is not enough; intervention is needed to teach self-monitoring techniques. The
effect on students from this intervention was increased metacognitive awareness and enhanced self-efficacy.

**Metacognitive Awareness.** “A strategy is defined as a conscious, deliberate use of a specific method, whereas a skill is defined as a refined strategy which is used selectively, automatically, and unconsciously as needed” (Hartman, 2001, p. 33). Garner’s (1990) theory of settings states several contextual factors affect strategy use; lack of knowledge about the relationship between strategy use and task demands, classroom settings that do not value the effortful application of strategies, and learner’s who use “primitive” routines and demonstrate inadequate cognitive monitoring (in Hartman, 2001). Metacognition functions to direct the cognitive processes such as thinking and remembering that take place during learning (McCown & Roop, 1992). Two distinct constructs of metacognition have been generally recognized; knowledge of cognition and regulation of cognition (Brown, 1987; Davidson & Sternberg, 1998; Flavell, 1987; Schraw, 2001). Research has shown learners’ who have the ability to plan, monitor and evaluate their own learning are more strategic and perform better (Garner & Alexander, 1989; Hartman, 2001; Schraw, 1998, 2001).

According to the North Central Regional Educational Laboratory (1995), metacognition includes three fundamental components:

1. Developing a plan of action: Consider what prior knowledge has been brought to current task, what are the first steps to be taken, and how much time will it take.

2. Maintaining/monitoring the plan: Is the plan on task? What information is needed to proceed? What other resources can be used to continue? Is the pace too fast, too slow, or adequate?

3. Evaluating the plan: Did the outcomes align with the plan of action? What went
Applying metacognitive strategies is particularly critical to learning because it affects the acquisition, understanding, retention, and relevance of knowledge while impacting critical thinking, problem-solving and learning effectiveness. “Reflective thinking is the essence of metacognition” (Hartman, 2001, p. xi).

White and Frederiksen (1998) analyzed an instructional approach based on scientific inquiry developed to engage students, specifically targeting those of diverse backgrounds. The curriculum consisted of two dimensions: (a) a metacognitive model of research and (b) a metacognitive reflective process. Students in middle school physics classes were specifically instructed on how to reflect and critique their own and other students’ analyses while learning to build complex models of force and motion. The results from this research are consistent with other research findings (Case, Gunstone, & Lewis, 2001; King, 1991; Mevarech & Kramarski, 2003; Schoenfeld, 1985) which found lower achieving students gained more benefits from the implementation of metacognition into the curriculum, actually closing the gap in performance with the higher achieving students. However, overall both high achievers and low achievers showed increased improvement.

Metacognition and Performance. “Metacognition is essential to successful learning because it enables individuals to better manage their cognitive skills and to determine weaknesses that can be corrected by constructing new cognitive skills” (Schraw, 2001, p. 13). Regarding academic success, metacognitions “are the kinds of knowledge and strategies that successful people tend to figure out for themselves and that
some people must be taught” (Hartman, 2001, p.33). Critically important, but frequently overlooked in learning, is that many times students possess the necessary knowledge and skills to tackle complex issues, but often do not make use of them. In other words, according to Hartman and Sternberg (1983) students may have “declarative and procedural knowledge, but not the contextual or conditional knowledge needed for application and transfer” (as cited in Hartman, 2001, p. 34).

According to Hartman (2001), research reports the following about metacognition:

1. High achieving students (HAS) learn and remember more than others (Woolfolk, 1998) and are more metacognitive than low achieving students (LAS) (Sternberg, 1985).

2. (HAS) have been found to possess more metacognitive awareness and engage in more self-regulatory behavior than low achieving students.

3. Metacognition has been found to be an important characteristic of expertise. (Meichenbaum & Biemiller, 1998; Sternberg, 2001).

4. Demonstrated to be essential to learning: general strategic, metacognitive knowledge and strategies, and domain-specific knowledge have been shown to have important roles in thinking and problem-solving (Bransford et al., 1986).

Unless the student is able to employ self-regulation, metacognition alone is not adequate for academic success.

According to Case, Gunstone, and Lewis (2001) “enhanced and appropriate metacognitive abilities will only be achieved by means of an integrative perspective on metacognition, in which metacognitive training is recognized to be intimately bound up in issues of content and context” (p. 315). In a study by Mevarech and Kramarski (2003), an assimilated approach was used to examine differences among students who were informed of metacognitive training (MT) and those who used worked out examples
The research occurred over two academic years following a group of eighth grade students through ninth grade.

A pretest was administered to all participants, followed by random assignment to either the MT or WE groups. Learning materials designed explicitly for each treatment were used to study the unit, ending with an immediate posttest of the material. The following year, all ninth grade classrooms underwent the delayed posttest examination. Additionally, within the cooperative setting, each group was videotaped to observe and later analyze problem-solving behaviors. Results concluded significantly higher for the MT students than the WE students on the immediate posttest. Dimensions of mathematical reasoning (verbal explanations, algebraic representations and algebraic solutions) analysis confirmed statistically significant results for both lower and higher achievers in the treatment condition.

King (1991) reported similar results for students who were trained in asking and answering metacognitive questions. They demonstrated the ability to express conceptual understanding better and gave more explanations to peers when presented with novel problems, than those who were not trained. In a related study by Schoenfeld (1985), more than 100 hours of videotapes were reviewed by researchers depicting the behaviors of high school and college students’ attempts at solving problems. He found more than 60% of students’ problem-solving abilities were hampered by the tendency to jump into the problem quickly without first attempting to ask questions and plan a solving strategy.

Zhang and RiCharde (1998) performed a longitudinal study of outcomes on the dimensions of academic achievement and metacognitive development. The study followed university students (N= 300) at a public institution from freshman year up to
graduation. The authors concluded metacognitive development is fostered by academic achievement, indicating students with “good academic standing possess a stronger ability to reason, think, and make decisions about personal and social issues than their peers and that ability is central to metacognitive and intellectual development” (Zhang & Richarde, 1998, p. 15). A comparison of means throughout the four years of the study revealed the top 10% of the participants scored significantly higher on logical reasoning and probability estimate than the middle 40% or the bottom 50%. Also the top 10% obtained significant differences on problem-solving approach than the bottom 50%. The study found the middle 40% of students scored significantly higher on the measure of metacognition than the lower 50%. Their results are in agreement with previous research by Flavell (1985). Interestingly, this research found engineering majors exhibited an increased level of metacognitive development over liberal arts students as measured by logical reasoning, probability estimate, and problem-solving approach, however, science students outperformed both engineering and liberal arts majors on problem-solving approach during the four-year period.

**Metacognitive Cues.** The maintenance and monitoring aspect of metacognitive regulation has been the focus of research on metacognitive prompts. Strategies are embedded as indicators in the instructional event to stimulate the learner’s conscious control over their own learning. There are many instructional methods that can be used to facilitate or strengthen a student’s use of cognitive strategies. Some of these teaching approaches include (a) procedural prompts—having the student pose questions of who, what, where, when and how; (b) model responses for students; (c) thinking aloud to summarize, thinking ahead or clarifying difficult concepts; (d) guide student practice; and
(e) provide feedback and corrections (Lloyd, Kameanui, & Chard, 1997).

The web-based learning environment in this study employed more than one instructional method. Specifically, guided student practice has been designed into the web-based instruction using modeled responses accessed through the “help” button. During the lesson, feedback and corrections were used during and following the problem-solving activity for the experimental group.

Prior research has concluded feedback during the learning process is favored over learning without feedback (McDaniel & Fisher, 1991; Zellermayer, Salomon, Globerson, & Givon, 1991). Feedback has been found to be an essential component of success in student-centered environments (McCown, Driscoll & Roop, 1996). In the study by Kramarski and Zeichner (2001), students who were exposed to two differing kinds of feedback in a computerized environment resulted in significantly higher achievement outcomes for students receiving the metacognitive feedback (MF) than students receiving result feedback (RF). A group of 186 eleventh grade students from eight classes in four schools were randomly assigned to either the control or experimental condition. MF consisted of metacognitive questions (e.g. “what is this problem/task all about?”) acting as cues for mathematical reasoning, whereas RF provided cues relevant only to the final answers (e.g. “check it once more” and “very good!”). Students’ self-regulated learning was performed in a computer laboratory setting with a teacher present only for technical problems, not intervention with the learning sequence. Indications were reported from the researchers on the importance of metacognitive feedback embedded in a computerized learning environment on achievement and mathematical reasoning skills. Analytical results of the two research questions (achievement and mathematical explanations)
concluded: 1) significantly higher performance of the MF group on the total scores of all measures: general term formula, rule of recursion and verbal problems and 2) richer mathematical reasoning by the MF group using verbal arguments (30.2%) more often than the RF group (20%). Similarly, the MF students demonstrated frequency of use (63.5%) employing a combination of algebraic rules and verbal arguments more than RF students (31.6%).

Watson and Allen (2002) studied the use of embedded metacognitive prompts or cues in a computer-based tutorial for 5th-grade students studying science concepts. The instructional sequence involved a 20-30 minute lesson, an announcement of a quiz followed by the actual examination. Two quizzes were administered over the course of the study. Both the control and experimental groups received the same instruction, the same quiz announcement, and the same quiz, in that order. However, the experimental group had access to metacognitive prompts directly after the quiz announcement. The prompts asked questions such as “Are you ready? If you think you need to review, you can use the [navigational] back button to go back now”.

Results indicated a significant difference in the two groups of students to accurately predict their own posttest performance. Nevertheless, there was no significant overall effect when measuring posttest comprehension of the combined score for the two embedded quizzes. The researchers were surprised by these results and upon further examination tentatively concluded a more complex interaction of gender differences influenced the overall effect on comprehension. Posttest outcomes found an improvement among the female students while there was a decrease in posttest results for the male students.
Metacognitive prompts provide a means of coaching students to think about cognitive processes involved in problem-solving, skills that are essential when transferred to other kinds of problems (Kapa, 1999b). Kapa’s (2001) study considered appropriate timing for intervention of metacognitive reinforcement during problem-solving. The study explored the effect of metacognitive support introduced at differing intervals of the problem-solving process in a computerized learning environment. Eighth-grade students were randomly assigned to groups for one of four different intervention implementation phases: (a) during the solution process and after the completion of the problem-solving process, (b) during the problem-solving process, (c) at the end of the solution process, and (d) no metacognitive supports. The treatment occurred over the course of a two-month period while complete data gathering transpired over the entire academic year. Pretest scores exhibited no significant differences between the groups; however, a significant difference existed between students with high or low prior knowledge. The three treatment groups of students with low previous knowledge were able to reduce the difference in problem-solving abilities between themselves and students with high previous knowledge in problem-solving.

A study by Condor (2001) analyzed the differences in metacognitive ability when comparing two groups using different computer environments and the relationship between problem-solving ability and metacognitive ability when solving statistical word problems. The study consisted of 120 community-college students enrolled in a beginning-level statistics course. Students were randomly assigned to one of four groups (two groups for each of the two course sections): metacognitively-cued, computer-tool (MCCT) and metacognitively-cued, computer-coached (MCCC). Performance was
measured on the outcomes of an instructor-developed objective examination and responses to written metacognitive cues.

Each of the two sections of the course was taught by separate instructors, one being the researcher, however, the same curriculum, guidelines and time schedules were adhered to by both teachers. The study lasted twelve weeks, the entire summer semester. Treatment began in week four and three unit exams were included in this phase for analysis. Students from both groups (MCCT & MCCC) were directed to complete written metacognitive cues sheets in class while attempting to solve the word problems.

The MCCT group had access to their textbook, class notes and the instructor whenever they required assistance. The computer was utilized strictly as a tool to manipulate the problem-solving activities. The MCCC group also had access to their textbooks, class notes, and instructor although in this case instructors merely guided the student to where they could find explanations on how to solve the problem. This group also had unlimited access to a computer program on CD-ROM which allowed further discovery to problem solutions through in-depth explanations and examples, acting as a computer coach. Both groups were also administered an instrument to report how successful they felt their performance was on the in-class examinations. Measurement of students’ test scores were compared to the self-report measure checking for discrepancies of students’ perceived ability to actual performance.

The study resulted in slight differences of problem-solving ability between the two groups and a small to medium correlation between metacognition and problem-solving. There was, however, a significant difference in academic performance between the two groups in their metacognitive awareness. By the fifth exam, the MCCC group
was outperforming the MCCT group. The author attributes this to a slow, but steady progression of the treatment effect. Several limitations to the study could impact the findings. First, a small sample size was used due to convenience sampling of the naturally occurring class sizes. Second, one of the instructors was also the researcher which may explain the differences in group scores. Additionally, homogeneity of the students may have negatively inhibited a stronger correlation between metacognitive ability and problem-solving abilities.

Instrumentation. In development of this study’s instrument, a literature search was initiated for inventories evaluating metacognitive awareness. Over the years, a number of instruments have been designed for domain-general measurement of metacognition. The following discussion reviews those tools as they relate to the current research on the metacognitive strategies of planning, monitoring, and evaluation.

Armour-Thomas and Haynes (1988) developed an instrument to evaluate a student’s metacognitive awareness in problem-solving called the Student Thinking About Problem-solving Scale (STAPSS). Their aim was to create a measurement “used to diagnose inefficiencies in metacognitive processing and help to improve problem-solving skills” (p. 92). At the time, inventories to judge lower level cognitive abilities such as learning and study strategies existed but none to gauge high order thinking processes.

In crafting the STAPSS instrument, items were generated based on problem-solving processes identified by Sternberg (1986). Three learning and cognition experts reviewed for content validity, narrowing the pool to thirty-seven statements. Once piloted and revised, the STAPSS was administered to 172 students representing three high schools. The participants were categorized into groups based on achievement: (a) below
average (> 65), (b) average (66-84), and (c) above average (85-100) established through report card grades for all subjects and SAT scores. The ability of this inventory to classify the participants according to achievement level indicated “modest predictive ability” (p. 92) with 58 percent accuracy.

Fortunato, Hecht, Tittle, and Alvarez in 1991 set about to re-focus students’ attention away from problem solutions to the strategic cognitive activities necessary to solve problems. They developed an instrument, called “How Do I Solve Problems (HISP)” to measure the way students worked a problem and the strategies a student might use. A sample of 165 seventh graders from twenty-three classes was asked to work an atypical coin problem and to fill out one of three questionnaires distributed randomly among the classes. The questionnaires consisted of twenty-one statements divided into four sections: (a) planning, (b) monitoring, (c) evaluation, and (d) ways in which the problem was worked out. A three-point scale indicated student responses of “yes, no, or maybe”. Interestingly, when students were asked to solve routine problems, they were less cognitively aware of the strategies they used. The researchers felt the results were useful for creating classroom activities based on the questionnaire responses. Forty percent of students indicated “yes” to the statement, “I tried to remember if I had worked a problem like this before”, however, another forty-two percent indicated “no” to the use of this strategy. The findings from this study were also supported in the research by Hong et al. (2001), indicating problems should be challenging for students in order for metacognitive activities to be useful.

Schraw and Dennison (1994) constructed the Metacognitive Awareness Inventory (MAI) to facilitate the measurement of metacognition without lengthy and cumbersome
interviews. Organized into eight subcomponents and grouped into two larger categories of knowledge and regulation of cognition, the tool is directed at adult learners. Undergraduates at a Midwestern university ($N = 197$) took part in experiment one of the study. Out of the original 120 items, a fifty-two item self-report inventory resulted in the two broad categories and six subcategories. Experiment two consisted of 110 participants, for the purpose of validating the instrument on three measures: (a) metacognitive knowledge, (b) test performance, and (c) metacognitive regulation.

The conclusions provided support for both constructs of the metacognitive model; knowledge and regulation. The results confirmed a high internal consistency, whereas the internal consistency on the factors measuring multiple subcomponents of metacognition was marginal. Statistical significance was achieved between the relationship of knowledge and regulation.

When the MAI was compared to performance, significant relationships existed between pre-test self-assessment and monitoring ability, as well as pre-test assessment and test performance. However, the results of monitoring accuracy and the MAI or monitoring accuracy and pre-test assessment did not withstand testing for significance.

Hong et al. (2001) followed the work of Fortunato et al. (1991) to develop an instrument which also measured the general domain of metacognition. The study was conducted in two phases, the first measured variables of current techniques through a self-report. The second phase collected data with two existing inventories of metacognition and problem-solving. Initial item were sorted using reliability analysis, and factor analysis on the remaining items. Their research resulted in five constructs of
metacognition related to problem-solving: 
(a) knowledge of cognition, (b) objectivity, (c) problem representation, (d) subtask monitoring, and (e) evaluation.

The goal of the researchers was to develop an instrument targeted at 12-18 year-olds within a classroom environment. A 32-item inventory was created to self-report metacognition. Participants (N = 829) from across the United States tested the revised inventory resulting in a reliable instrument. The inventory (Appendix C) created for this research is modeled upon “How Do You Solve Problems” questionnaire by Hong et al. (2001) however; it is modified for domain specificity and to meet the course objectives of the thermodynamics class in engineering. While the instrument has been customized to this course, the structure is general in nature following previous research on factors considered important to metacognitive awareness; planning, monitoring and evaluation. Further discussion of the instrument will follow in Chapter Three, the Methods section.

Chapter Summary

This chapter began with a discussion of how Information Processing Theory set the underlying context to define and understand cognition with further investigation of Social Cognitive Theory hypothesizing about control over one’s actions through intentional behaviors and strategies (Bandura, 2001). A comprehensive review of the literature supported the development of metacognitive awareness as a process for students to develop problem-solving strategies. Through the monitoring of their own progress towards previously outlined goals and completing the development of self-directed activities, the responsibility of learning is placed with the student. The chapter concluded with a retrospective look at several instruments to measure metacognitive
activity which, have been developed for the domain general constructs of planning, monitoring, and evaluation.
As suggested by Livingston (1997), faculty can help students understand problem-solving and cognitive goal setting by having them use metacognitive strategies to control their cognitive abilities. More research is needed in the area of metacognitive cuing embedded in web-based instruction on learning outcomes and student self-perception of problem-solving ability. This research study investigated the relationship between metacognitive strategies intervention in a web-based instructional model with student achievement and perception of problem-solving. Through metacognitive prompting provided within the lessons, students were asked to reflect upon the processes used in solving problems and to rate their problem-solving ability. The chapter provides an overview of the research procedures, including information about the participants, instructional methods, the instruments, and the research design.

Participants

The study took place at a Research I university in the southeastern United States. Approximately 40,000 enrolled students comprise a diverse population of ethnic backgrounds represented by 11.1 percent African American, 9.8 percent Hispanic, 5.3 percent Asian, and 0.4 percent American Indian. Students participating in this study were selected from an undergraduate engineering core course in thermodynamics which is prerequisite to subsequent courses in the engineering curriculum. All students enrolled in
the course are engineering majors from varying engineering disciplines including civil, chemical, computer science, electrical, industrial, and mechanical within the college.

Participants were selected using a non-probability strategy of convenience sampling. Convenience sampling as described by Tashakkori and Teddlie (1998) is a sampling selection technique undertaken due to accessibility of participants such as a class of students. The thermodynamics course typically has 140 students enrolled; thus, the minimum criteria for adequate sample size will likely be met (Cohen, 1988). Participants were selected at end of the first week of classes when the drop/add period was completed to minimize attrition.

**Ethical Considerations**

Use of this course and the students enrolled was approved by the Chair of the Chemical Engineering Department and the course instructor of record. The application to conduct research involving human participants was submitted to the Institutional Review Board (IRB) at this university and has been approved following submission of the research proposal. Although quantitative data was used for this study, only aggregated data was reported in order to maintain the confidentiality and privacy of the participants. All data was kept in the locked office of the researcher. Risks to individuals were minimized, and students were not exposed to any undue discomfort or deception during or following the investigation. Any provisions needed to comply with cultural or language barriers, physical or mental impairments or other unforeseen factors were handled on an individual basis.

**Instructional Procedures**

*Both Groups.* The thermodynamics course met twice each week for a total of
three hours classroom lecture. The course format combined in-class lectures and out-of-class homework problems. Mixing web-based instruction and classroom techniques can take advantage of the complementary strengths of each (Horton, 2000).

The interactive web-based tutorial of homework problem sets was developed to provide individualized, immediate feedback through built-in assessments. Features of the tool include: (a) easily accessible interface through the web by students, (b) time-limited exercises not to exceed one hour in length, (c) immediate feedback to facilitate knowledge of results and motivation, (d) online help function to guide the student towards a correct response, (e) links to additional course material for supplemental information, (f) creation of unique problems sets to provide individualized participation, and (g) integration with other tools such as Matlab® to assist in solving complex engineering problems (Buck, 2004). Students from both the experimental and control groups who required more guidance on a particular problem or section of a problem accessed additional information through the aid of the “help” button which displayed a pop-up window.

Control group. The control group followed the usual course instructional format of encountering the problems within the website, solving them, and submitting them for grading without any direct instruction on metacognitive strategies, cuing, or evaluation/reflection on the utility of metacognitive strategies for problem-solving in engineering. Figure 4 is an example of an instructional screen a student in the control group encountered during one of the web-based problems sets.
Experimental Group Instruction and Materials. The metacognitive instruction for the treatment group had three elements: direct instruction, cuing, and reflection. Students in the experimental group began by reviewing a problem-solving model called “Engineering Problem-solving” (Appendix A) developed by Joseph (2004) to guide a student through the solution process for engineering problems. Eight separate stages: (1) abstract abstraction, (2) list variables, (3) identify basis for calculation, (4) list assumptions, (5) list references, (6) develop model equations, (7) solve, and (8) interpret solution were defined to illustrate the manner in which problems are solved (see Figure 5).
Next, metacognitive cuing was integrated within each instructional screen designed for the web-based problems as reminders of how to solve engineering problems. At the end of the problem set, students were required to reflect upon the usefulness of metacognitive strategies for solving the completed problems by indicating which of the eight stages were used during the problem-solving process. In order to accomplish this, a parallel website was constructed for the experimental group containing the same problem sets; however, the second website introduced and highlighted metacognitive prompting within the instructional lessons. In this second web-site, metacognitive cues of the engineering problem-solving procedures were inserted within each instructional frame as

Figure 5. Screen Shot of the Engineering Problem-Solving Model

a prompting reminder to students while they practiced solving thermodynamics problems (see Figure 6).

Figure 6. Screen Shot of Instructional Frame for Problem Sets with Embedded Cuing


An online help function for the experimental group assisted in the scaffolding of students’ learning through the use of metacognitive strategies embedded within the instructional framework. The term scaffolding is used to describe the models, cues, prompts, hints or partial solutions that provide links guiding students from what they can do by themselves toward what they can do with assistance from others (Hartman, 2001). Scaffolding is a particularly effective teaching method for improving higher level cognitive strategies (Rosenshine & Meister, 1994). Prompts within the “help” screen are
included in the early problem sets (1 & 2) and withdrawn from the later sets (instructional fading) as students became familiar with the eight step model of problem-solving (see Figure 7).

Figure 7. Screen Shot of Metacognitive Cuing Within the “Help” Feature


At the end of a problem set, students in the metacognitive cuing group reflected on which of the eight steps they used during the problem-solving process, checked the ones they used from a list provided, and submitted their responses electronically. An instructional screen containing the metacognitive reflection response section was presented to the student at the conclusion of the problem set (Figure 8). Both the cues, for evaluation, and the problem solutions, for recording of grades, were collected.
Instruments

Pretest. Multiple achievement instruments were used to explore the effect of metacognitive instruction on students’ achievement including a matched pretest and posttest as well as a comprehensive posttest for examining group differences in depth. In order to gather a baseline of students’ prior knowledge, a test (not a true pre-test) of thermodynamics concepts and skills was given at the beginning of the semester before the intervention implementation followed by a posttest at the end of the semester. Scores from this test were used to create matched samples in pre-requisite knowledge and skills in thermodynamics.
The pretest consisted of seventeen questions developed students’ knowledge and skills in: (1) the general understanding of the concepts of energy, how to measure it and the different forms of expression of energy in nature, (2) the concept of conservation of energy which says that energy cannot be created or destroyed, but can be converted from one form to the other, and (3) the approach to analyzing engineering problems and application of basic knowledge to answer simple engineering questions.

Test items of the pretest consisted of objective multiple-choice and short answer formats (Appendix D). Possible responses were valued at one point each for a potential total score of 27. To inaugurate grading consistency, all exams were scored by the same teaching assistant. The exam, given by pencil and paper, had been used and refined over multiple semesters. The content validity of this instrument was established through a survey of two professors with expert knowledge in chemical engineering. Content validity, as defined by Wiersma (2000, p. 300), is “the process of establishing the representativeness of the items with respect to the domain of skills, tasks, knowledge, and … whatever is being measured”.

Posttest. A more comprehensive posttest of students’ knowledge and skills in thermodynamics was used to compare the groups for statistical differences in their problem-solving skills. The major instructional units covered include; the control volume analysis using energy, the second law of thermodynamics, and the use of entropy.

For this measure, a composite posttest score was created by combining students’ scores on exams three, four, and five administered in the latter two-thirds of the class. Aggregated scores were used, rather than the thermodynamics concepts pre-test and the twin posttest. The composite posttest instrument measured specific course outcomes,
avoided administration bias of a test-retest procedure, and controlled for history effects where participants’ responses may be influenced through new experiences and learning opportunities (Davis & Smith, 2005). Content validity, as explained by Gay and Airasian (2003), is the degree to which a test measures the representative content of a specific subject area when determined by experts in the field. The content validity of the achievement tests was reviewed by two tenured professors from the Chemical Engineering Department who teach the thermodynamics course. They judged the items contained in the tests were congruent with the thirteen course outcomes of exit knowledge and skills required for students completing the course. Both the treatment and control groups were given the same exams.

Wiersema (2000) suggests using several methods to establish consistency among the graders. Three procedures were used in this study to control for grader consistency: 1) use of a grading rubric (see Appendix E) created to restrict “drift” during the exam assessments; 2) training of the teaching assistants (TA) on the proper use of the grading rubric; and 3) random assignment of exams from both the control and experimental group to each TA. To standardize evaluation procedures, intrarater and interrater reliability measures were used. Each grader formed clusters of his or her exams consisting of strong, mid-range, and weak exams, and then three exams were randomly chosen from each TA’s clusters for a total of nine examinations. One week later, each TA re-graded the nine randomly selected exams to verify intrarater reliability. Interrater reliability will be checked by having each TA re-grade the other’s tests. Because the tests consist of
interval rating scales, reliability was assessed using Pearson’s product-moment correlation coefficient.

*Attitudes.* The second hypothesis related to whether significant differences existed between the groups in their perceptions of their problem-solving abilities in thermodynamics. A separate self-report instrument, *How Do You Solve Problems? (HDYSP)* (Zabel, 2004), was administered at the beginning and end of the course (Appendix B). The HDYSP was developed by modifying a metacognitive inventory, titled Inventory of Metacognitive Self-Regulation (IMSR) authored by Hong et al. (2001). The original instrument collected responses applied to general problem-solving focusing on five independent factors (a) knowledge of cognition, (b) objectivity, (c) problem representation, (d) subtask monitoring, and (e) evaluation.

The revised instrument, based on expert review, reflected specific problem solving processes used in engineering. Three self-regulatory constructs (planning, monitoring, and evaluating) were identified as important as metacognitive strategies related to problem-solving. Each section, defined separately for administrative clarity, contained statements to rate self-report responses for a total of 32 items. The HDYSP was divided into three distinct dimensions of metacognition: (1) planning, (2) monitoring, and (3) evaluating. Part 1 - *Planning* contained nine items pertaining to the selection of appropriate strategies and allocation of resources that affect performance. Part 2 – There were eighteen items related to defining one’s awareness of comprehension and task performance in the *Monitoring* section. Part 3 – The *Evaluating* section was made up of five items concerning the appraisal of products and efficiency of one’s learning.
The responses were formatted using a frequency base and a Likert-type scale ranging from 1 = rarely to 4 = almost always. The possible scores ranged from 32 to 128.

The construct validity of the instrument was reviewed using two content experts in problem-solving strategies within the Chemical Engineering Department and two professors in the College of Education knowledgeable in survey construction and instructional technology. Coefficient of reliability was calculated using Cronbach’s alpha because it “provides a convenient way to estimate the lower bound of the coefficient of precision for a test by using item-response data obtained from a single administration of that test” (Crocker & Algina, 1986, p. 122).

Research Design

The analysis of data for this study involved a mixed methodology framework congruent with the Tashakkori and Teddlie’s (1998) definition for mixed methods studies which “are those that combine the qualitative and quantitative approaches into the research methodology of a single study or multiphase study (p.17).” According to Onwuegbuzie and Teddlie (2003), the reason for this type of data analyses is two-fold; representation and legitimation. The former is to cull sufficient information from the data while the latter is conducted with a concern for validity. The design approach, as defined by the principles of mixed methods, combined both quantitative and qualitative research strategies in a simultaneous approach (Quan + qual). Morse (2003) explains the use of more than one technique presents a “more complete picture of human behavior and experience” (p. 189). In order to obtain a power level of .8 at the .05 level of significance for the analysis, thirty-one participants were needed for both the control and the treatment
groups. Based upon enrollment records from previous classes, 140 students were expected to participate in this study.

*Establishing Comparable Groups.* At the beginning of the semester, students completed an achievement pretest of thermodynamics concepts and skills and an attitude questionnaire to measure their perceptions of their problem-solving ability. Students were ranked according to their pretest achievement scores and then assigned in order to one of two treatments (e.g. highest score = treatment 1; next highest = treatment 2; next down = treatment 2; next down = treatment 1, and so forth down the spiral pattern).

After group assignment, a t test was run on pretest scores to verify the initial comparability on achievement for the two groups. Table 4, below, is an example of ranking assignment based upon group matching according to their prior achievement.

Table 4

<table>
<thead>
<tr>
<th>Pretest Exam Score</th>
<th>Group Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>Group 1</td>
</tr>
<tr>
<td>99</td>
<td>Group 2</td>
</tr>
<tr>
<td>98</td>
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<td>Group 1</td>
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<tr>
<td>91</td>
<td>Group 2</td>
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<tr>
<td>90</td>
<td>Group 2</td>
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<td>89</td>
<td>Group 1</td>
</tr>
<tr>
<td>88</td>
<td>Group 1</td>
</tr>
<tr>
<td>87</td>
<td>Group 2</td>
</tr>
</tbody>
</table>

Continued …
Post Treatment Data Analysis. Materials and procedures in this section are organized using the hypotheses for the study. Two research hypotheses and four qualitative questions were analyzed in this study:

1. Was there a difference of posttest achievement between students who received direct instruction using metacognitive strategies and embedded cues in their thermodynamics problem sets and students who did not receive instruction in metacognitive strategies information and cuing?

2. Was there a difference in perceptions of their thermodynamics problem-solving abilities between students who received direct instruction in using metacognitive strategies and embedded cues in their problem sets and students who did not receive instruction on metacognitive strategies information and cuing?

3. What were the differences in thermodynamics knowledge between students who received direct instruction using metacognitive strategies and embedded cues in their thermodynamics problem sets and student who did not received instruction in metacognitive strategies information and cuing?

4. Which ones of the problem-solving steps did students report using across the problem sets?

5. What were the characteristics of the students in the sample?

6. What were the participants’ perceptions of the web-based problem sets?

All data collection was conducted by this researcher. Table 5 represents the schedule of instrument administration for pre-treatment, treatment and post-treatment phases of the experiment.
Table 5

*Data Collection Before, During and After Treatment Phases*

<table>
<thead>
<tr>
<th>Week</th>
<th>Pre-Treatment Phase</th>
<th>Treatment Phase</th>
<th>Post-Treatment Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Informed Consent</td>
<td>Performance Analysis</td>
<td>Composite Performance Analysis-Exams 3, 4, 5</td>
</tr>
<tr>
<td></td>
<td>Biographical Questionnaire</td>
<td>-Exam 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pretest: Thermodynamics concepts/skills</td>
<td>-Exam 4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pre-survey: HDYSP</td>
<td>-Exam 5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spiral Group Assignment</td>
<td></td>
<td>Posttest: Thermo Concepts</td>
</tr>
<tr>
<td>7</td>
<td>Performance Analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Performance Analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Performance Analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Composite Performance Analysis-Exams 3, 4, 5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Both groups will receive the same problem sets, however only the treatment group will receive direct instruction in using metacognitive strategies and cuing to solve problems. A t-test design was chosen to compare the composite posttest scores and the posttest of student attitudes towards problem-solving between the control and treatment groups. In order to analyze any observed differences in problem-solving skills, a .05
level was used to establish statistical significance. Correlation analyses by group and all were performed to report, (a) perception of problem-solving and achievement grade, and (b) pre- and post- attitudes.

**Qualitative Questions**

*Matching Posttest for Pretest.* What are the differences in skills among students as measured by this test? The pretest of achievement, described previously, will be administered again as a posttest at the end of the semester in order to graph students’ growth in the particular skills included on that test. This posttest was used in comparing groups statistically since it lacks adequate comprehensiveness, i.e., few items, and is potentially compromised by the same items being experienced by students on the prior administration. Descriptive statistics depict reported results of each group’s achievement scores which are graphed and subsequently discussed.

*Reflections on Procedures Used.* Which ones of the problem-solving steps do students report using across the problem sets? At the end of each problem set within the instruction, students were asked to reflect on the steps they used in the problem-solving process and report their process when submitting their score of the exercises. An item analysis of this data using descriptive statistics was reported through graphical representation.

*Biographical Questionnaire.* What are the characteristics of the students in the sample? Demographic information was collected through a participant survey (Appendix C) given in the beginning of the semester. Students were asked to indicate age, race, major, status as a student (part-time vs. full-time), year of study, current GPA, and
residency declaration. Responses were used to portray an accurate description of the student sample.

*Attitude Survey.* What are the participants’ perceptions of the web-based problem sets? A survey, developed by the academic department, was administered on paper to participants for their subjective impressions when using the web-based problem-solving tutorials during the last week of classes. The survey consisted of thirty-four statements (see Appendix G) regarding the web-based problem-solving tutorial. Five of the statements specifically related to familiarity and use of problem-solving strategies. Descriptive statistics were used to report means for each of the five statements.

*Chapter Summary*

The chapter presented the approach to this study. Methodology of the research discussed herein included the nature in which the study was conducted (mixed-method design), the data collected via various instruments (pre- and posttest of thermodynamics concepts and skills, HDYSP, composite performance analysis) and interpretation of data through t-tests, correlations, and descriptive statistics. The research questions have been addressed within the context of the experimental procedures for the study.
Chapter Four Results

Introduction

Several research questions were posed that were associated with dimensions of achievement and attitude, metacognitive reflection, characteristics of the participant sample, and their relationship to performance as measured by learning assessments. This chapter is organized to present the analyses of data and findings relative to each research question.

Participants. The potential sample consisted of 113 students enrolled in thermodynamics, a core course in the engineering undergraduate curriculum. However, 32 participants were eliminated based upon their decision not to take part in the research. This left an effective sample size of 81 total, with assignments to the experimental group \((n = 39)\) and the comparison group \((n = 42)\). Overall, the population was 65 percent male, 51 percent white (non-Hispanic), and 64 percent indicated that English was their native language. The age of the participants ranged from 19 to 50, with a mean of 29 years. For more details related to the demographics of the control and treatment groups, see Question 5 on page 76.

As stated in Chapter One, typically 25 percent student drop-out rates are reported in thermodynamics courses in any given semester at this college. By comparison, the enrollments for this class declined by 39 percent throughout the semester.
Establishing Comparable Groups

Achievement Pretest. A pretest was used to determine whether differences existed in thermodynamics background knowledge between the control and experimental groups at the outset of the study. An achievement pretest of thermodynamics concepts and skills measured students’ ability. When a t test was performed on pretest scores to confirm initial comparability on achievement between the two groups (see Table 6), no significant differences were observed ($p = .28$), using a .05 alpha level.

Table 6

Thermodynamics Knowledge Pretest Results

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Treatment</th>
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<tbody>
<tr>
<td>Mean</td>
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<tr>
<td>Standard Deviation</td>
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<tr>
<td>Sample Variance</td>
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<tr>
<td>Kurtosis</td>
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<tr>
<td>Skewness</td>
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<tr>
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<tr>
<td>Hypothesized Mean</td>
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</tr>
<tr>
<td>Difference</td>
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<tr>
<td>Df</td>
<td>79</td>
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</tr>
<tr>
<td>t Stat</td>
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<tr>
<td>P(T&lt;=t) two-tail</td>
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</tr>
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<td>t Critical two-tail</td>
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</table>
Attitude Pretest. Attitudes were assessed using a survey instrument titled “How Do You Solve Problems” (HDYSP), which was administered to both groups as a pretest. Obtained reliability coefficients for each section, planning ($\alpha = .53$), monitoring ($\alpha = .83$) and evaluating ($\alpha = .72$) were computed using Cronbach alphas. Each dimension of the HDYSP varied in the number of survey items, therefore a Spearman-Brown Prophecy coefficient analysis was run for equalization comparison. This test predicts how the reliability coefficients would compare if the number of items in each dimension were equivalent. Predicted $r$ values, when equated to items size of the monitoring section, resulted in modified coefficients for planning ($r = .69$) and evaluating ($r = .90$). Testing for group equivalence of attitude revealed a significant difference between means of the two groups ($t (79) = -2.19, p = .03$), with a higher mean for the treatment group ($M = 78.98, SD = 28.02$) than the control group ($M = 63.55, SD = 34.67$).
Table 7

**Attitude Pretest Results**

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
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<tr>
<td>Standard Deviation</td>
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<td>Sample Variance</td>
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<td>Observations</td>
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<td>t Stat</td>
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<td>P(T&lt;=t) two-tail</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>t Critical two-tail</td>
<td>1.99</td>
<td></td>
</tr>
</tbody>
</table>

**Post Treatment Data Analysis**

Further analyses are discussed by addressing each question separately. An alpha level of .05 was used for all statistical analyses.

**Question 1.** Was there a difference in achievement between students who received direct instruction using metacognitive strategies and embedded cues in their thermodynamics problem sets and students who did not receive instruction in metacognitive strategies information and cuing?
A composite of the scores for exams 3, 4, and 5 were used to measure student achievement. These exams were chosen because they were given mid-way through the semester, allowing the treatment time to take effect. These exams were graded by two graduate assistants assigned to the course. Therefore, prior to the analysis of group differences for the achievement scores, both interrater and intrarater reliability were examined. Students’ test papers were randomly assigned to each grader, forming two groups. Graders were unaware of (blind to) whether the students’ papers were from the experimental or control group. After each of the three exam administrations, the graders selected from their exams one strong, one mid-range, and one weak exam for a total of nine exams per grader. The selected exams were then given to the other grader for scoring. One week later the graders re-graded their own exams. Pearson correlation analyses of the original scores and re-graded scores indicated strong positive relationships for intrarater ($r = 1.00$) and interrater ($r = .99$) reliability as shown in the following table.
Table 8

*Intrarater-Interrater Reliability Correlation Matrix*

<table>
<thead>
<tr>
<th>Exam 3</th>
<th>Original Grader A</th>
<th>Re-grade Grader A</th>
<th>Re-grade Grader B</th>
<th>Original Grader B</th>
<th>Re-grade Grader B</th>
<th>Re-grade Grader A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strong</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Mid-range</td>
<td>67</td>
<td>66</td>
<td>66</td>
<td>75</td>
<td>75</td>
<td>73</td>
</tr>
<tr>
<td>Weak</td>
<td>39</td>
<td>39</td>
<td>42</td>
<td>39</td>
<td>39</td>
<td>39</td>
</tr>
<tr>
<td>Exam 4</td>
<td>Strong</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Mid-range</td>
<td>63</td>
<td>62</td>
<td>62</td>
<td>81</td>
<td>81</td>
<td>81</td>
</tr>
<tr>
<td>Weak</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>64</td>
<td>64</td>
<td>66</td>
</tr>
<tr>
<td>Exam 5</td>
<td>Strong</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Mid-range</td>
<td>82</td>
<td>82</td>
<td>84</td>
<td>70</td>
<td>70</td>
<td>67</td>
</tr>
<tr>
<td>Weak</td>
<td>67</td>
<td>67</td>
<td>67</td>
<td>32</td>
<td>32</td>
<td>34</td>
</tr>
<tr>
<td>Correlation</td>
<td>1</td>
<td>0.99</td>
<td></td>
<td>1</td>
<td>0.99</td>
<td></td>
</tr>
</tbody>
</table>

The achievement score used in the analysis consisted of a composite score from the three comprehensive exams. When the data was analyzed using a *t* test, no significant differences (see Table 9) existed between the control and treatment groups, suggesting
that one group cannot report doing better than the other when metacognitive cuing is embedded within the problem sets ($p = .96$).

Table 9

<table>
<thead>
<tr>
<th>Achievements Composite Score</th>
<th>Control</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>191.10</td>
<td>190.47</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>57.91</td>
<td>61.68</td>
</tr>
<tr>
<td>Variance</td>
<td>3353.08</td>
<td>3804.12</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>0.18</td>
<td>0.20</td>
</tr>
<tr>
<td>Skewness</td>
<td>0.05</td>
<td>-0.55</td>
</tr>
<tr>
<td>Range</td>
<td>264</td>
<td>266</td>
</tr>
<tr>
<td>Observations</td>
<td>42</td>
<td>39</td>
</tr>
<tr>
<td>Hypothesized Mean Difference</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>df</td>
<td>79</td>
<td></td>
</tr>
<tr>
<td>t Stat</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) two-tail</td>
<td>0.96</td>
<td></td>
</tr>
<tr>
<td>t Critical two-tail</td>
<td>1.99</td>
<td></td>
</tr>
</tbody>
</table>

**Question 2.** Was there a difference in perceptions of their thermodynamics problem-solving abilities between students who received direct instruction in using metacognitive strategies and embedded cues in their problem sets and students who did not receive instruction on metacognitive strategies information and cuing? A pretest, discussed earlier, was used to determine initial differences in the groups when measuring attitudes towards problem-solving. There was a significant difference between means for
the control group ($M = 63.55$) and for the treatment group ($M = 78.97$) when a $t$ test was performed on the data (refer to Table 7). Pretest to posttest responses were analyzed separately for each group. Results from the control group indicated no significant difference in attitudes ($t (82) = -1.65, p = .10$), when measured using a two-tail $t$ test. Similarly, a comparison of the treatment group’s posttest results on attitude towards problem-solving abilities also indicated (Table 10) no significant difference from the pretest data ($t (76) = .60, p = .55$).

Table 10

<table>
<thead>
<tr>
<th>Attitude Pretest and Posttest Results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Control</strong></td>
</tr>
<tr>
<td>Pretest</td>
</tr>
<tr>
<td>Posttest</td>
</tr>
<tr>
<td><strong>Treatment</strong></td>
</tr>
<tr>
<td>Pretest</td>
</tr>
<tr>
<td>Posttest</td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>Standard Deviation</td>
</tr>
<tr>
<td>Sample Variance</td>
</tr>
<tr>
<td>Kurtosis</td>
</tr>
<tr>
<td>Skewness</td>
</tr>
<tr>
<td>Range</td>
</tr>
<tr>
<td>Observations</td>
</tr>
<tr>
<td>Hypothesized Mean Difference</td>
</tr>
<tr>
<td>df</td>
</tr>
<tr>
<td>$t$ Stat</td>
</tr>
<tr>
<td>$P(T&lt;=t)$ two-tail</td>
</tr>
<tr>
<td>$t$ Critical two-tail</td>
</tr>
</tbody>
</table>
Because of the significant differences in the pretest attitudes, an ANCOVA was conducted to examine the posttest data. After removing the effect of the pretest covariate, no significant differences were shown between the two groups ($p = .75$). Means and standard deviations for the control and treatment groups were ($M = 75.93, SD = 33.93$ and $M = 74.51, SD = 36.82$), respectively (refer to Table 11).

Table 11

<table>
<thead>
<tr>
<th>Effect</th>
<th>SS</th>
<th>Df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>72505.40</td>
<td>1</td>
<td>72505.40</td>
<td>58.06</td>
<td>0.00</td>
</tr>
<tr>
<td>Pretest</td>
<td>131.61</td>
<td>1</td>
<td>131.61</td>
<td>0.11</td>
<td>0.75</td>
</tr>
<tr>
<td>Error</td>
<td>98649.45</td>
<td>79</td>
<td>1248.73</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Question 3.** Were there differences in thermodynamics knowledge between students who received direct instruction using metacognitive strategies and embedded cues in their thermodynamics problem sets and students who did not receive instruction in metacognitive strategies information and cuing? The pretest and subsequent posttest of thermodynamics skills and concepts were used to descriptively compare the groups. As was assumed, both groups significantly increased pretest to posttest. The evidence, (see Table 12), demonstrates a significant difference within groups comparison of the pre- and posttest administrations using a paired $t$ test for the control group ($t (75) = -4.18, p < .001$) and the treatment group ($t (71) = -3.64, p < .001$).
### Table 12

*Thermodynamics Knowledge Pretest and Posttest Results*

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th></th>
<th>Treatment</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pretest</td>
<td>Posttest</td>
<td>Pretest</td>
<td>Posttest</td>
</tr>
<tr>
<td>Mean</td>
<td>11.71</td>
<td>15.51</td>
<td>12.59</td>
<td>15.65</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>3.80</td>
<td>4.16</td>
<td>3.49</td>
<td>3.68</td>
</tr>
<tr>
<td>Sample Variance</td>
<td>14.45</td>
<td>17.32</td>
<td>12.20</td>
<td>13.51</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>0.19</td>
<td>0.35</td>
<td>-0.54</td>
<td>-1.02</td>
</tr>
<tr>
<td>Skewness</td>
<td>-0.34</td>
<td>-0.81</td>
<td>0.16</td>
<td>0.21</td>
</tr>
<tr>
<td>Range</td>
<td>18</td>
<td>18</td>
<td>14</td>
<td>13</td>
</tr>
<tr>
<td>Observations</td>
<td>42</td>
<td>35</td>
<td>39</td>
<td>34</td>
</tr>
<tr>
<td>Hypothesized Mean Difference</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>df</td>
<td>75</td>
<td>71</td>
<td></td>
<td></td>
</tr>
<tr>
<td>t Stat</td>
<td>-4.18</td>
<td>-3.64</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) two-tail</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>t Critical two-tail</td>
<td>1.99</td>
<td>1.99</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

An ANCOVA was conducted to examine the posttest data after removing for the effect of pretest performance. The results, reported in Table 13, demonstrates no significant difference between the control and treatment groups ($p = .70$).
Table 13

<table>
<thead>
<tr>
<th>Effect</th>
<th>SS</th>
<th>Df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>433.97</td>
<td>1</td>
<td>433.97</td>
<td>35.53</td>
<td>0.00</td>
</tr>
<tr>
<td>Pretest</td>
<td>228.46</td>
<td>1</td>
<td>228.46</td>
<td>18.71</td>
<td>0.00</td>
</tr>
<tr>
<td>Group</td>
<td>1.93</td>
<td>1</td>
<td>1.93</td>
<td>0.16</td>
<td>0.70</td>
</tr>
<tr>
<td>Error</td>
<td>806.05</td>
<td>66</td>
<td>12.21</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Question 4.* Which of the problem-solving steps did students report using across the problem sets? At the conclusion of the six problem sets, participants in the experimental group were asked to reflect upon which, if any, of the eight steps to engineering problem-solving they used during the solution phase of the problem exercises. The frequency distribution for the metacognitive reflection responses are shown in Table 14. For any one of the eight categories, there were a total of 234 possible responses. The two most frequently reported responses were *Step Two - List Variables* (91%) and *Step Seven - Solved Equations* (91%). The least chosen response was *Step Four – Made/stated Assumptions*, which was selected only three percent of the time. Another item, selected less than 50 percent of the time, was *Step Five – Listed References* (30%).
Table 14

*Frequency Distribution for Metacognitive Reflection Responses*

<table>
<thead>
<tr>
<th>Categories</th>
<th>Response Frequencies</th>
<th>Possible # of Responses</th>
<th>Frequency Percentages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Abstract Problem</td>
<td>165</td>
<td>234</td>
<td>70 %</td>
</tr>
<tr>
<td>2. List Variables</td>
<td>214</td>
<td>234</td>
<td>91 %</td>
</tr>
<tr>
<td>3. State Basis of Calculations</td>
<td>144</td>
<td>234</td>
<td>62 %</td>
</tr>
<tr>
<td>4. Made/stated Assumptions</td>
<td>6</td>
<td>234</td>
<td>3 %</td>
</tr>
<tr>
<td>5. Listed References</td>
<td>72</td>
<td>234</td>
<td>30 %</td>
</tr>
<tr>
<td>6. Developed Model Equations</td>
<td>167</td>
<td>234</td>
<td>71 %</td>
</tr>
<tr>
<td>7. Solved Equations</td>
<td>214</td>
<td>234</td>
<td>91 %</td>
</tr>
<tr>
<td>8. Interpret Solutions</td>
<td>143</td>
<td>234</td>
<td>61 %</td>
</tr>
<tr>
<td>Total</td>
<td>1125</td>
<td>1872</td>
<td></td>
</tr>
</tbody>
</table>

*Question 5.* What are the characteristics of the students in the sample? Gibbons (2004) provides descriptive information on the engineering student population in the United States. Responses targeted at obtaining the same information as Gibbons, reveals a near identical pattern, where composition was mostly white (non-Hispanic), male, and in their twenties. More than 90 percent of the participants listed Florida as their primary residence, closely split between the control (45%) and the treatment (47%) groups. Slightly more recorded Junior as their Year of Study in the control group (33%) than in the treatment group (27%) and entered the university as Freshman with 27 percent and 31 percent, respectively. All academic departments in this college were represented with the exception of the Computer Science and Engineering department. Mechanical Engineering was listed more often than the other declared majors as indicated by 25
percent of the control group and 19 percent of the treatment group. Following behind were the Civil and Environmental (control = 8%, treatment = 14%) and the Chemical Engineering departments (control = 13%, treatment = 8%). The Electrical, Industrial, and General Engineering responses were less than 10 percent for both the control and treatments groups as seen in Table 15. Of the participants who completed the survey, 23 percent control and 30 percent treatment answered they were taking 13 to 18 Credit Hours this semester while 22 percent of the control group and 19 percent of the treatment group were taking 9 to 12 Credit Hours this semester. At the far ends of the response scale, 2 percent of only the treatment group responded to taking 0 to 3 Credit Hours or More Than 18 Credit Hours this semester. More of the treatment group answered to working Part-time (22%) or Not Working (20%) outside of class than the control group who answered working Part-time (20%) or Not Working (17%) outside of class. However, the control group reported a larger percentage working Full-time (11%) than treatment group (9%). The highest self-reported GPA in the 3.5 to 4.0 range was 20 percent by the treatment group and 14 percent by the control group. Both groups indicated that three percent of them were in the lowest GPA range of 2.0 to 2.4. When asked How Many Times Have You Take a Thermodynamics Course?, the control group answered First Time (44%), Second Time (3%) and Other (2%) while the treatment group answered First Time (42%), Second Time (6%) and Other as (3%). The following data were self-reported responses by participants to the biographical questionnaire.
Table 15

*Group Comparison by Biographical Dimension*

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Control</th>
<th></th>
<th>Treatment</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Frequency</td>
<td>Total</td>
<td>Frequency</td>
</tr>
<tr>
<td></td>
<td></td>
<td>%</td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>Gender</td>
<td>64</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>25</td>
<td>39%</td>
<td>28</td>
<td>44%</td>
</tr>
<tr>
<td>Female</td>
<td>6</td>
<td>9%</td>
<td>5</td>
<td>8%</td>
</tr>
<tr>
<td>Ethnicity</td>
<td>64</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>African American</td>
<td>2</td>
<td>3%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Asian/Pacific Islander</td>
<td>2</td>
<td>3%</td>
<td>6</td>
<td>9%</td>
</tr>
<tr>
<td>American Indian</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Hispanic</td>
<td>2</td>
<td>3%</td>
<td>4</td>
<td>6%</td>
</tr>
<tr>
<td>White/Non-Hispanic</td>
<td>22</td>
<td>34%</td>
<td>19</td>
<td>30%</td>
</tr>
<tr>
<td>Other</td>
<td>3</td>
<td>5%</td>
<td>4</td>
<td>6%</td>
</tr>
<tr>
<td>Native Language</td>
<td>64</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>English</td>
<td>26</td>
<td>41%</td>
<td>26</td>
<td>41%</td>
</tr>
<tr>
<td>Spanish</td>
<td>1</td>
<td>2%</td>
<td>2</td>
<td>3%</td>
</tr>
<tr>
<td>Other</td>
<td>4</td>
<td>6%</td>
<td>5</td>
<td>8%</td>
</tr>
<tr>
<td>Residency</td>
<td>64</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Florida</td>
<td>29</td>
<td>45%</td>
<td>30</td>
<td>47%</td>
</tr>
<tr>
<td>Out of State</td>
<td>1</td>
<td>2%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Out of Country</td>
<td>1</td>
<td>2%</td>
<td>3</td>
<td>5%</td>
</tr>
<tr>
<td>Year of Study</td>
<td>64</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------</td>
<td>----</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freshman</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sophomore</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Junior</td>
<td>21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Senior</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>When Did You Enter the University?</th>
<th>64</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freshman</td>
<td>17</td>
</tr>
<tr>
<td>Transfer From a Community College</td>
<td>5</td>
</tr>
</tbody>
</table>

| Community College | 64 |
| Transfer From Another University | 64 |

<table>
<thead>
<tr>
<th>Declared Major</th>
<th>64</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Engineering</td>
<td>8</td>
</tr>
<tr>
<td>Civil/Environmental Engineering</td>
<td>5</td>
</tr>
<tr>
<td>Engineering</td>
<td>0</td>
</tr>
<tr>
<td>Computer Science &amp; Engineering</td>
<td>0</td>
</tr>
<tr>
<td>Electrical Engineering</td>
<td>2</td>
</tr>
<tr>
<td>Industrial &amp; Management Engineering</td>
<td>0</td>
</tr>
<tr>
<td>Management Engineering</td>
<td>0</td>
</tr>
</tbody>
</table>
Engineering

Undecided

<table>
<thead>
<tr>
<th># of Credit Hours Taken</th>
<th>64</th>
</tr>
</thead>
<tbody>
<tr>
<td>This Semester</td>
<td></td>
</tr>
<tr>
<td>0 – 3</td>
<td>2</td>
</tr>
<tr>
<td>4 – 8</td>
<td>14</td>
</tr>
<tr>
<td>9 – 12</td>
<td>15</td>
</tr>
<tr>
<td>13 – 18</td>
<td>0</td>
</tr>
</tbody>
</table>

| More than 18            |    |

<table>
<thead>
<tr>
<th># of Hours Working</th>
<th>64</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside of Class</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>11</td>
<td>11</td>
</tr>
</tbody>
</table>

| I do not work at this    |    |
|                          |    |

<table>
<thead>
<tr>
<th>Current GPA</th>
<th>64</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0 – 2.4</td>
<td>2</td>
</tr>
<tr>
<td>2.5 – 2.9</td>
<td>9</td>
</tr>
<tr>
<td>3.0 – 3.4</td>
<td>11</td>
</tr>
<tr>
<td>3.5 - 4.0</td>
<td>9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Times Taken a</th>
<th>64</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermodynamics Class?</td>
<td></td>
</tr>
</tbody>
</table>
### Questionnaire Results

<table>
<thead>
<tr>
<th></th>
<th>28</th>
<th>44%</th>
<th>27</th>
<th>42%</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Time</td>
<td>28</td>
<td>44%</td>
<td>27</td>
<td>42%</td>
</tr>
<tr>
<td>Second Time</td>
<td>2</td>
<td>3%</td>
<td>4</td>
<td>6%</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
<td>2%</td>
<td>2</td>
<td>3%</td>
</tr>
</tbody>
</table>

**Note.** Number of blank responses to questionnaire: Control = 12, Treatment = 5.

**Question 6.** What were the participants’ perceptions of the web-based problem sets? Data were collected at the end of the study to analyze participants’ attitudes of the web-based problem sets. There were 61 participants who completed the survey, a 74 percent response rate. Five-point Likert-type rating scales were used with answers including: 1 (strongly disagree) to 3 (neutral) to 5 (strongly agree). Five of the statements from the survey, numbers 29 through 33, focused on perceptions of web-based problem-solving strategies, therefore only the statements directly related to this study will be discussed.

**Statement 29.** I am familiar with the general problem-solving strategies. Both control and treatment means \((M = 4.07)\) were the same, indicating the groups equally agreed to their level of general familiarity with problem-solving strategies.

**Statement 30.** *I used general problem-solving strategies when doing these problems.* The mean for the control group’s responses were \(M = 3.9\) while the mean for the treatment group’s responses were slightly higher at \(M = 4.0\). Both groups appeared to agree with the statement.

**Statement 31.** *I have not had a formal introduction to engineering problem-solving.* Means for the control and treatment groups, \((M = 2.5, M = 2.63)\) respectively, were in the mid-range between neutral and disagree responses.

**Statement 32.** *I think an introduction to general problem-solving strategies would have helped me.* While the mean for the control group’s responses was \(M = 3.0\) indicating a neutral response, the mean for the treatment group was slightly lower at \(M = 2.67\).

**Statement 33.** I am learning problem-solving strategies through example, but it would be helpful to formalize it. Means for the groups’ responses regarding whether formalizing the problem-solving process would be useful were \(M = 3.33\) for the control group and \(M = 3.27\) for the treatment group.
The entire instrument *Survey of Students Using Web-Based Problem-Solving Tutorials* is available in Appendix G. The following table (16) summarizes the results from the survey.

Table 16

<table>
<thead>
<tr>
<th>Statement</th>
<th>Control</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>29. I am familiar with the general problem-solving strategies</td>
<td>4.07</td>
<td>4.07</td>
</tr>
<tr>
<td>30. I used general problem-solving strategies when doing these problems</td>
<td>3.9</td>
<td>4</td>
</tr>
<tr>
<td>31. I have not had a formal introduction to engineering problem-solving</td>
<td>2.5</td>
<td>2.63</td>
</tr>
<tr>
<td>32. I think an introduction to general problem-solving strategies would have helped me</td>
<td>3</td>
<td>2.67</td>
</tr>
<tr>
<td>33. I am learning problem-solving strategies through example, but it would be helpful to formalize it</td>
<td>3.33</td>
<td>3.27</td>
</tr>
</tbody>
</table>

Chapter Summary

The research study investigated the effect of metacognitive cuing on problem-solving ability. No significant differences were found in achievement or attitude of problem-solving abilities between the two groups. Several reasons are offered for these results:

1. Other studies have found statistically significant results in achievement when longer experimentation was used. Statistically significant resulted when participants were followed for more than one semester, two academic years in one study while the other study longitudinally looked at students from freshman through graduation. The current study occurred over one academic semester.

2. No differences in perception of problem-solving abilities were discerned because students perceived their problem-solving abilities as highly developed.

3. The same questions were used to collect pre- and posttest data for both administrations of the thermodynamics knowledge instrument. Changes in scores
can occur simply because the test has been repeated. Practice effect is a possible threat to internal validity.

4. Participants were asked to record upon which, if any, of the eight steps to engineering problem-solving they used while working the problem sets. Qualitative reflection – why participants made certain choices – was not captured resulting in only frequency data for the responses.

An ancillary finding resulted from development of an effective grading rubric. In the analyses, strong relationships were found for intra- and interrater reliabilities of the instrument. In previous semesters of the thermodynamics course, a structured grading method did not exist resulting in differences in the scoring of exams. Informal feedback from the graders was very positive regarding the use of rubrics in future offerings of the course.
Chapter Five Discussion

Introduction

This research study investigated the effect of using metacognitive strategies through instructional cuing on problem-solving abilities and perceptions of abilities in web-based learning. The chapter is a discussion summarizing the significance of the study results. Included herein are limitations within the study, conclusions and recommendations for further study, and implications for practice.

Discussion of Results

Question 1. The purpose of the first research question was to determine if differences existed -- as indicated by achievement on a composite exam score -- between students who received direct instruction in using metacognitive strategies with web-based embedded cuing and those students who did not receive the instruction and cuing. From the analysis of this question, statistically significant differences in achievement from the cuing of metacognitive strategies were not attained ($p = .96$). These findings are not consistent with results from previous research. In several previous studies, use of metacognitive strategies practiced over time positively influenced problem-solving abilities (Ellis, 1984; Kramarski & Zeichner, 2001; Swanson, 1990).

Results from the following three studies lend support to slow, yet significant, cognitive maturation of metacognitive strategy use. Mevarech and Kramarski (2003) reported significant differences between students receiving metacognitive training and
students practicing worked-out examples without the metacognitive training. In their study, the participants were followed over two academic years; whereas participation in the present study occurred over one academic semester.

After pretest administration to both groups, the Mevarech and Kramarski participants were randomly assigned to either the metacognitively-trained (MT) or worked-out examples (WE) in cooperative groups. Students in both groups had been using cooperative learning since the seventh grade. The WE group was given worked-out examples and then practice problems. Students had the opportunity to explain the material with the members of the group. The MT group was not given the worked-out examples, but was instructed to use a metacognitive questioning procedure while they solved the practice problems. At the conclusion of the instructional unit, students took an immediate posttest of the material. The next academic year the same students, as ninth-graders, were given a delayed posttest examination. Results were significantly higher for the MT students than the WE students on both the immediate and delayed posttests results. Dimensions of mathematical reasoning (verbal explanations, algebraic representations and algebraic solutions) analysis confirmed statistically significant results for both lower and higher achievers in the treatment condition.

Two other studies found similar results as the Mevarech and Kramarski study of metacognitive knowledge developing over time. In the first of the two studies, Zhang and RiCharde (1998) conducted a longitudinal investigation tracking metacognitive and intellectual development of undergraduates from their freshman year to graduation. Students were measured three times: as incoming freshman, at completion of the sophomore year, and prior to graduation. The researchers concluded metacognitive
development: 1) has an irregular pattern during the undergraduate years; 2) fluctuates by academic discipline with engineering students outperforming liberal arts majors and science majors outperforming both engineering and liberal arts majors on problem-solving ability; 3) is influenced by academic achievement; 4) plays a role in students’ increased confidence as their perspective changes from absolute thinking to a broader understanding of events; 5) differs with personality type. The Zhang and RiCharde study differed from the current study in: sample size - over three times as many participants; gender - only male students were included; academic training – three different disciplines were included; and length of the study - a four-year longitudinal investigation.

In the third study, Condor (2001) recommended extending the time of treatment exposure based upon his research results. He analyzed the differences in metacognitive ability when comparing two groups using different computer environments and the relationship between problem-solving ability and metacognitive ability when solving statistical word problems. The study consisted of 120 community-college students enrolled in a beginning-level statistics course. Students were randomly assigned to one of four groups (two groups for each of the two course sections): metacognitively-cued, computer-tool (MCCT) and metacognitively-cued, computer-coached (MCCC). Performance was measured on the outcomes of an instructor-developed objective examination and responses to written metacognitive cues.

Each of the two sections of the course was taught by separate instructors, one being the researcher, however, the same curriculum, guidelines and time schedules were adhered to by both teachers. The study lasted twelve weeks, the entire summer semester.
Treatment began in week four and three unit exams were included in this phase for analysis. Students from both groups (MCCT & MCCC) were directed to complete written metacognitive cues sheets in class while attempting to solve the word problems.

The MCCT group had access to their textbook, class notes and the instructor whenever they required assistance. The computer was utilized strictly as a tool to manipulate the problem-solving activities. The MCCC group also had access to their textbooks, class notes, and instructor although in this case instructors merely guided the student to where they could find explanations on how to solve the problem. This group also had unlimited access to a computer program on CD-ROM which allowed further discovery to problem solutions through in-depth explanations and examples, acting as a computer coach. Both groups were also administered an instrument to report how successful they felt their performance was on the in-class examinations. Measurement of students’ test scores were compared to the self-report measure checking for discrepancies of students’ perceived ability to actual performance.

The study resulted in slight differences of problem-solving ability between the two groups and a small to medium correlation between metacognition and problem-solving. There was, however, a significant difference in academic performance between the two groups in their metacognitive awareness. By the fifth exam, the MCCC group was outperforming the MCCT group. The author attributes this to a slow, but steady progression of the treatment effect.

Condor’s study was similar to the current research in a number of ways. First, convenience sampling of naturally occurring classes was used for both studies. Second, the sample size was limited by enrollments within the course. Third, the length of the
experiment spanned one semester. Condor’s research differed from the present study because he used more than one instructor for the course, two types of computer programs were used (MCCT and MCCC), and reflection from the metacognitive cuing was completed on paper rather than within the computer instruction.

An ancillary finding, resulting from Question 1, was the effective development of an effective grading rubric for the thermodynamics course. In previous semesters of this course, a structured method of grading was not implemented and differences in the scoring of tests were experienced among the graders. The TA’s, acting as subject matter experts, developed the rubrics for exams 3, 4 and 5. An analysis for intra- and interrater reliability coefficients found strong intrarater \((r = 1.00)\) and interrater \((r = .99)\) relationships for the instruments.

Informal feedback from the graders was extremely positive regarding the use of grading rubrics. Their perception of the grading consistency resulted in personal confidence when scoring student exams. This confidence extended their ability to reduce scoring discrepancies when using the objective evaluation methods. The graders expressed a desire to use the grading rubric model in future engineering courses.

**Question 2.** The intent of the second research question was to investigate if differences existed in the attitudes towards thermodynamics problem-solving abilities between the group who received metacognitive strategies instruction and cuing and the group who did not receive the treatment. Results did not indicate a change in perceptions of the participants’ problem-solving ability from pretest to posttest on the attitude instrument. No significant differences were shown on pretest to post test data between-
groups ($p = 0.75$). When measured within-groups, there were no significant differences from pre- to post test results (control, $p = .10$ and treatment, $p = .55$).

Problems get increasingly more difficult in thermodynamics as new concepts are introduced. Hong et al. (2001) found problems need to have conceptual and structural complexity in order for students to engage in regulation of cognition. Problem-solving studies have demonstrated experts more efficiently use metacognitive strategies than novices in complex problem-solving situations (Brown, 1987; Davidson & Sternberg, 1998; Sweller, 1988). Schoenfeld (1985) states novices perceive problem-solving differently than experts and that more adeptness at problem-solving leads to more expert-like behavior. A similarity in self-perception of expert-like behavior towards problem-solving ability could explain no significant differences between the groups.

In a 2005 study by Hutchinson, Follman and Bodner, students were given a survey to “identify the factors related to students’ self-efficacy beliefs during their first engineering course. The survey was administered to freshmen engineering students (n=1387) mid-way through the semester to enrolled in a course titled *Engineering Problem-Solving and Computer Tools* (ENGR 106).

The open-ended survey asked student to list the factors “affecting their confidence in their ability to succeed in the course” (p. 6). Eight factors emerged as indicated by students responding to the survey. In the order of influence on self-efficacy according to the survey responses:

1. Understanding / Mastery of materials
2. Drive / Motivation
3. Teaming
Understanding or learning the course content was the most important factor listed by students as an influence of their confidence to succeed in the course ENGR 106. Problem-solving was rated near the bottom of the 8 items, listed in seventh-place. The majority of the responses from males indicated an increase in their self-efficacy beliefs was due to their perception as successful problem-solvers. On the contrary, the women did not respond with as much confidence towards problem-solving abilities leading to their success. Three-quarters of the women sampled were positively influenced by their problem-solving abilities and the remaining women perceived them harmful to success.

The present study sample consisted of 39 percent males and 9 percent females in the control group and 44 percent males and 8 percent females in the treatment group. As the majority of the sample was males, it is possible there were no significant results between the groups’ perception of problem-solving ability because they considered themselves already adept at problem-solving skills. “Again, students’ efficacy beliefs are being shaped by whether or not they feel they have mastered the ability to use problem-solving techniques effectively” (p. 9).

Another consideration was the instrument measuring perception of problem-solving ability. The HDYSP survey results were averages of answers taken from students’ attitudes toward their own problem solution skills. Measurement of the
instrument’s reliability fell within an acceptable range for *monitoring* and *evaluating* dimensions \( (r = .83, r = .90) \), respectively. However, modification of the reliability coefficient for the *planning* dimension resulted in a lower predicted value \( (r = .69) \). The planning dimension of the instrument should be re-examined to improve the reliability of this section as a coefficient of .80 or above is considered acceptable in most social science applications. It is suggested in the future that research tease apart actual strategies rather than perceptions of problem-solving ability.

*Question 3.* Differences in thermodynamics knowledge and skills between students were measured in the beginning of the semester prior to the start of the experiment and repeated again at the end of the semester after the conclusion of the intervention. It was anticipated significant differences might exist when comparing posttest to pretest within-subjects comparison of means. There was sufficient evidence to conclude improvement of thermodynamics’ skills and concepts for both groups throughout the semester. Pretest to posttest results showed equal improvement for both groups, contradicting the hypothesis those students in the treatment group would improve in skills and knowledge more than the control group.

Another possible reason there were no significant differences in thermodynamics knowledge between groups because of the data collection instrument. Test items of the pretest consisted of objective multiple-choice and short answer formats. Seventeen questions were developed by content experts in the Chemical Engineering Department to assess universally students’ knowledge and skills in: (1) the general understanding of the concepts of energy, how to measure it and the different forms of expression of energy in nature, (2) the concept of conservation of energy which says that energy cannot be
created or destroyed, but can be converted from one form to the other, and (3) the approach to analyzing engineering problems and application of basic knowledge to answer simple engineering questions.

The data in the current study was measured using an instrument with the same test items for both administrations. Practice effect is a definite threat to internal validity when testing participants more than once (Davis & Smith, 2005). Changes in scores can occur simply because you have done nothing other than repeating the test. Future studies should look at an instrument designed to measure thermodynamics concepts equally, however, varying the test items.

**Question 4.** The fourth question examined which of the eight steps to engineering problem-solving students used across the problem sets. A frequency analysis revealed differences in the amount of times students’ reported using the various engineering problem-solving steps while working through the exercises. In this study, students responded most frequently to using Step Two - List Variables (91%) and Step Seven - Solved Equations (91%). The least chosen response was Step Four – Made/stated Assumptions, which was selected only three percent of the time. Another item, selected less than 50 percent of the time, was Step Five – Listed References (30%).

Taking a closer look at the response frequencies, Step One – Abstract the Problem was selected 70 percent of the time. This item has two parts – first, to understand fully what is being asked in a particular problem and secondly to draw an engineering sketch to depict the problem graphically. Considering the 70 percent response frequency, students may have completed the first part of the step, skipping the second more involved practice of drawing the sketch. Step Two - List Variables had one of the highest
frequencies (91%) reported by students. In Step Two students are asked to list all variables and unknowns related to the problem. This is a necessary phase to solving the problem sets. Step Three – State the Basis for Your Calculations and Step Eight – Interpret Solution were reported 62 percent and 61 percent of the time. Because many of the problems include the basis for calculation, students may not have deemed this step essential to completing the problems. Step Eight suggests validation of the solution using common sense. Students are encouraged to use their intuition in deciding if their answer is reasonable. It is possible students automatically (unconsciously) completed this step, as just above half of the respondents indicated they interpreted the solution. The least chosen responses, selected less than 50 percent of the time, were Step Four – Made/stated Assumptions (3%) and Step Five – List Your References (30%). It was recommended in Step Four to make assumptions about the problem including justification for the answer. Step Five proposed reporting all sources of information and data used in the problem solutions. Using Steps Four and Five in the web-based program to complete the problem sets were not required, which may be why very few students reported using them. Nearly three quarters of the students reported using Step Six – Develop Model Equations (71%) which advised writing down problem variables, using algebraic symbols, and stating how each equation was obtained. It is possible students used only one or more parts of this step, therefore they did not report it in the metacognitive reflections. Nearly all the respondents indicated they used Step Seven – Solved Equations (91%). The assumption is this step should be used 100 percent of the time, however, some students may not have completed all the problem sets which reduced the frequency for Step Seven. Universally for all the steps, it is possible students
made arbitrary choices of the *Eight-steps to Engineering Problem-solving* during the reflection phase since they were not required have to explain why they chose a certain response.

Research from Hong et al. (2001) indicated justification skills are an important predictor for open-ended problem-solving scores. They concluded “in order to promote students’ problem-solving skills, educators must develop teaching and learning strategies that use different cognitive components. Specific educational goals and the problems adapted for their instruction must in turn be designed to build specific cognitive skills” (p. 4). In two related studies, one group included ninth-grade students and the second group included sixth to eighth-grade students, participated in research to look at four mental components (cognition, metacognition, non-cognitive variables and justification skills) deemed important for successful problem-solving. Both studies were investigated separately over a 4-week period. The first study used an open-ended response format for presentation of both the well-structured and ill-structured problems. The second study used a multiple-choice format for similar well-structured and ill-structured problems. Hong et al. found justification skills were statistically significant as predictors in solving open-ended problems and concluded students who were able to provide logical arguments would be able to successfully solve those problems.

In another study by Condor (2001), students were asked to fill out a *Metacognitive Cue Worksheet* while they worked through statistical word problems following a computer-based lesson. The students responded to a series of metacognitively-structured questions by writing on the cue worksheets *how* they worked through the problem solutions. Students recorded written reflections on paper. An
example of the type of questions asked included: *What exactly are you doing? (Can you describe it precisely?)* Slight differences in problem-solving for the treatment group were found when metacognitive cuing was introduced: and there was a positive correlation between metacognitive awareness and problem-solving.

A third study by King (1991) found that students in the fifth-grade who were trained in asking and answering metacognitive questions demonstrated the ability to express conceptual understanding better and gave more explanations to peers when presented with novel problems, than those who were not trained. During a three-week period, forty-six students were assigned to one of three treatment groups: guided questioning, unguided questioning, and control. Eleven general questions were divided into three dimensions (planning, monitoring, and evaluating). Examples include questions such as “What is the problem?”, “Are we using our plan or strategy?”, and “What worked?”. Only the two questioning groups were instructed on how to use questioning during problem-solving. These same two groups were given cards with the eleven questions printed on them to refer to during the problem-solving exercises.

Additional results from the study indicated students trained in the questioning procedures were more successful than the non-trained students in a paper and pencil test of problem-solving abilities and in solving novel computer problems.

The metacognitive reflection section of the learning sequence for the *Eight-Steps to Engineering Problem-Solving* model required students to check off which of the eight steps they used during the problem-solving process. The web-based instructional program did not include an area for short answer responses allowing students the opportunity to articulate why they chose one response over another. According to Gupta
(1992), “Reflection on the feedback from experiences and subsequent abstraction of the results of the reflection into one’s cognitive structures fosters metacognitive development” (as cited in Zhang, RiCharde and Stephen, 1998). Further development of the web-based program could include the ability to capture short-answer data for analysis.

A prerequisite prior to treatment was for students to read the *Eight-Steps to Engineering Problem-Solving*. It is possible students failed to complete this assignment. The web-based program was not designed to track if students spent time on the reading section or how much time was spent on the reading section. Tracking if students completed the reading could be a future version of the web-based problem set tutorial.

In the current study, all students received the same debriefing of the problem solutions in-class. Students using the web-based problem sets did not receive feedback specific to the metacognitive strategies they employed while problem-solving. Development of metacognitive awareness requires practice and reflective contemplation (Kramarski & Zeichner, 2001) One way to help students learn the cognitive skills of planning, monitoring and evaluating is to have the instructor model the behavior. Additionally, the web-based instructional program should provide examples of how to effectively use the strategies. Students worked independently on problem-solving without formalized discussion of the metacognitive process. Any group work among students was done informally in an ad hoc nature, as it was not part of the study design. Therefore, there may have been no difference between the groups in achievement because students did not debrief their problem-solving activities either verbally or through written reflection.
Although the metacognitive reflections appeared at the end of each problem set, responses could have been completed by students at a later time, rather than immediately after the problem sets. Future programming should address requiring a response from students before the program allows continuation to the next lesson.

This study was concentrated on achievement outcomes, however, establishing a relationship between the exercises and the engineering problem-solving model could further extend this study. It may be possible to understand why students responded in a certain way by adding an interview component to the study.

The metacognitive reflection was used as an intermission to allow student contemplation of the steps used while solving problems. Encouraging successive approximation is needed, through feedback, as a student engages in the problem-solving process. Further study is needed on the effectiveness of a computer tutoring program prompting students as to which strategy is appropriate while students practice problem-solving. Rather than generalizing the problem-solving steps on each instructional screen, incorporation of how and when a student should implement the steps. According to Campione (1987), instruction of metacognitive skills concurrently with the domain-specific skills they are to manage appears more effective than teaching each type of skill independently. This was not a part of this research, however, it could be used to extend future versions of the web-based problem sets.
Question 5. The biographical questionnaire was completed by study participants to collect demographical information. Overall, national statistics gathered on undergraduate engineering students were reflected. Composition of the group indicated mostly white, non-Hispanic, males in their early twenties who declared English as their native language. The majority had entered the university as freshmen as First Time in College (FTIC) students, rather than transfers either from community colleges or other institutions. Geographically, the participants were mainly Florida residents, with two percent of the participants declaring out-of-state residency and seven percent declaring out-of-country residency.

Responses from the questionnaire confirmed the homogeneity of this group. The majority of students reported their academic standing (GPA) from 3.0 to 4.0 and their year of study as Juniors. This would imply highly motivated, capable students, with academic success the engineering academic curriculum. Zhang and RiCharde (1998) concluded metacognitive development is fostered by academic achievement, indicating students with “good academic standing possess a stronger ability to reason, think, and make decisions about personal and intellectual development” (p. 15).

As discussed previously in Question Two, the Attitudes section, Hutchinson et al. (2005) found Understanding / Mastery of Materials as having the most influence on students’ self-efficacy beliefs in their ability to succeed in a course. Problem-solving abilities ranked seventh out of eight factors identified by students as influential towards their self-confidence in course completion. Men responding to the Hutchinson et al. survey clearly showed an increase in their self-efficacy beliefs was due to their perception as successful problem-solvers. The women responding the same survey, on
the other hand, did not indicated as much confidence towards problem-solving abilities leading to their success. Most of the women sampled believed they were positively influenced by their problem-solving abilities and about one quarter of the group perceived problem-solving abilities harmful to their success.

The perception of problem-solving abilities might have limited variability among engineering students due to predisposition as they chose this particular discipline in part because of their problem-solving skills. It is possible because of their similarities in abilities, they already have well-developed problem-solving skills and any treatment would have minimal effect. “Regarding self-efficacy, students who indicated confidence in comprehension of course materials were more apt to also indicate they employed cognitive and self-regulatory strategies” (Wolters & Pintrich, 2001, p. 28).

Generalization from such a homogenous group to other populations or settings may have different results. Future researchers should consider a more diverse sample such as multiple institutions, the same group of students in different courses, and/or examining student differences longitudinally.

This thermodynamics class had an unusually large percentage of course non-completers. Swanson (1990) found problem-solving performance is positively influenced by high-metacognitive ability regardless of aptitude. A comparison of high, mid, and low achieving students’ use of metacognitive strategies when utilizing the engineering problem-solving model warrants additional study. Further research could investigate the potential impact of using metacognitive strategies on drop-out rates.
Question 6. Participants were asked to self-report their perceptions of the web-based problem sets. The Survey of Students on Web-based Problem-Solving Tutorials was developed by the academic department offering the thermodynamics course and added *a priori* to the research. Questions regarding perceptions of problem-solving knowledge and ability were vague and open to individual interpretation. The results for the problem-solving statements of this survey are ambiguous and can lead to misinterpretation. It is recommended the wording of the statements in the survey is changed in future research.

More specific statements about metacognitive strategies could be used as the statements may have been too general for students to understand the implication of them. For example, the statement (#29) *I am familiar with the general problem-solving strategies* resulted in both groups agreeing with the statement, as reflected by the mean \((M = 4.07)\) of their responses. The statement (#30), *I used general problem-solving strategies when doing these problems*, indicated a slightly higher mean \((M = 4.0)\) for the treatment group than the control group’s mean (3.9). It was expected the treatment group’s mean to be significantly different from the control group’s mean as a result of the intervention. It is possible the treatment group was referring to their general knowledge of problem-solving skill level, based upon the prior question, and did not interpret this question to mean metacognitive strategies. Responses to the statement (#31) *I have not had a formal introduction to engineering problem-solving* showed answers, for both groups, in the mid-range between either *neutral* and *disagree* with this statement. As students read that particular statement, it is unclear whether it they took the meaning as their experience with formal instruction in problem-solving skills before this course or
during this course. When reviewing the data for the statement (#32), *I think an introduction to general problem-solving strategies would have helped me*, means for the control ($M = 3.0$) and treatment ($M = 2.67$) groups were similar, with the mean for the treatment group slightly lower. Since both groups indicated a neutral response, it appeared the experimental group received little to no effect from the treatment. Again, it is possible this statement was interpreted by the students as problem-solving skills they received prior to this course. Results for statement #33, *I am learning problem-solving strategies through example, but it would be helpful to formalize it*, revealed a higher mean for the control group ($M = 3.33$) than for the treatment group ($M = 3.27$). This statement does not clarify whether the problem-solving strategies through example were from in-class lectures, from homework problems set or, in the case of the treatment group, from metacognitive cuing.

**Limitations**

This study was conducted on an intact group of students from one section of thermodynamics in the spring semester of 2005. When interpreting the findings from this study, the following limitations should be considered:

1. Population validity – The selected group of participants were students majoring in engineering. No other academic disciplines were included in the study. Generalization to other populations should take into account the selection bias of this sample.

2. Attrition – As reported in the results, this class section had an atypical number of participants withdraw from the course throughout the semester. Anticipating experimental mortality, a robust sample size was chosen reducing the impact of the 39% participant loss. The end result maintained comparable sizes between the control group ($n = 42$) and the experimental group ($n = 39$).
3. Random Sampling – ABBA Matching was used for group assignment. Choosing this method suggests the group means are not identical, however they are as alike as you can expect without random assignment. When measured, prior to treatment, group comparability was established.

4. Social Threats – The possibility of students discussing differences in instructional format existed. The same section of the thermodynamics course was divided into the two groups (treatment and control). Using separate sections of the same course could minimize this effect.

5. Diffusion of treatment effect: If students chose to work together informally, their responses may have been the consensus of a group rather than their own answers. Students worked on their homework assignments in a natural setting without observation, not in a controlled environment.

Conclusions and Recommendations for Further Study

The purpose of this research was to investigate the effect of metacognitive cuing on problem-solving ability. No significant differences were found in achievement or perception of problem-solving abilities between the two groups. Several reasons are offered for these results. First, the length of the study needs to be increased to allow time for maturation of the treatment condition. Other studies have found a significant difference in achievement when longer experimentation was used. Second, students’ perceived their problem-solving abilities to be highly developed. Future research should tease apart actual strategies rather than the students’ perceptions. Third, the instrument used to collect data of students’ thermodynamics knowledge before and after treatment was suspect to practice effect. The same test items were used for both administrations. Fourth, when students’ were asked to reflect upon the Eight-steps to Engineering Problem-Solving they used, justification of why they used certain steps was absent. Further study is needed linking metacognitive strategies with the problem-solving steps. Fifth, the composition of this sample demographically was homogeneous and therefore
results may not be generalized to other populations. And finally, to benefit from the results of students’ perceptions of the web-based problem sets tutorial, changes need to be made to the instrument, specifically, clarifying the statements relating to problem-solving.

Research of web-based learning environments is just beginning in the area of embedded metacognitive cuing. There is still much to be learned about the role metacognitive strategies play on problem-solving ability when embedded cuing is used in a web-enhanced environment.

*Implications for Practice*

The findings from this investigation, along with previous research, facilitate the definition of boundary conditions when employing metacognitive cuing in web-based learning. Translating the research advances practical application of the work. Recommendations can be made to incorporate the outcomes of this study into the classroom.

Modeling the utility of metacognitive strategies should become part of classroom lectures to supplement the web-based homework problems. The format of the thermodynamics course combined a didactic approach of in-class lecture with homework assignments practiced outside of class. Problem set solutions were reviewed at the following class meetings. In the future, a four-step method is suggested: (1) introduction and demonstration of metacognitive strategies during the classroom lectures; (2) practice of the problem sets by students through the homework assignments; (3) reinforcement of the strategies by the instructor during the solution review sessions in the following class period; and (4) reflection of the process by the student after the review
sessions. “When new, and particularly difficult, skills are being taught, it may be necessary to include self-regulation training, even for subject who, on other occasions, have been known to engage those skills themselves” (Day as cited in Campione, 1987, p. 134).

A tutorial should be included to the web-based instructional program before students begin using the on-line problem sets. Because the *Eight-Steps to Engineering Problem-Solving* model is such an important component in skill development, it should be required reading prior to using the on-line homework problems. The tutorial would allow students the opportunity to practice before beginning the graded on-line instruction.
References


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http://thermodynamics.eng.usf.edu/index.html


http://condor.depaul.edu/~courses/other/outmn444/ch7think.htm


Appendices
Appendix A: Engineering Problem-Solving

By

Joseph Babu, PhD and Professor

2004

Good problem-solving ability is an essential skill for all engineers. There is no universally accepted methodology for solving engineering problems. Problem-solving skills are attained through practice. The problem sets assigned as homework in your engineering courses are the mechanisms for mastering the concepts learned in the lecture and in the reading material. It is important that you spend time trying to do the problems on your own before seeking help, because the process of thinking about and strategizing a solution procedure is extremely important in assimilating the concepts.

The computer-based problem sets designed for this course are intended to build up your problem-solving skills. They are not different from chapter end problems in a good text book, except that we have tried to give you guidance and feedback during the problem-solving process so you know you are on the right track. Hint and help files are provided to guide you towards a solution. In case you are unable to get the right answer, you can take a look at how the solution was arrived at. Where possible we have provided references to text readings and examples that are relevant to the problem at hand.

Even though there are no general procedures for problem-solving, several techniques can help. Resist the urge to write formulas and substitute numbers into them. This usually leads to errors and mistakes besides making it harder for some one else to check your solution. Some suggested steps are given below. At first these steps may seem superfluous and unnecessary, but being systematic is the hallmark of a good engineer. It
Appendix A: (Continued)

will also help you develop good written communication skills which are essential to
function as an effective engineer. Not all problems will require you to go through all the
steps, so use your judgment and intuition.

Step 1. Abstract the Problem

Remind yourself that you can do the problem with the information given. While
some problems appear to be difficult at first, rest assured that after reading it a few times,
you will be able to tackle it. Write an abstract of the problem statement listing all of the
information given and defining some variables and constants along the way. Ask the
question: what exactly is being asked in this particular problem? Do not repeat the
problem statement, rather try to restate it in terms of how you interpreted it. One good
way to abstract the problem statement is to draw an engineering sketch. This means if
the problem is about a compressor you would draw a sketch and supply appropriate
information. Use engineering symbols where possible as shown in your reading
assignments. You are defining and planning. Include the specified constraints. If it is
useful, write down given information at appropriate locations in the sketch.

Drawing a sketch, even if it is given in the problem statement, allows you to
concentrate and focus your attention on the problem. This is good practice even in tests.
When you are drawing a sketch you are translating from a verbal to a graphical
interpretation of the problem statement. The sketch may be of the equipment or of the
events taking place as verbally described in the problem. Use engineering paper if it helps
you to draw better sketches. This paper has vertical and horizontal ruling that allows
better sketches.
Appendix A: (Continued)

Step 2. Make a List of Variables

List all the variables/unknowns associated with the problem. Make a list of known quantities. Pay close attention to dimensional units. Each number (variable) must be accompanied by units. Do not assume that you have to use all the data given in the problem statement to solve the problem. On the other hand, data given may not be sufficient and in that case you may need to make certain assumptions as stated below.

Step 3. State the Basis for Your Calculations

In many problems, the statement may include a base flow rate or volume or production capacity. If it is given in the problem, restate it. If it is necessary to assume one (e.g. you can do the problem assuming 100 kg of feed) do so and state your basis clearly.

Step 4. Make and State Your Assumptions

Most problems require assumptions to arrive at an answer. Sometimes these assumptions are given in the problem statement. Sometimes you may need to make them yourself. If you do, you must state it, and if possible, justify why you made that assumption. Any assumptions you make in arriving at your mathematical model should be clearly stated. Do not oversimplify the problem because in that case your answer may not apply.

Step 5. List Your References

Often, you need to get additional data to solve the problem. The source of all data and information used in your solution, except that contained in the problem statement, should be referenced. References must contain enough information so that your
supervisor could easily look up your referenced data.

Step 6. Develop Model Equations

Write down all the governing equations using the algebraic symbols to represent the unknowns. Remember the acronym: KISS (Keep it Simple and Solvable). If necessary make more assumptions to simplify the problem. You may need to add more variables to define the model. Check for consistency of units used, eg. Both sides of an equation must have the same set of units. All terms being added or subtracted must have the same units.

Terms within exponentials or logarithms must be dimensionless. Each equation must be preceded by a line stating what it is or how it is obtained. All variables should be clearly identified and defined with appropriate units. The most common mistake is using inconsistent sets of units. Try to use conventional symbols where possible (e.g. $x_i$ for liquid mole fractions, $L$ for liquid flow rates, etc.). Graphical correlations would be included here if they are required to solve the problem.

You will need one equation for every unknown variable in the problem. If you do not have enough equations, you may need to think about other possible relationships among the variables you have overlooked. If you have more equations than variables, some of the equations may be redundant in nature. Go back and check your assumptions and model if there is an inconsistency. Later on, you will be introduced formal methods of analyzing a model to determine if there are enough degrees of freedom to solve the problem (called degrees of freedom analysis).
Step 7. Solve the Equations

Equations may be algebraic in nature or they may be in the form of differential equations if there is a time or distance variable involved in the problem. There is powerful software available for solving such equations. TKSolver® is great for solving collections of linear and nonlinear equations. Mathcad®, Matlab® and Maple® are great for differential equation systems. Simulink® is great for ordinary differential equation models. Femlab® is great for solving partial differential equations. Maple® and Mathematica® are great for solving symbolic equations. You should get familiar with these tools in the course of your engineering education. Use the right tool for the problem.

Choose a method of solving the mathematical model for the unknowns and execute the solution. You should label each equation when you write it down. Round off answers to reasonable significant digits because calculators and computers report 7 or more digits and typically you do not have that kind of accuracy in the data or the model used. Remember the principle “GIGO: Garbage in; Garbage Out” as it applies to computer based solutions. Your answer is only as good as what you put in. This is why the next step is important.

Step 8. Interpret the Solution and Make Conclusions

Look at the solution to the equation and interpret the numbers in light of the problem statement. Check if it makes sense physically. For example, if the answer is a fluid velocity, then compare against normally expected velocities in the problem context. If it is a temperature, then check if it is very high or very low. Use your intuition and
Appendix A: (Continued)

common sense to validate your answer. If the answer is unreasonable, then may be you need to check your assumptions and/or model equations. Using computers and calculators you can avoid errors in arithmetic.

Engineering design problems are a different breed. These are typically stated with minimal information and often have multiple answers or solutions. The problem statements are often vague. Eg. Design a bridge to cross the river. You as the engineer must choose the location, the length, width, material of construction, structure etc., and taking into account the requirements of the bridge and constraints imposed by social, economic, safety and political considerations. By the time you graduate, you are expected to pick up the necessary skills to tackle such open ended problems.

Example of Engineering Problem-solving

Problem Statement: A ball is through into the air with a velocity of 1.0 m/sec. at a 45° angle. Calculate the time it takes before it hits the ground. Assume that the ball is initially 1m above the ground.

(This is actually a problem from Physics, but quite similar to engineering problems)

*Step 1. Problem Abstraction*

First draw a figure depicting the scenario outlined in the problem.
Needed: time to hit the ground

Given: Initial velocity and direction and initial location.

Abstraction: Ball goes up and is pulled down by gravity and follows a “parabolic” path (from empirical observation of thrown objects). Vertical velocity will decrease, become zero and then become negative. Motion in vertical and horizontal directions can be decoupled.

Step 2. List of Variables

We will need vertical and horizontal velocities, \( v_x \) and \( v_y \)

Initial Velocities are known:

\[
v_{xo} = (1\text{m/sec}) \cos 45^\circ = \frac{1}{\sqrt{2}} \text{ m/s}
\]

\[
v_{yo} = (1\text{m/sec}) \sin 45^\circ = \frac{1}{\sqrt{2}} \text{ m/s}
\]

\( d_y \) = vertical distance traveled by the ball, m

\( t \) = time, sec
Appendix A: (Continued)

Step 3. Basis for Calculations

None required for this problem

Step 4. Assumptions

Ground is flat

Air resistance can be neglected

Acceleration due to gravity is 9.8 m/sec²

Step 5. List References

Physics Text, p.135

Step 6. Develop Model Equations

The vertical motion is governed by the equation (from the definition of acceleration). We define a new variable, y (meters) to indicate the vertical distance from the ground. The variable g is used to indicate the acceleration due to gravity (assumed constant, another assumption).

\[ \text{Acceleration} = \frac{d^2y}{dt^2} = -g \]

Initial position (t=0) \( y = 1.0 \) m; Initial vertical velocity \( = \frac{1}{\sqrt{2}} m/\text{sec} \)

Step 7. Solve

Integrating:

\[ \frac{dy}{dt} = -gt + v_{yo} \]
Appendix A: (Continued)

(Applying initial velocity) \[ v = -gt + \frac{1}{\sqrt{2}} \]

Integrating Again:

\[ y = \frac{1}{2}gt^2 + \frac{1}{\sqrt{2}}t + y_o \]

(Applying Initial Position)

\[ y = -\frac{1}{2}gt^2 + \frac{1}{\sqrt{2}}t + 1 \]

We want to know when the ball hits the ground (y = 0).

\[ 0 = -\frac{1}{2}gt^2 + \frac{1}{\sqrt{2}}t + 1 \]

Substituting for \[ g = 9.8 \frac{m}{s^2} \]

\[ t = 0.529 \text{ sec} \quad \text{or} \quad -0.385 \text{ sec} \]

Negative answer is not acceptable. Hence time to hit the ground = + 0.529 sec.

*Step 8. Interpret Solution*

The answer seems reasonable from an intuitive point of view. The ball does not travel far before it hits the ground. You can get a physical feel for the answer by throwing the ball yourself and seeing how long it takes to hit the ground.
Appendix B: How Do You Solve Problems (HDYSP) Inventory

How Do You Solve Problems?

In order to provide the best instruction possible, we need to understand how engineering students approach solving problems in this course. Help us obtain this understanding by reading the following sentences and choosing the answer that BEST describes your approach to solving problems. To help, you might think about a typical problem that you have encountered in your other math or engineering courses.

There is no right or wrong answers, so simply identify the frequency with which you personally use each of the following problem-solving procedures. Please tell what you actually do rather than what you think you should do.

This questionnaire is confidential and will not be graded. Your responses will be summarized with those of the total group, and your individual answers will not be used or shared with your instructor or fellow students.

There are three sections to this questionnaire:
1. Planning – what do you do before you begin to solve a problem?
2. Monitoring – what do you do while you are solving a problem?
3. Evaluating – what do you do after you finish working on a problem?

Choose ONE of the following responses for each statement:

1 = Rarely  2 = Sometimes  3 = Frequently  4 = Almost always

<table>
<thead>
<tr>
<th>Part 1 – Planning is defined as (1) selecting appropriate strategies and (2) allocating resources that affect performance. An example would be allocating time or attention selectively before beginning a task.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. When considering a problem, I ask myself what exactly is being asked.</td>
</tr>
<tr>
<td>2. To be sure I understand the problem, I read it more than once.</td>
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<tr>
<td>3. Instead of repeating the problem statement, I try to restate it in terms of how I interpret it.</td>
</tr>
<tr>
<td>4. I remind myself that I can do the problem with the information given.</td>
</tr>
<tr>
<td>5. When I prepare to solve a problem, I write an abstract of the problem statement listing all given information.</td>
</tr>
<tr>
<td>6. I define the variables and constants when approaching a problem.</td>
</tr>
<tr>
<td>7. I use engineering symbols when I am abstracting a problem.</td>
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</table>
Appendix B: (Continued)

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</thead>
<tbody>
<tr>
<td>1</td>
<td>Rarely</td>
<td>2</td>
<td>Sometimes</td>
</tr>
</tbody>
</table>

### Planning continued.

8. Depending on the problem, I draw an engineering sketch.

9. When drawing an engineering sketch, I use engineering paper for a more accurate picture.

### Part 2 – Monitoring is defined as a person’s awareness of comprehension and task performance. An example is the ability to engage in periodic self-testing while learning.

10. When assumptions are not provided in the problem, I state my own.

11. When necessary, I make further assumptions to simplify the problem.

12. I write down the known quantities of the problem.

13. I list all the variables/unknowns associated with the problem.

14. If needed, I gather additional data to solve the problem.

15. When using additional data not stated in the problem statement, I clearly reference it.

16. If the base flow rate or volume or production capacity is not given, then I assume one.

17. When thinking about the basis for my calculations, I restate the base flow rate or volume or production capacity.

18. When developing model equations, I write down all governing equations using algebraic symbols to represent the unknowns.

19. I justify my assumptions in arriving at my mathematical model by clearly stating them.

20. If needed, I use more variables to define the model.

21. I label each equation when I write it down.

22. When developing model equations, I use conventional symbols where possible.

23. I precede each equation with a line stating what it is or how it is obtained (e.g. L for liquid flow rates).

24. For every unknown variable in the problem, I have one equation.

25. When solving for unknowns in a mathematical model, I am able to choose an appropriate method to execute the solution.
Appendix B: (Continued)

1 = Rarely  2 = Sometimes  3 = Frequently  4 = Almost always

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<tr>
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<tbody>
<tr>
<td>26. I check for consistency of units (e.g. both sides of an equation must have the same set of units).</td>
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**Part 3 – Evaluating is defined as appraising the products and efficiency of one’s learning. An example is re-evaluating one’s goals and conclusions.**

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<tbody>
<tr>
<td>28. When checking the solution against the equation, I interpret the numbers in light of the problem statement.</td>
<td></td>
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</tr>
<tr>
<td>29. I check to make sure the solution makes sense physically (e.g. if the answer is a fluid velocity, then compare against normally expected velocities in the problem context).</td>
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<tr>
<td>30. To validate my answer, I use my common sense/intuition.</td>
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<tr>
<td>31. If my answer seems unreasonable, I re-check my assumptions and model equations.</td>
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<tr>
<td>32. I check the <strong>efficiency</strong> of my solutions and “rethink” my errors and “false starts.”</td>
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</table>

**Thank you for your time in taking this questionnaire**
Appendix C: Participant Survey

Participant Survey

This survey will be used to collect anonymous demographic information of students enrolled in Thermodynamics (EGN 3343) during the current academic semester (fall 2004). According to the Institutional Review Board (IRB), the information you provide will remain confidential and used for the express purpose of this study.

Directions:

For each question, select the most appropriate response to reflect the information indicated below.

1. My year of study is:
   - Freshman
   - Junior
   - Sophomore
   - Senior

2. When did you enter USF? As a:
   - Freshman
   - Transfer from a community college
   - Transfer from another university

3. My declared major is:

4. The number of credit hours I am taking this semester are:
   - 0-3 credit hours
   - 4-8 credit hours
   - 9-12 credit hours
   - 13-18 credit hours
   - More than 18 credit hours

5. Outside of this course, the number of hours I am working are considered:
   - Part-time
   - Full-time
   - I do not work at this time
Appendix C: (Continued)

6. My current GPA is:
   o 4.0-3.5
   o 3.4-3.0
   o 2.9-2.5
   o 2.4-2.0

7. How many times have you taken a Thermodynamics class?
   o First time
   o Second time
   o Other

8. My gender is:
   o Male
   o Female

9. My year of birth is:

10. My ethnic background is:
    o African American
    o Asian/Pacific Islander
    o American Indian
    o Hispanic
    o White/Non-Hispanic
    o Other

11. My native language is:
    o English
    o Spanish
    o Other

12. For residency purposes, I am considered a:
    o Florida resident
    o Out of state resident
    o Out of country resident

Thank you for your time in completing this survey.
Appendix D: Pre/Posttest of Thermodynamics Concepts


Which of the following units can be used to measure pressure? Check all that apply.

a. lbf  b. lbf/in\(^2\)  c. mm Hg  d. Pascal  e. atm

Which of the following units can be used to measure specific volume of a fluid?

a. cubic feet/lbm  b. liter/gm  c. gm/cc  d. cc/gm  e. gm/liter

The atomic weight of Oxygen is 16. The atomic weight of hydrogen is 1. What is the mass in lbs of a lbmole of water?

a. 16  b. 17  c. 18  d. 19  e. 20

4. 1 gm of water has a volume of 1 cm\(^3\). What is the mass of 1 ft\(^3\) of water?
(1 lbm= 454 g; 1 ft=12 in; 1 in = 2.54 cm)

5. What is the volume occupied by 1 kg of oxygen at 25 C and 1.1 atm? Assume it is an ideal gas and the universal gas constant is \(R = 82.5 \text{ liter.atm/(kmol.K)}\)

Air is compressed from 1 atm to 2 atm in a completely insulated cylinder. This process is
a. an adiabatic process  b. an isothermal process  c. an adiabatic and isothermal process  d. none of the above

6. A pump is used to deliver water to a reactor. If the pump is to be modeled as a system how would you characterize it? Check all that apply.

a. an open system  b. a closed system  c. both open and closed system  d. neither open nor closed system.

7. Grape juice is fermented in a tank to make wine. How will you characterize this process? Check all that apply.

a. steady state system  b. unsteady state system  c. transient process  d. continuous process  e. batch process

8. If you are stirring a cup of coffee are you transferring any energy to the coffee?

9. A box containing 10 red marbles is separated by a thin wall from a box above it containing 10 blue marbles. The wall is removed and the marbles mix with each other. Is this a reversible process?
Appendix D: (Continued)

10. A water pump is run by an electric motor that uses 100 watts of power. If the pump efficiency is 60% how much energy is converted into thermal energy in the pump?

11. A fluid is flowing at a steady rate through a constant diameter pipe. There is friction between the wall and the flowing fluid. Will the velocity be the same at the inlet and the outlet of the pipe?

Will the pressure in the pipe be the same at the inlet and the exit?

12. Can thermal energy be transferred from a room at 75°C to a room at 85°C?

13. If a person living in a well insulated apartment (heat neither enters nor leaves through the walls or windows) leaves her fan running will the temperature of the room:
   a. remain constant b. increase c. decrease

14. A gas is in a cylinder is expanding in volume while the pressure remains constant. Does it do any work?

15. Can a gas expand in volume while the pressure remains constant?

16. Does it take the same amount of energy to raise the temperature of 1 g of water by 1 deg C when it is near room temperature versus when it is near 80°C?

17. The conservation of energy principle applied to a system says that the total energy entering a system at steady state must equal the total energy leaving the system if there are no chemical reactions taking place inside the system. Consider a mixing tank which is being heated by a 1000 watt (1 watt = 1 joule/s). Water enters and leaves the system at a constant rate. Thermal energy losses from the system totals 300 calories/s. (1 cal = 4.2 joules). Will the temperature of the fluid leaving the system be greater or less than the entering temperature?
### Appendix E: Grading Rubric

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>Excellent (Weight)</th>
<th>Very Good (Weight)</th>
<th>Good (Weight)</th>
<th>Poor (Weight)</th>
<th>Incomplete (Weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering Problem-solving</td>
<td>100 pts.</td>
<td>99-80 pts.</td>
<td>79-69 pts.</td>
<td>&gt;60 pts.</td>
<td>0 pts.</td>
</tr>
<tr>
<td>1. Problem Abstraction</td>
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<tr>
<td>2. List Variables</td>
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<tr>
<td>3. Basis for Calculation</td>
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<td>4. Assumptions</td>
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<tr>
<td>5. List References</td>
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<tr>
<td>6. Develop Model Equations</td>
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<tr>
<td>7. Solve</td>
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<td></td>
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<td></td>
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<tr>
<td>8. Interpret Solution</td>
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</tbody>
</table>
Appendix F: Web-Based Problem-Solving Tutorial Survey

Survey of Students Using Web-Based Problem-Solving Tutorials
Check the answer which best reflects your experience with web-based problem sets

Please note the following Conventions:


<table>
<thead>
<tr>
<th>Do not complete survey if you did not do web-based problems</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Web-based problems sets are too easy and do not force me to think as well as paper-based problem sets</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1.74</td>
</tr>
<tr>
<td>2. I prefer Web-based problems sets over paper based assignments</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2.34</td>
</tr>
<tr>
<td>3. I learned better from paper-based problems sets than web-based assignments</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>3.19</td>
</tr>
<tr>
<td>4. The help features of web-based problem sets, allowed me to tackle the problem better</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2.97</td>
</tr>
<tr>
<td>5. Web-based assignments were difficult to access</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2.38</td>
</tr>
<tr>
<td>6. My performance in the course suffered because of the web-based assignments</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2.58</td>
</tr>
<tr>
<td>7. Web-based assignments forced me to review my course material</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>3.18</td>
</tr>
<tr>
<td>8. I liked the fact that I got immediate feedback on whether I did the problem correctly</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2.59</td>
</tr>
<tr>
<td>9. I found web-based assignments frustrating because it did not let me see the entire problem at once</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>3.19</td>
</tr>
<tr>
<td>10. I think I got a fair score in the web-based problem sets</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2.22</td>
</tr>
<tr>
<td>11. The problem set was broken down into too many questions</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>3.51</td>
</tr>
<tr>
<td>12. I prefer to work alone on my homework</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2.31</td>
</tr>
<tr>
<td>13. The web-based problem sets took much longer for me to complete</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2.45</td>
</tr>
<tr>
<td>14. The web-based problems sets prepared me better for the assessment quizzes and mid-term tests</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2.34</td>
</tr>
<tr>
<td>15. The web-based problem sets were frustrating to use</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2.89</td>
</tr>
<tr>
<td>16. The web-based problem sets motivated me better</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2.43</td>
</tr>
<tr>
<td>17. In the future I would prefer to use paper based homework problems</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>3.05</td>
</tr>
<tr>
<td>18. I had problems with the technology in using the web based problems, and couldn’t use them effectively</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1.81</td>
</tr>
<tr>
<td>19. My performance in the course improved because of web-based problem sets</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2.05</td>
</tr>
<tr>
<td>20. I did not like the grading system used in the web-based problem sets</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2.65</td>
</tr>
<tr>
<td>21. I felt isolated when working the web-based problem sets</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2.04</td>
</tr>
<tr>
<td>22. The web-based problem sets offered too much guidance</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2.01</td>
</tr>
<tr>
<td>23. I found the web-based problem sets too easy, did not offer enough of a challenge to me</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2.86</td>
</tr>
<tr>
<td>24. I learn better when I collaborate with fellow students to solve homework problems</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2.96</td>
</tr>
<tr>
<td>25. I chose to solve more problem examples than were provided in the web-based problem sets as additional practice</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1.86</td>
</tr>
<tr>
<td>26. I would prefer to take the exams and quizzes on the web rather than with paper and pencil</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2.92</td>
</tr>
<tr>
<td>27. I would prefer more guidance through the help and hint buttons than was provided to me</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1.80</td>
</tr>
<tr>
<td>28. It is too easy to cheat on web-based problems and hence it should not be used</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>3.88</td>
</tr>
</tbody>
</table>
## Survey of students on Web-Based Problem-Solving Tutorials – page two

Check the answer which best reflects your experience with web-based problem sets

Please note the following Conventions:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Strongly Agree</td>
<td>Agree</td>
<td>Neutral</td>
<td>Disagree</td>
<td>Strongly Disagree</td>
</tr>
<tr>
<td>29. I am familiar with the general problem-solving strategies</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>30. I used general problem-solving strategies when doing these problems</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>31. I have not had a formal introduction to engineering problem-solving</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>32. I think an introduction to general problem-solving strategies would have helped me</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>33. I am learning problem-solving strategies through example, but it would be helpful to formalize it</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>34. Circle the % that best describes the amount of time you worked with others on your homework</td>
<td>0</td>
<td>25</td>
<td>50</td>
<td>75</td>
<td>100</td>
</tr>
</tbody>
</table>

Responses to question # 34

|          | 28 | 14 | 14 | 4 | 1 |

Comments:

- # of respondents = 74
- 5 did not complete survey
- 8 did not attempt survey
- 13 comments (see attached Word document)
Appendix G:  Web-based Homework Survey
04.26.05
Written Comments

1. The only problem with the web-based problems are that ¼ of the solutions are wrong because they used the wrong information. Also, sometimes the “write” solutions would not go through. When looking at the solutions, if they were wrong, showed the wrong way to solve the problem.

2. I didn’t like the online homework. Many solutions were wrong, or at least different from Dr. Smith. I didn’t like it that we weren’t given full solutions so we could study for a test.

3. Quizzes should be online and given more time, they bring down the grades of the students.

4. The homework has a lot of bugs that need to be worked out.

5. On your 3rd attempt of missing a problem most of the time the hints would just blatantly give you the answer. This should not happen, too easy then. Maybe a better hint not the answer. Or make the examples given have #’s further form what the get values will give!

6. The web-based homework assignments were very useful. I was much more likely to do the homework, especially if I was already using my compy [computer]. That fact alone probably helped bring up my final grade almost a whole letter. Thank you web-based homework and your noble deeds. Thou art a modern day Lancelot … here to steal my woman.

7. The online homework is a pain. It does no good. All the things I learned were from going to class everyday. We would be better served to work problems on paper and then turn in the paper. I often wonder how engineers learned before without online homework. They used pencil and paper!

8. The web-base design would work if all bugs were worked out of the system (i.e. when entering a value you are told it is incorrect, but when the solution pops up, it is the same value that you entered.) These program errors caused students to not know if they were doing the problem correctly. Also, I believe that paper would facilitate learning more effectively. Just look @ the grade differences between the morning and afternoon sections.

9. The web homework as more of a problem than a help. Often times the site would not work or the images need to solve the problem wouldn’t load. The web h.w. was also a nuisance when the answers would contradict what the professor had solved in class or even posted on Blackboard. The same problem with 3 different answers is very misleading in a class. The h.w. “tool” just complicated the course.
10. The online problems would be ok if the person who did the solutions got their act together. Time and again, the program would tell me that I was wrong when I wasn’t. It was hard to build confidence with the material. The piss-poor quality in the solutions reinforced my belief that the online problem sets are intended to make life easier for the LAZY TA’s and professor than to enhance the learning experience (maybe overworked would have been more appropriate and fair … point is, the format of this class was frustrating). After sitting in on a few afternoon classes, I feel cheated from what could have been an excellent learning experience from what seems to be a very knowing Professor with exceptional teaching potential.

11. In answer to Question 10 of the survey, “I think I got a fair score in the web-based problem sets” – Don’t Know! Never got any kind of confirmation on whether or not Jen received my submissions. The web problems are plagued with mistakes that left me extremely frustrated and wondering if I know what I was doing. I was told by a TA that I “should know when Jen mistakenly used wrong values”. How would I? When I am supposed to be just learning this material. The previous comments are not coming from someone with a low grade in this class. I will leave with a strong A but it was after a semester of self-teaching. I think the web problems could be a wonderful tool if they are fixed. I should not have to spend hours figuring out if I know what I am doing or if the problems I am working on have yet again wrong values or a wrong answer.

12. Someone should verify the problems solutions to ensure they are correct before they are posted. The online problems did have a few bugs, but overall I liked the format.

13. The online problems did have a few bugs, but overall I liked the format.
About the Author

Sally A. Zabel received a B.A. in Interdisciplinary Studies in 1996 and a M.S. in Curriculum and Instruction (Instructional Technology) from the University of South Florida in 1997. She has been working for the continuing education and professional development office in the College of Engineering at USF since 1998. Recently, the responsibilities of her department have been expanded to include marketing and public relations for the college. She is currently the Director of the program.

Ms. Zabel is an active board member of the Continuing Professional Development Division of the American Society for Engineering Education (ASEE). She also serves on USF’s Engineering Executive Committee, and is a participating member of the Statewide Systems Operating Committee (SSOC) – an oversight body for engineering distance education in the State of Florida.