

## Chapter 1. Nature of the Study

### Overview

Encouraging students to recognize, define, and solve problems is a growing trend in education (Kirshner, 2002). Problem-solving occurs when an individual achieves new understanding in unfamiliar contexts (Renkl, 1997), and is a form of transfer (Ormrod, 1999). The definitive goal of problem-based learning is to promote transfer from the educational environment to the “real world” environment. Transfer is defined as “when something you learn in one situation affects how you learn or perform in another situation” (Ormrod, 1999, p. 347). Appropriate educational curriculum must promote transfer between problem-solving tasks in the classroom and the outside world (Daugherty, 2001).

The need for problem-solving skills extends across all educational curricula. As expressed by James (1990), “The necessity for problem investigation, experimentation, and feedback is evident at all levels of education, preschool through college/university” (p. 29). Infinite forms of problems exist and occur in every field from automotive repair to zoology. “Problem-solving has been identified and promoted by many disciplines including mathematics, psychology, the physical sciences, the arts, and more. In different contexts and in different ways, all employ the problem-solving process” (Wu, Custer, & Dyrenfurth, 1996, p.56). In *Standards for Technological Literacy*, one of the necessary improvements in American education is the need to improve problem-solving skills (International Technology Education Association, 2000). Additional literature from science education supports this contention and states, “students in the United States are well below the international level in problem-solving” (American Association for the Advancement of Science, 1990, p. xv). “Preparing students to become effective problem-solvers, alone and in concert with others, is a major purpose of schooling” (American Association for the Advancement of Science, 1993, p. 282). The need for scientific and technological problem-solving skills throughout the K-12 curriculum framework must be stressed (National Research Council, 1996). Technological problem-solving is one type of problem-solving that primarily includes design, research and development, trouble shooting, invention and innovation, and experimentation (ITEA, 2000).

Technology education is one subject area that promotes technological problem-solving processes involving ill-defined, open-ended problems and group participation. Education based on open-ended, ill-defined problems, recognizing, defining, and solving problems, and working in groups, is quite different from accustomed instructional formats (Kirshner, 2002). According to Daugherty (2001), “The paradigm in technology education is changing. Technology teachers are moving from the age of teaching traditional industrial processes to the contemporary age of teaching problem-solving and technological application” (p. 172). The inclusion of instruction based on technological problem-solving may prove difficult for many instructors. In order to be successful, educators need to understand the challenges associated with multidimensional technological problem-solving (Custer & Wright, 2002).

One of the challenges that instructors face is developing higher-order thinking skills in students. Problem-solving requires students to use higher levels of thinking and application skills, such as analysis and synthesis, which are not necessary in rote memorization and item recall tests. Bloom, Englehart, Furst, Hill, and Krathwohl (1956) defined six levels constituting a taxonomy of educational objectives. These levels include knowledge, comprehension, application, analysis, synthesis, and evaluation. Higher order thinking skills such as analysis, synthesis, and evaluation require learners to process large volumes of information in order to analyze and solve problems. As students analyze more information, they are forced to select relevant information while disregarding information that is irrelevant.

Another challenge for instructors is designing instructional strategies that will enhance problem-solving and take into account the limited working memory capacity of students. Miller (1956) found that working memory is capable of holding approximately seven (plus or minus two) elements of information at one time. After reaching this plateau, an individual is unlikely to absorb additional elements, and working memory overload occurs. According to Kirshner (2002), working memory capacity can be enhanced by combining elements of information into one cognitive schema. In addition to enhancing working memory, schema construction supports long-term memory by incorporating new schemas into existing ones stored in long-term memory (Valcke, 2002).

One way to combat the challenges associated with working memory and enhance problem-solving is through the implementation of worked examples in instruction. Studies performed by Ward and Sweller (1990), Sweller and Cooper (1985), and Zhu and Simon (1987) revealed improvements in schema construction and problem-solving efficiency when worked examples were displayed during problem-solving tasks. According to Renkl, Stark, Gruber, and Mandl (1998), “worked examples comprise the specification of a problem, the solution steps, and the final solution itself” (p. 90). Students use worked examples as models to establish solutions for problems (Renkl et al., 1998).

Learning from worked examples is similar to the process of learning-by-doing. A student involved in the process of learning-by-doing works through a problem and creates a solution while the instructor provides feedback as to whether or not the solution is accurate and successful (Zhu & Simon, 1987). The instructor confirms successful and unsuccessful attempts and the student is able to use the results to work through similar problems using the completed solution as a worked example (Zhu & Simon, 1987). The learning-by-doing method has an extended, effective history in discovery learning and child-centered education promoted by educational philosophers like Pestalozzi, Froebel, and Dewey, but is very time consuming (Zhu & Simon, 1987). Time restrictions encountered in instructional settings need to be considered when discovery learning and learning-by-doing are implemented. With limited instructional time available, the substitution of the initial learning-by-doing procedure with worked examples may be more effective by providing an initial solution to problem-solvers. This initial solution primes student ideas about how to develop additional solutions.

For example, Zhu and Simon (1987) found that students were capable of learning how to factor quadratic equations using worked examples. The authors conducted additional worked example experiments concerning factoring, exponents, geometry, ratios, and fractions with similar success. Sweller and Cooper (1985) conducted experiments to determine if worked examples facilitated mathematical problem-solving. In their study, worked examples decreased the amount of processing time compared to conventional problems, and participants solved algebra problems faster when viewing worked examples. Ward and Sweller (1990) explored the effectiveness of worked examples in enhancing science instruction. They found that if worked examples were structured appropriately (a presentation format that reduced cognitive load and promoted schema acquisition), then they facilitated problem-solving in many areas of science. Paas and Van Merriënboer (1994) investigated geometric problem-solving skills associated with computer numerically controlled (CNC) machinery programming. The results indicated that instruction using worked examples led to better transfer performance, decreased instructional time, and less mental effort when compared to the conventional problem-solving group.

However, Tuovinen and Sweller (1999) propose that worked examples are not always the most appropriate means of instruction. Tuovinen and Sweller (1999) suggested, “the effectiveness of worked examples clearly depends on the previous domain knowledge of the students. If they have sufficient domain knowledge, the format of practice is irrelevant, and discovery or exploration practice is at least as good, or maybe even better, than worked examples practice” (p. 340). Kalyuga, Chandler, Touvinen, and Sweller (2001) also studied the impact of prior domain knowledge using worked examples or instructional guidance on a series of problem-solving tasks. The researchers found that the worked example condition was more beneficial to inexperienced apprentices. They also discovered that as experience increased, the use of worked examples proved redundant and explorative problem-solving was more effective.

According to Kalyuga et al. (2001), research exploring worked examples and problem-solving reveals a pattern concerning the use of worked examples.

1. Learners who are inexperienced or novices in a subject domain benefit from guided direct instruction (Kalyuga et al., 2001).
2. The amount of guidance necessary decreases as subject material becomes easier and/or experience of the learner increases (Kalyuga et al., 2001).
3. Worked examples are best suited for novices and should be gradually removed from instruction as knowledge and understanding increases (Kalyuga et al., 2001).
4. Guidance may eventually act as a deterrent to learning as knowledge and learner understanding increase (Kalyuga et al., 2001).

According to Sweller (1988), Kalyuga, Chandler, Touvinen, and Sweller (2001), Tuovinen and Sweller (1999), Paas and Van Merriënboer (1994), Sweller and Cooper (1985), and Ward and Sweller (1990), the implementation of guided instructional techniques using worked examples promotes learning and problem-solving over the use of conventional means-ends analysis that requires learners to focus on multiple aspects of the problem. Problem aspects involved in means-end analysis are described by Sweller (1988) as the goal, the givens, differences and relationships between the goals and the givens, and any subgoals established related to the other differences. For worked examples to be successful, Tarmizi and Sweller (1988) found that they must be structured in a way that do not impose heavy cognitive load and thereby nullify their beneficial aspects that include efficient construction and acquisition of schemas, improved transfer, and enhanced problem-solving speed for inexperienced or novice learners.

As discussed above, successful example solutions often enhance problem-solving abilities. However, the implementation of unsuccessful example solutions for technological problem-solving has yet to be explored. Students are rarely exposed to unsuccessful examples unless they do not succeed in the problem-solving task and produce their own unsuccessful example. The effect of unsuccessful examples on problem-solving is unknown. Unsuccessful examples may provide some useful information and thus enhance problem-solving or unsuccessful examples may increase extraneous cognitive load and thus hinder problem-solving. If unsuccessful examples prove effective for enhancing problem-solving, then instructors should consider exploring the employment of successful and unsuccessful example types to promote schema acquisition, transfer, and problem-solving efficiency.

## **Statement of the Problem**

The problem investigated was whether presenting middle school students with successful example solutions, unsuccessful example solutions, or no example solutions enhances the efficiency of solving open-ended technological problems.

## **Purpose of the Study**

The purpose of this study was to investigate the usefulness of different example solutions in enhancing the problem-solving efficiency of middle school students working on open-ended technological problem-solving assignments. Enhancing problem-solving efficiency makes more time available for the promotion of higher order thinking skills such as application, analysis and synthesis that enhance student technological problem-solving abilities and understanding. Denton and Williams (1996) relate efficiency to technological problem-solving design as, “the suitability of the design outcome compared with the time and effort put into the design process” (p. 15). Denton and Williams (1996) highlighted the importance of efficiency in education and problem-solving design by emphasizing the potential opportunity to enhance and develop solutions. They wrote, “If we are efficient, then more time can be spent developing the design and the effectiveness can be improved. In school, time is generally limited, and in the commercial context, time is money” (Denton & Williams, 1996, p. 15-16). Efficiency has been portrayed here as a

valuable instructional strategy employed to enhance available time thus increasing problem-solving practice and higher order thinking skills.

“Issues related to problem solving and strategies for helping students learn how to solve problems in efficient and creative ways are a key element [sic] in several recent school reform initiatives” (Hill & Wicklein, 1998, p. 1). The importance of problem-solving is stressed in the national standards established for science (AAAS, 1990), mathematics (National Council of Teachers of Mathematics, 1989), and *Standards for Technological Literacy* (ITEA, 2000). Discussion concerning the importance of problem-solving has ensued in science, mathematics, and technology education, but research in promoting the enhancement of technological problem-solving abilities and solution efficiency has received minimal discourse. “There has been little if any research into the nature of task oriented technological problem-solving” (Watts, 1991, p. 132).

The lack of problem-solving research has left educators to implement methods based on intuition and leaves many unanswered questions. For example, educators often present some form of example before enlisting students to begin a problem-solving assignment. But, the use of examples raises the following questions among many: Why do educators provide examples for students? Is this done to provide clarity, increase the efficiency of student work, or for other purposes? Does the presence of examples help or hinder student problem-solving? Is showing a successful example beneficial to students if they cannot copy the example? Can they transfer ideas from the example to help solve a problem or is the example irrelevant because they must find a new way to solve the problem? Is showing an unsuccessful example solution beneficial or harmful? Will students use some elements of the unsuccessful example solution and disregard others? Do students learn from others’ mistakes or is an unsuccessful example solution merely irrelevant information?

The purpose of this study was to investigate the usefulness of different example solutions in enhancing the problem-solving efficiency of middle school students working on open-ended technological problem-solving assignments. This study was designed to determine if successful example solutions, unsuccessful example solutions, or no example solutions enhances technological problem-solving efficiency for middle school students.

## **Research Hypotheses**

Two hypotheses were examined:

H1: Successful example solutions and unsuccessful example solutions influence technological problem-solving efficiency.

H2: Successful example solutions will enhance technological problem-solving efficiency more than unsuccessful example solutions, which in turn, will enhance technological problem-solving efficiency more than no example solutions.

## Delimitations

Delimitations that narrowed the scope of this study include:

1. The participant pool was selected from 7<sup>th</sup> and 8<sup>th</sup> grade students from one middle school in the southwest region of Virginia.
2. Participants were selected from technology education classes.

## Definitions of Terms

The following definitions were assigned to the terms in this study:

<b>Cognitive load</b>	Working-memory load (Tuovinen & Sweller, 1999).
<b>Cognitive load theory</b>	“Cognitive load theory claims that an optimal use of working memory requires a maximum number of mental operations that directly contribute to the learning process and a minimum number of operations that do not contribute to the learning process” (Van Gerven et al., 2002, p. 88). This process is promoted through the use of schema construction and suitable levels of cognitive load (Kirshner, 2002; Sweller, Van Merriënboer, & Paas, 1998).
<b>Efficiency</b>	“Relates to the suitability of the design outcome compared with the time and effort put into the design process” (Denton & Williams, 1996, p. 15).
<b>Extraneous cognitive load</b>	Information that does not contribute to the learning process (Sweller, Van Merriënboer, & Paas, 1998).
<b>Germane cognitive load</b>	Information that relates closely or shares a connection with the subject area (Van Gerven, Paas, Van Merriënboer, & Schmidt, 2002).
<b>Intrinsic cognitive load</b>	“The inherent aspects of the mental task that must be understood for the learner to be able to carry out the task” (Tuovinen & Sweller, 1999, p. 335).
<b>Open-ended problem</b>	Problems with multiple solutions (Watts, 1991).
<b>Problem-solving</b>	“A process of seeking feasible solutions to a problem” (Hatch, 1988, p. 89).
<b>Successful example</b>	Display of a method that succeeded in meeting the criteria to solve the problem encountered.

<b>Technological problem-solving</b>	Problem-solving that primarily includes design, research and development, troubleshooting, invention and innovation, and experimentation (ITEA, 2000).
<b>Unsuccessful example</b>	Display of a method that did not succeed in meeting the criteria to solve the problem encountered. Contains one characteristic of height, length, or width that is different from a successful example solution and prevents the example from being successful.
<b>Worked example</b>	“ Comprises the specification of a problem, the solution steps, and the final solution itself” (Renkl et al., 1998, p. 90).

## Chapter 2. Review of Literature

### Overview

The *Standards for Technological Literacy, National Science Education Standards*, and *Curriculum and Evaluation Standards for School Mathematics* promote the use of problem-solving skills throughout the K-12 curriculum framework in order to prepare students to live in a technological world (AAAS, 1990; ITEA, 2000; National Council of Teachers of Mathematics, 1989; NRC, 1996). According to the American Association for the Advancement of Science (1993), “preparing students to become effective problem-solvers, alone and in concert with others, is a major purpose of schooling” (p. 282). Ultimately, the objective of problem-solving in the school environment is to make curricular information relevant and applicable to real world experiences (Watts, 1991). The ability for students to become effective real world problem solvers requires and stimulates the development of higher order thinking skills.

Effective problem-solving requires students to use skills such as application, analysis, and synthesis which are not necessary in rote memorization and item recall tests. Bloom, Englehart, Furst, Hill, and Krathwohl (1956) defined six levels constituting a taxonomy of educational objectives. These levels include knowledge, comprehension, application, analysis, synthesis, and evaluation. Higher order thinking skills such as analysis, synthesis, and evaluation require learners to process large volumes of information in order to analyze and solve problems. Processing large quantities of information during higher order thinking skills consumes working memory capacity and must be counteracted with strategies that promote the efficient use of limited working memory. The cognitive demands of problem-solving coupled with working memory limitations create instructional challenges for educators.

As individuals analyze large quantities of information, they are forced to select relevant information while disregarding information that is irrelevant. Cognitive overload can occur if an individual’s working memory limit is surpassed during information processing. Instructors should be aware of working memory limits when designing classroom activities. Miller (1956) found that working memory is capable of holding approximately seven (plus or minus two) items at one time. After reaching this threshold, an individual is unlikely to absorb any more information, and working memory overload occurs.

According to Kirshner (2002), working memory capacity can be enhanced by combining elements of information into one cognitive schema. For example, when trying to remember the following elements: a ruler, a notebook, paper, a pencil, some money, and your lunch, it is more difficult to remember each element individually than it is to combine all of the elements into a schema of what should go into your backpack. Studies performed by Ward and Sweller (1990), Sweller and Cooper (1985), and Zhu and Simon (1987) have revealed improvements in schema construction and problem-solving efficiency when worked examples were displayed during problem-solving tasks.

The presentation of worked examples in geometric problems, statistical problems, factoring quadratic equations, algebra transformation problems, computer programming, physics, science, and electronic wiring diagrams during problem-solving has been explored and the research data provides promising results. Results of worked example research include optimizing working memory capacity, facilitating schema construction and schema automation, and enhancing problem-solving efficiency (Sweller & Chandler, 1994; Tuovinen & Sweller, 1999).

Enhancing problem-solving efficiency is important because problem-solving is a process that is not generally performed rapidly by novices. Moreover, time restrictions encountered in educational settings typically prohibit in-depth study or extensive exploration of problem solutions and solution refinement. As Watts pointed out (1991), “most school sessions take place in a slot lasting an hour or so...students do not do research, or, more likely, they rely on their own knowledge as it is at the time. Once started on a solution, they seldom make and test several prototypes (if any)- they go all out for the full-blown resolution in one go” (p. 37). Developing efficient problem-solving and schema acquisition strategies is imperative in order to enhance problem-solving tasks and to enable students to improve problem solutions.

Problem-solving strategies designed with a step-by-step process have been developed in several fields including technology, science, mathematics, and engineering. Although problem-solving strategies and procedures have been developed in multiple fields, optimal methods for presenting problems for instructional purposes are still being evaluated.

## **Problem-Solving**

Individuals in every occupation encounter problems that must be recognized and solved. Problem-solving is described by Renkl (1997) as achieving new understanding in unfamiliar contexts. Hatch (1988) defined problem-solving as “a process of seeking feasible solutions to a problem” (p. 89).

*Problem groups.* Problems can be categorized into two groups, well-defined problems and ill-defined problems. A well-defined problem has clearly stated goals and often contains information required to solve the problem. Well-defined problems are frequently solvable with an algorithm and often have one correct solution (Ormrod, 1999). Students frequently encounter well-defined problems in mathematics. For example, students might use an algorithm to solve a long division problem. In contrast, ill-defined problems are most often encountered in real life situations and do not have algorithmic solutions. Ill-defined problems can typically be solved with multiple solutions and are often associated with vague goals and limited information (Ormrod, 1999). Ill-defined problems are also sometimes referred to as open-ended problems. For example, a student might encounter an open-ended problem when trying to design an aerobatic kite. There are many potential solutions to this problem and one solution is not necessarily better than another.

*Problem-solving formats.* Creating solutions for ill-defined problems has led to the development of various problem-solving strategies in mathematics, technology, science, and engineering. Wallas (1926) recognized four steps in problem-solving:

1. Preparation
2. Incubation
3. Inspiration
4. Verification

Polya (1957) also constructed a four-part strategy for problem-solving in mathematics that included the following processes:

1. Understanding the problem
2. Devising a plan for solving the problem
3. Carrying out the plan
4. Looking back

Waetgen (1989) described six stages involved in technological problem-solving:

1. Recognizing the problem, situation, and constraints
2. Considering multiple solutions and collecting information
3. Hypothesizing about the best solution
4. Building solutions
5. Re-creating failing hypothesis
6. Deciding whether or not the objectives for the solution were met

Watts (1991) described the following science problem-solving steps:

1. Formulating the problem
2. Reformulating the problem
3. Generating ideas
4. Graphic time (drawing diagrams or forming mental representations)
5. Researching stage

6. Experimenting, the design stage, solving the problem

The International Technology Education Association (2000) defined problem solving in their document, *Standards for Technological Literacy*, as a four-part process that consists of:

1. Understanding the problem
2. Devising a plan
3. Carrying out the plan
4. Evaluating the plan in order to solve a problem or meet a need or want

The problem-solving and design process implemented in the field of engineering as identified by the International Technology Education Association (2000) consists of:

1. Identifying the problem
2. Generating ideas
3. Identifying design requirements
4. Exploring potential solutions
5. Developing and testing models and prototypes
6. Refining solutions
7. Constructing and testing product for effectiveness and necessary changes
8. Production of product

Halfin (1973) developed a list of seventeen operations used by technologists to solve technological problems:

1. Defining the problem or opportunity operationally
2. Observing
3. Analyzing
4. Visualizing
5. Computing
6. Communicating
7. Measuring

8. Predicting
9. Questioning and hypothesizing
10. Interpreting data
11. Constructing models and prototypes
12. Experimenting
13. Testing
14. Designing
15. Modeling
16. Creating
17. Managing

Analysis of the separate problem-solving methods designated by mathematics, technology, science, and engineering, reveal several problem-solving processes that are common to all of the categories. These include:

1. Recognition and understanding of the problem
2. Development of a solution
3. Solving the problem
4. Evaluating the solution

Although many similarities are apparent among the diverse subject areas presented above, differences in problem-solving methodologies are also evident. Engineering and technological problem-solving is focused on developing new products and tools using natural and human made resources. Problem-solving methods in engineering and technology promote the design and construction of multiple solutions and the development of prototypes and models. The construction of physical models is intended to provide opportunities to reflect, test, and refine the ultimate design prior to establishing a final solution. A large quantity of time and effort is devoted to these processes during engineering and technological problem-solving. Mathematical problem-solving may also involve the construction of models (mathematical) to search for optimum solution modes, but this is not often the case in general mathematics. Math problems are typically solved using algorithmic procedures where the solution format is performed by a number of prescribed steps in order to obtain the solution. Solution procedures are generally not tested and refined prior to selecting the most appropriate algorithm. Problem-solving in science also has characteristics that differ from mathematics, engineering and technology. Science seeks to gain knowledge about the

natural world. Problem-solving in science is based on systematic testing of research hypotheses for the generation of new knowledge, not products.

The fields of mathematics, engineering, technology, and science have each established some form of problem-solving procedures, but they are seldom followed in a numerical, step-by-step fashion as listed above. The use of problem-solving steps is suitable for discussion or academic assessment, but rarely are specific steps followed in problem-solving practice. “Problem-solving models listing skills arranged in some sequence or a series of stages may not provide an accurate picture of how children tackle classroom problem-solving” (Gustafson, Rowell, & Guilbert, 2000, p.18). Individuals tend to randomly bounce between different steps versus progressing numerically from step one to step two and so forth. Williams (2000) refers to these as problem-solving “aspects” rather than steps due to the inference of sequential order associated with the latter. As noted by Watts (1991), “categorizing problem solving methods into idealized steps is a means of organizing student thinking and instructional format but problem-solving is not likely to occur in any particular order, method, nor technique” (p. 29). Students faced with a problem-solving task often solve problems using their own methodology, individual interest and background experience (Custer & Wright, 2002).

*Problem-solving experience.* Parkinson (2001) explored past experience as it related to problem-solving activities. Participants included 77 first year students enrolled in a three-year teacher education program and were asked to construct paper bridges capable of supporting 50 grams and spanning 40 centimeters. Parkinson (2001) found that past experience, misconceptions, and knowledge base heavily influenced problem-solving understanding of material capabilities, forces, and structural strength. Students had a difficult time differentiating between the terms “strong” and “force” and commonly referred to the term “strong” as a description to validate component positioning on the bridge. Students described the construction material, a sheet of paper, as a weak material due to the tendency to bend during compression and described their manipulation of the paper as giving it strength. Parkinson (2001) surmised that pre-existing ideas of how things function are influenced by how objects “look” with minimal consideration or knowledge of the forces acting upon them. This appears to bolster the idea that problem-solving understanding and solution methodologies are heavily influenced by past experience, knowledge, and individual problem-solving processes.

Williams (2000) explained that, generally, student problem-solving processes are very convoluted and different during each design task. Students adapt to the problem situation and prefer their own methodology. “For example in the common requirement to sketch four design alternatives to a problem or brief, a student is often interested in only one, and does the others just to satisfy the teacher” (Williams, 2000, p. 53).

Along with individual differences influencing problem-solving, age also impacts solution strategies. Studies investigating the relationship between age and problem-solving strategies reveal that hypothesis testing tends to begin around the second grade (Eimas, 1969; Gholson, 1980; Gholson, Levine, & Phillips, 1972; Mosher & Hornsby, 1966). These studies suggest that younger children tend to select a hypothesis through trial and error, and remain fixed on the hypothesis until it is disconfirmed by each piece

of evidence. Older children develop more efficient strategies by eliminating more than one possibility at a time as evidence is revealed.

Problem-solving instruction and strategies are ultimately tied to student experience, knowledge, age, and their ability to assess and understand information. Promoting these skills enhances future problem-solving success. It is the instructors' obligation to present suitable amounts of information in order for students to comprehend, absorb, and maintain appropriate cognitive load throughout the problem-solving process.

## **Cognitive Load**

Instructional format that disregards limited working memory capacity is often the cause of cognitive overload (Bannert, 2002). Instructional objectives concerning cognitive load should consist of increasing the amount of relevant information (germane cognitive load) and decreasing the amount of irrelevant information (extraneous cognitive load) in order to enhance schema construction and problem solving effectiveness. According to Bannert (2002), maintaining an appropriate level of cognitive load is dependent upon the summation of three factors, intrinsic cognitive load, extrinsic cognitive load, and germane cognitive load.

*Intrinsic cognitive load.* Different levels of subject matter have varying degrees of inherent difficulty. This creates differences in cognitive load levels for learners. For example, understanding how the human heart functions is easier and less complex than understanding the multiple functions of the human endocrine system. Complex and interconnected information is less easily understood than simple isolated information, and places a heavy cognitive load on the learner. The complexity of the subject matter induces intrinsic cognitive load (Sweller & Chandler, 1994). Bannert (2002) suggested that high intrinsic cognitive load is imposed by the nature of the material, the amount of element interactivity, the method in which the material is presented, and lack of understanding of the material.

*Extraneous cognitive load.* Extraneous cognitive load is defined as information that does not contribute to the learning process or information not directly related to the information to be learned (Sweller, Van Merriënboer, & Paas, 1998; Van Merriënboer, Schuurman, Crook, & Paas, 2002). Specific instructional techniques and poorly designed instructional materials carry high extraneous cognitive load (Bannert, 2002). These include the use of means-ends analysis (breaking a problem into sub-goals and solving each one) during problem-solving experiments, mentally integrating multiple sources of information that are physically separated, and working with redundant information (Van Merriënboer et al., 2002). One example of extraneous cognitive load on a student is as follows. Imagine that a fourth grade student is learning how to solve a mathematical word problem involving addition skills. If the word problem contains redundant information (such as repeating the variables involved), the problem requires the student to devote more time to information contained within the problem and less time focusing on how to solve the problem using addition skills. The nature of how the problem was written

(containing redundant information) increases extraneous cognitive load on the student and hinders the mathematical learning process.

Research concerning cognitive load instruction stresses the importance of reducing the amount of extraneous cognitive load, information that is not relevant to the learned information, and increasing the amount of germane cognitive load, information that is relevant to the information being learned (Van Gerven, Paas, Van Merriënboer, & Schmidt, 2002; Van Merriënboer et al., 2002).

*Germane cognitive load.* Germane cognitive load is defined as information that relates closely or shares a connection with the subject area directly relevant for learning (Van Gerven et al., 2002; Van Merriënboer et al., 2002). Germane cognitive load is necessary for individuals to construct and store new schemas required for long-term memory storage (Kirshner, 2002). Bannert (2002) clarifies germane cognitive load by classifying it as the utilization of free working memory for the development of schema construction and automation.

Germane cognitive load can be enhanced by providing opportunities for learners to expand their understanding of information through in-depth study and exploration (Bannert, 2002). Van Merriënboer et al. (2002) explored the effects of redirecting learners' attention from extraneous cognitive load to germane cognitive load and found that learning efficiency improved. Instructional methods seeking to increase germane cognitive load while decreasing extrinsic cognitive load have been explored. Results indicate that the implementation of completion problems and worked examples has positive results on cognitive load (Kalyuga, Chandler, Tuovinen, and Sweller, 2001; Paas & Van Merriënboer, 1994; Sweller, 1988; Sweller & Cooper, 1985; Tuovinen & Sweller, 1999; and Ward & Sweller, 1990).

Evidence suggests that varying degrees of intrinsic, extraneous, and germane cognitive load impact mental load and ultimately influence schema construction, transfer, and learning efficiency (Bannert, 2002; Sweller & Chandler, 1994; Tuovinen & Sweller, 1999; Van Gerven et al., 2002; Van Merriënboer et al., 2002). Exploring the influences of cognitive load on learning has developed into a theory referred to as cognitive load theory. Cognitive load theory provides instructional guidelines aimed to improve learning efficiency, schema acquisition, and transfer (Van Merriënboer et al., 2002).

## **Cognitive Load Theory**

The human information processing system is limited by cognitive factors (Ormrod, 1999). Cognitive load theory implies that human limitations concerned with processing information must be considered when designing lessons and instructional strategies (Sweller & Chandler, 1994). According to Van Gerven et al. (2002), "cognitive load theory claims that an optimal use of working memory requires a maximum number of mental operations that directly contribute to the learning process and a minimum number of operations that do not contribute to the learning process" (p. 88).

When faced with high cognitive load during higher-order thinking activities, such as analysis, synthesis, and evaluation (Bloom et al., 1956), cognitive function relies on four aspects of cognitive load. These aspects include the use of a limited short-term memory, an unlimited long-term memory, the creation of schemas, and the automation of learned schemas (Sweller & Chandler, 1994; Tuovinen & Sweller, 1999). These four processes will be discussed next.

*Working memory.* Cognitive load theory prescribes focusing a learner's working memory on relevant information. According to Van Gerven et al. (2002), "training should be designed in such a way that the learner is encouraged to spend as much working-memory capacity as possible to relevant operations and is not forced to waste resources on operations that are not relevant or even detrimental to the learning process" (p. 88).

Working memory is used for all conscious activities (Kirshner, 2002). Other memory, content and function, is not available until an individual brings it into working memory (Kirshner, 2002). The working memory capacity of individuals is limited to approximately seven elements at any one time (Miller, 1956), and memory limitations decrease the effectiveness of incorporating multiple elements of information (Sweller & Chandler, 1994). However, working memory limitations can be enhanced by incorporating multiple elements into one cognitive schema. As described by Kirshner (2002), an entire schema can be imported into working memory as one entity containing an abundance of information that would otherwise overwhelm working memory capacity.

*Long-term memory.* Long-term memory must also be considered when working memory is at issue. Long-term memory capacity is assumed to be unlimited as opposed to the very limited nature of short term/working memory (Berk, 2001). Long-term memory storage is thought to have two characteristics. The first characteristic concerns the transfer of information from working memory to long-term memory. Working memory is typically not brought into long-term memory as an exact copy. Memory established in long-term memory is normally an abbreviated version of what was experienced in working memory (Ormrod, 1999). The second characteristic of long-term memory is the way information is sorted and stored. Long-term memory is typically sorted and stored with similar information already existing in an individual's memory (Ormrod, 1999). New information is organized into associated units directly or indirectly connected to existing memories (Ormrod, 1999). Associated units of long-term memory are often arranged in the human brain in packages or groupings called schemas (Ormrod, 1999). For example, an individual may have grouped previously learned knowledge into a schema for how to resolve mathematic problems dealing with multiplication. In order to solve a multiplication problem, the person searches for correct solutions within the established schema, thus retrieving a long-term memory.

*Schema construction.* Schemas are domain-specific knowledge structures held in long-term memory and organized into specific chunks of knowledge (Kalyuga et al., 2001; Ormrod, 1999; Sweller & Chandler, 1994). Schema development is a valuable learning mechanism during cognitive activities requiring higher order thinking skills. Schemas are created to circumvent short-term memory limitations and to enhance effective long-term memory (Sweller & Chandler, 1994). According to Sweller and

Chandler (1994, p. 187), “schemas reduce cognitive load by permitting us to ignore most of the information impinging on our senses.”

As new information is presented, individuals re-organize and sort it using their own methodology. The mental re-organization of information creates schemas based on the new information, combined with previous knowledge and experience. Existing schemas then provide a link for new sensory input and information. The links enable new information to be incorporated into current schemas existing in long-term memory (Valcke, 2002). Schemas are malleable and are re-formed as individuals gain knowledge and experiences expand. For example, a schema developed concerning how to drive in the snow changes as a driver spends more time driving in the snow and has more experience with ice and other difficult road conditions.

Schema construction and layout varies between individuals. Individuals who possess expertise in a particular subject area are likely to have a more developed schema as opposed to those with very limited expertise in the same subject. As individuals gain experience and expertise, they construct increasingly more elaborate schemas that expand with their knowledge base (Quilici & Mayer, 1996). Elaborate schemas allow individuals to view a problem from multiple angles and to develop problem-solving strategies based on previous experience.

Individuals who are experts in a particular field develop schemas that allow them to decipher information and make appropriate decisions faster than novices who possess minimal schema development. For example, in DeGroot’s (1965) classic study of chess skills, he compared the general memory ability of expert and novice chess players and found no difference between the two groups. However, when he compared the ability to memorize specific chess patterns that would be encountered during a chess match, the experts had better recall of chess piece placement on the board than the novice players. The experts used their elaborate schemas involving chess positions to recall the patterns of the chess pieces. The ability of experts to solve problems (win the chess game) is enhanced by the acquisition of schemas that free cognitive resources to be used to interpret solutions versus wasting cognitive resources attempting to understand the problem.

According to Sweller (1994, p. 297) “knowledge and intellectual skill based on knowledge is heavily dependent on schema acquisition. Schemas provide the basic unit of knowledge and through their operation can explain a substantial proportion of our learning-mediated intellectual performance.” Over time, the accumulation of knowledge, experience, and continuous use of acquired schemas results in schema automation.

*Schema automation.* As stated above, individuals with high levels of experience and knowledge perform certain operations with minimal thought or difficulty when compared to novices. A few examples of schema automation include professional musicians playing instruments, engineers performing mathematical calculations, and master chess players deciding where to position a chess piece.

Material that has been learned well can be automatically processed and attention directed towards other objectives (Sweller, 1994). Cognitive processes used over time, such as reading music, can eventually be performed without conscious thought, a process referred to as schema automation. Automation of a schema allows an individual to perform a task with minimal or no aid from working memory, thus bypassing working memory and conscious thought (Sweller & Chandler, 1994). Schema automation provides a distinct advantage to individuals' ability to solve problems, and permits them to solve problems with minimal effort (Kalyuga et al., 2001).

Schema development can potentially produce schema automation, but initially controlled schema processing is likely to occur. Controlled processing of information requires an individual to mentally process information and consciously attend to it (Sweller, 1994). For example, someone learning how to play a stringed instrument might focus on hand positioning while attempting to learn a song. This situation requires the individual to consciously focus on hand position in order to produce the correct sounds. As Sweller (1994) stated, "any cognitive activity that requires deliberate thought is being processed in a controlled fashion" (p. 297). Contrarily, using the same example, an accomplished musician does not always need to focus attention on hand position. An accomplished musician can play an instrument with little or no conscious effort. According to Sweller (1994), without schema automation individual performance tends to be slower, clumsier, and mistakes occur more readily.

Schemas can be created and eventually become automated to solve problems, but an association must exist in order to connect existing knowledge with the solution to a problem. As Houston (1991) pointed out, "simple knowledge about a problem, without the realization of the relevance of that knowledge, is not enough to aid problem solution" (p. 379). The association of knowledge and problem solutions will be discussed in the next section concerning transfer.

## **Transfer**

The acquisition of knowledge, schema construction, and automation would have limited use if individuals were unable to transfer this information to other situations. According to Renkl (1997), applying knowledge, performance, or skill acquired in one situation to new instances or problems is a matter of transfer. Houston (1991) defined transfer as the impact of prior learning on subsequent performance. Transfer of knowledge allows individuals to apply experience from one situation to another. Without the occurrence of transfer, all learning would ultimately be situationally specific. Every new problem encountered would need to be exactly like a previously solved problem and people would have to learn how to behave in every new circumstance from scratch, spending most of their time in trial and error learning (Ormrod, 1999).

Transfer has been categorized into multiple types; four will be discussed in the following section. They include, general transfer, specific transfer, positive transfer, and negative transfer.

*General transfer.* According to Ormrod (1999), in general transfer “the original task and the transfer task are different in content” (p. 350). General transfer involves applying information learned to new problems under dissimilar circumstances. For example, learning how to study efficiently for a biology class may help a student perform well in an English course (Ormrod, 1999).

*Specific transfer.* Specific transfer occurs when “the original learning task and the transfer task overlap in content” (Ormrod, 1999, p. 350). For example, possessing knowledge of how the human circulatory system functions aids an anatomy student in understanding how a bird’s circulatory system functions. A second example of specific transfer is learning how to use a tape measure facilitates using a ruler to measure an object.

*Positive transfer.* Positive transfer occurs “when learning in one situation facilitates learning or performance in another situation” (Ormrod, 1999, p. 348). An example of positive transfer is applying addition rules from mathematics to balance the family checkbook (Ormrod, 1999). Also, the knowledge of Spanish should have a positive transfer when learning how to speak similar languages such as French and Italian (Houston, 1991). Moreover, experience driving an automobile may aid an individual in learning how to steer a boat.

*Negative transfer.* Negative transfer occurs “when something learned in one situation hinders a person’s ability to learn or perform in another situation” (Ormrod, 1999, p. 349). Some examples of negative transfer include poor study skills in high school that may carry over into college even though an individual is attempting to change behavior (Houston, 1991). Also, learning information about World War I may create uncertainty when recalling facts from World War II (Ormrod, 1999).

Transfer goals associated with educational problem-solving include promoting the use of information and skills learned in the classroom to real-world situations. Transfer in traditional instruction is often restricted to problems that are very similar to those used during instruction. However, schemas that are learned in the classroom can provide the foundation for transfer in new situations (Paas, 1992).

Experimentation concerning transfer and worked examples has suggested strategies to enhance problem-solving and transfer. Paas (1992) compared the effectiveness of using different instructional strategies to promote the transfer of basic statistical problem solving skills involving measures of central tendency. Instructional strategies included the use of conventional strategy (the presentation of conventional problems, the description of the initial problem state and a goal state), worked strategy (use of worked-out problems), and completion strategy (partly worked-out problems). Results indicated that the worked strategy and completion strategy more effectively promoted transfer when solving statistical problems versus the conventional strategy. Worked problems and partly worked problems led to decreased transfer effort and increased performance. Paas (1992) indicated that “the results of this study support the hypothesis that a cognitive structure resulting from instruction emphasizing practice with partly or completely worked problems is a more efficient knowledge base for solving

transfer problems than one resulting from instruction emphasizing conventional problems. Training with partly or completely worked-out problems leads to less effort and better transfer performance. Moreover, time on training was shortest in the worked condition” (Paas, 1992, p. 435).

In domains where instructional time and cognitive resources are limited, such as the school environment, instructional time devoted to transfer should implement the use of worked-out examples (Paas, 1992). Paas (1992) stated, “such instruction can direct attention to goal-relevant task aspects, thus preventing students from generating incorrect solutions. Consequently, there is no waste of cognitive resources, and the organization of knowledge in memory is fostered” (p. 435).

## **Worked Examples**

According to Renkl, Stark, Gruber, and Mandl (1998), “worked examples comprise the specification of a problem, the solution steps, and the final solution itself” (p. 90). Students use worked examples as models to establish solutions for problems (Renkl, et al., 1998). The use of worked examples and their influences on problem-solving have been investigated by many researchers.

Learning from worked examples is similar to the process of learning-by-doing. A student involved in the process of learning-by-doing works through a problem and creates a solution while the instructor provides feedback as to whether or not the solution is accurate (Zhu & Simon, 1987). The instructor confirms successful and unsuccessful attempts and the student is able to use the results to work through similar problems using the completed solution as a worked example (Zhu & Simon, 1987). The learning-by-doing method has an extended, effective history in discovery learning and child centered education, but is very time consuming (Zhu & Simon, 1987). Time restrictions found in educational settings need to be considered when discovery learning, and learning-by-doing are implemented. With limited instructional time available, substituting the initial learning-by-doing procedure with worked examples may save time resources by providing a preliminary solution to the problem-solving task. Based on cognitive load theory, the use of worked examples should be more effective when compared to conventional problem-solving (the description of the initial problem state and a goal state) due to the reduction of extraneous cognitive load while promoting the amount of germane cognitive load (Bannert, 2002).

Conventional problems require learners to use a high cognitive load method, means-ends analysis, requiring learners to focus on multiple aspects of the problem (Ward & Sweller, 1990). According to Sweller (1988), aspects of means-ends analysis include:

1. The goal
2. The givens
3. The differences and relationships between the goals and the givens

4. Any subgoals established related to the goal, givens, and additional subgoals

As opposed to means-ends analysis, worked examples lead to an efficient creation of cognitive schemas, by concentrating attention on problem operations (how to develop a solution), versus goals and subgoals (Van Gerven, Paas, Van Merriënboer, & Schmidt, 2002).

*Worked example solution experiments.* To determine if worked examples were feasible for instructional purposes, Zhu and Simon (1987) studied their effectiveness in mathematics. Their initial experiment, conducted with thirteen year olds enrolled in an algebra class, explored the possibility of learning to factor quadratic equations from worked examples. Zhu and Simon (1987) found that students were capable of learning how to factor quadratic equations from worked examples. The authors conducted additional worked example experiments concerning factoring, exponents, geometry, ratios, and fractions. They compared the performance of the experimental group that learned through worked examples to a control group that learned through traditional lecture instruction. Zhu and Simon (1987) concluded that “the experimental groups performed as well as, or slightly better than, the control groups on all tasks, and required substantially less time to learn the tasks” (p. 158).

Sweller and Cooper (1985) conducted experiments to determine if worked examples facilitated mathematical problem-solving. In their study, worked examples decreased the amount of processing time compared to conventional problems, and participants solved algebra problems faster when viewing worked examples. Sweller and Cooper (1985) concluded that schema acquisition used for problem-solving is faster when using worked examples as opposed to conventional problems. Sweller and Cooper (1985) suggested that by implementing worked examples, learners may focus their limited cognitive resources towards the associated moves of solving the problem and away from the problem goal.

However, Tarmizi and Sweller (1988) suggested that worked examples may slow problem-solving when the examples are structured in a manner that increases cognitive load. Tarmizi and Sweller used means-end analysis to compare conventional problem-solving methods to worked examples and guided instruction. The authors suggested that guided instruction has two consequences, “The intended consequence is to appropriately direct the thoughts and actions of students. Its unintended consequence is likely to be necessarily split attention between several sources of information and consequently increase cognitive load to the point where learning is slow and cumbersome” (p. 426). Timed Geometry tests were conducted to examine differences among the formats using 33 high school mathematics students. Tarmizi and Sweller’s results suggest that in many instances, worked examples will cause heavy cognitive load similar to conventional problems. In certain circumstances, cognitive load imposed by multiple sources of information or the necessity to integrate additional information nullifies the benefits of worked examples (Tarmizi & Sweller, 1988).

Ward and Sweller (1990) explored the effectiveness of worked examples in enhancing science instruction. Participants included high school students from Sydney,

Australia and experiments were conducted “within a routine teaching context” (p. 36). Ward and Sweller found that if worked examples were structured appropriately (a presentation format that reduced cognitive load and promoted schema acquisition) they facilitated problem-solving of lens and mirror ray problems, simple linear motion problems, projectile motion problems, and two dimensional collision problems.

Tuovinen and Sweller (1999) compared discovery learning to worked example learning practices. Discovery learning provides students the opportunity to explore concepts and procedures that would normally be communicated by an instructor during direct instruction (Tuovinen & Sweller, 1999). Participants included thirty-two education students studying to become secondary teachers in Australia. Students were tested on their ability to use HyperCard, a computer database program. This study revealed that students with no experience using HyperCard benefited from the worked examples and exhibited improved efficiency. However, students with some experience did not show any difference in efficiency when using worked examples compared to discovery learning. Tuovinen and Sweller (1999) suggested that “the effectiveness of worked examples clearly depends on the previous domain knowledge of the students. If they have sufficient domain knowledge, the format of practice is irrelevant, and discovery or exploration practice is at least as good, or maybe even better, than worked examples practice” (p. 340).

Kalyuga, Chandler, Touvinen, and Sweller (2001) also studied the impact of prior domain knowledge and levels of instructional guidance on a series of problem-solving tasks using worked examples. Participants included twenty-four mechanical trade apprentices from two Australian manufacturing companies. The apprentices were tested on their ability to write programs for programmable logic controller relay circuits. Researchers found that apprentices with less experience benefited from the use of worked examples by indicating a decreased mental load (measured by subjective ratings of task difficulty on a nine point likert scale) when compared to individuals who worked in the problem-solving group with no examples (Kalyuga, Chandler, Touvinen, & Sweller, 2001). It was also discovered that as experience level and domain knowledge increased, the benefit of worked examples vanished and problem-solving appeared to be as or more effective in writing programs for relay circuits.

Paas and Van Merriënboer (1994) investigated geometric problem-solving skills associated with computer numerically controlled (CNC) machinery programming. Specifically, participants were tested on “geometric theories and principles to construct right-angled triangles in a two-dimensional space, and to recognize and apply trigonometric ratios and Pythagorean principles to these triangles” (Paas & Van Merriënboer, 1994, p. 125). The researchers studied the effects of worked example conditions versus conventional problem-solving on transfer performance, speed, and mental effort. Participants ranged in age from nineteen to twenty-three years and were obtained from a technical school in The Netherlands. Instruction was presented using two methods. The worked example group received problems presented with solutions, and the conventional group was only presented with the problems. The results indicated that instruction using worked examples led to better transfer performance, decreased

instructional time, and less mental effort when compared to the conventional problem-solving group.

Based on research exploring worked examples and problem-solving, a pattern has emerged concerning the use of worked examples (Kalyuga et al., 2001).

1. Learners who are inexperienced or novices in a subject domain benefit from guided direct instruction by exhibiting decreased mental load ratings (Kalyuga et al., 2001).
2. The amount of guidance necessary decreases as subject material becomes easier and/or experience of the learner increases (Kalyuga et al., 2001).
3. Worked examples are best suited for novices and should be gradually removed from instruction as knowledge and understanding increases (Kalyuga et al., 2001).
4. Guidance may eventually act as a deterrent to learning as knowledge and learner understanding increase (Kalyuga et al., 2001).

When comparing conventional problem-solving/means-ends analysis to worked examples, learning differences have been found. According to studies performed by Sweller (1988), Kalyuga, Chandler, Touvinen, and Sweller (2001), Tuovinen and Sweller (1999), Paas and Van Merriënboer (1994), Sweller and Cooper (1985), and Ward and Sweller (1990), the implementation of guided instructional techniques (worked examples) promote learning and problem-solving over the use of conventional means-ends analysis. However, based on research conducted by Tarmizi and Sweller (1988), worked examples must be structured in a way that the examples do not impose heavy cognitive load and thereby nullify the beneficial aspects of worked examples. These benefits include efficient construction and acquisition of schemas, improved transfer, and enhanced problem-solving speed for inexperienced or novice learners. Researchers have explored the implementation and effectiveness of successful worked examples, but the use of unsuccessful worked examples has apparently yet to be investigated.

*Successful and unsuccessful example solution displays.* The display of successful and unsuccessful example solution images and diagrams has a long, well established history in textbooks dealing with technological subject matter such as carpentry, electronics, boat construction, and engine repair. Successful and unsuccessful examples are provided to clarify concepts and assist inexperienced individuals with technical topics not easily accomplished by text alone.

Example diagrams used in Graham and Emery (1951), *Audels Carpenters and Builders Guide # 3* provides both successful and unsuccessful methods for performing numerous home construction tasks. Diagrams displaying unsuccessful example solutions show common mistakes that an inexperienced carpenter might make and are located next to successful example diagrams. These diagrams are meant to provide assistance to the novice builder in order to prevent mistakes that lead to unsatisfactory construction practices and wasted time and resources. Tolman (1998) provided similar displays of

successful and unsuccessful examples pertaining to the construction of wooden boat components in *A Skiff for All Seasons*. Tolman (1998) provided these diagrams as guides to clarify appropriate boat construction methods that create strong joints, and structural integrity. Roth (1998) also used successful and unsuccessful examples solutions in his text, *Small Gas Engines*. Successful and unsuccessful examples in this text display and illuminate the process of preparing engine valves before installation. Roth (1998) used the examples to explain valve seating area and positioning on a gasoline engine valve face. Richter and Schwan (1992) displayed successful and unsuccessful example solutions in their technical guide for electricians. They provided diagrams that exhibited the proper and improper assembly of electrical components and the danger associated with unsuccessful installations. These four texts deal with technological problem-solving processes and concepts and implement the use of successful and unsuccessful example solutions in order to clarify concepts that are difficult to convey.

The implementation of worked example solutions has been explored in the literature and the use of unsuccessful example solutions has been implemented for many years in technological literature in subjects such as carpentry and home construction, boat construction, engine repair, and electrical wiring. Both successful and unsuccessful example solutions are intended to provide guidance and clarity in order to improve learning and understanding and enhance the problem-solving speed and accuracy of learners.

## **Problem-Solving Speed and Age**

Worked example experiments have provided evidence that demonstrates improved problem-solving speed when administered to novice learners and individuals with minimal subject knowledge (Kalyuga, Chandler, Touvinen, & Sweller, 2001; Paas & Van Merriënboer, 1994; Sweller, 1988; Sweller & Cooper, 1985; Tuovinen & Sweller, 1999; and Ward & Sweller, 1990). Moreover, researchers specifically concerned with problem-solving speed and its relationship to age have discovered that processing speed and problem-solving become faster as children age (Fry & Hale, 2000). Kail (1991) discovered a pattern of age differences when comparing the average speed of cognitive, perceptual, and motor skills comparing age groups of 8-10 year olds to 12 and 13 year olds and young adults. When compared to the average speed of young adults, children from eight to ten years old typically respond 5-6 standard deviations slower, and twelve to thirteen year olds respond one standard deviation slower than young adults.

Elliot and Murray (1977) looked at problem-solving speed and its relationship to age using 395 children ranging from ten to thirteen years old. Their experiment consisted of a block design test containing sixteen individual tasks. Children were presented with a block design diagram on a card and attempted to construct the design using a set of wooden blocks. The participants were divided into four age groups (10, 11, 12, and 13). During each problem-solving task, the experimenter decided if the solution was successful or unsuccessful and recorded the elapsed time to complete each task. Elliot and Murray concluded that, “speed, along with other cognitive abilities, increases as a function of age” (p. 57).

Hale (1990) tested the processing speed of four age groups that included 10, 12, 15, and 19 year-old participants. They were evaluated using multiple tasks assessing processing speed. The experimenter discovered that differences in processing speed did not occur between each of the four processing tasks but speed did appear to be influenced by age group. “Across all tasks, the time required by children of a particular age group was approximately proportional to the time required by the young adult group (e.g., in all conditions, 12 year olds were approximately 50% slower than young adults)” (Fry & Hale, 2000, p. 5). Based on these results, Hale proposed that processing speed is a developmental trend associated with each age group (Fry & Hale, 2000).

Kaufman (1979) explored the relationship of speed and performance to age in his study using participants ranging from six and one half years old to sixteen and one half years old. Kaufman separated the participants into eleven age groups, each one year apart. Problem-solving performance was determined by three timed tests that included block design, picture arrangement, and object assembly. Kaufman discovered that the amount of time it took for participants to answer the problems correctly was directly related to chronological age. For example, the picture arrangement task took an average of 28 seconds for six and one half year olds, 18 seconds for eleven and one half year olds, and 14 seconds for sixteen and one half year olds.

Studies exploring problem-solving speed and age have included diverse tasks and have established a consistent pattern. This pattern suggests that age differences among children and young adults limits the speed with which they are able to process information and solve problems. Processing speed is not tied to specific tasks or subject domains but appears to be dependent upon developmental change (Kail, 2000).

Based on the research conducted by Elliot and Murray (1977), Hale (1990), Kaufman (1979), and Kail (1991), age must be considered when participants are involved in problem-solving experiments exploring processing speed. As discussed in each study, participants within a similar age range should possess comparable processing speeds due to age-related developmental trends.

## **Summary of Literature Review**

Educational curriculum in science and mathematics, and *Standards for Technological Literacy*, convey the importance of problem-solving activities where students learn to transfer classroom activities to real-world experiences (AAAS, 1990; ITEA, 2000). The emphasis on problem-solving instruction and curriculum encourages the development of higher order thinking skills.

Problem-solving strategies including recognition and understanding of the problem, development of a solution, solving the problem, and evaluating the solution have been applied in various subject areas and are well established in the literature. Although problem-solving steps have been defined, optimal methods for presenting problems are currently being investigated.

When using problem-solving methodologies, the consideration of heavy cognitive load during higher order thinking must be addressed. Processing large quantities of information readily consumes working memory capacity and must be counteracted with instructional strategies that promote the efficient use of limited working memory. Cognitive load theory stresses the importance of reducing extraneous cognitive load while promoting the use of germane cognitive load. Studies concerning decreasing cognitive load have uncovered advantages associated with the use of worked examples.

Worked examples help to provide appropriate guidance on relevant tasks. When comparing conventional problem-solving to worked examples, the implementation of worked examples promotes learning. Research involving worked examples has provided evidence that demonstrates improved problem-solving speed when applied to novice learners and individuals with minimal subject knowledge. Researchers specifically concerned with problem-solving speed and its relationship to age have discovered that processing and problem-solving become faster as children develop with age.

Based on this literature review, the use of worked example solutions should enhance schema acquisition for novice learners and increase problem-solving efficiency. The implementation of unsuccessful example solutions acting as worked examples has yet to be explored. Students are rarely exposed to unsuccessful examples unless they do not succeed in the problem-solving task and produce their own unsuccessful example. If unsuccessful example solutions do prove effective for enhancing problem-solving efficiency, then instructors should explore the employment of successful and unsuccessful example solutions to promote schema acquisition, transfer, and problem-solving efficiency.

## Chapter 3. Methods and Procedures

### Overview

The purpose of this study was to investigate the usefulness of different example solutions in enhancing middle school students' problem-solving efficiency when working on open-ended technological problem-solving assignments. This chapter includes discussions of the participant pool, pilot study, research hypotheses, experimental design, construction materials, experimental setting, experimental procedures, task descriptions, diagrams, time measurement, and statistical analysis.

### Participants

In this study, seventh and eighth grade students enrolled in technology education courses were recruited as participants. Recruitment was conducted over a three-day period at the beginning of each of the participating technology classes. Participants were required to obtain parental permission in order to participate in the study and return signed forms to their instructor. Two grade levels were combined in order to increase the available population of participants. Fifty-one students participated in the study. Thirty-six participants were male and 15 were female. Thirty participants were seventh graders and 21 were eighth graders. All participants were selected from one middle school in the southwest region of Virginia.

Technology education courses at the selected institution were implemented through twelve modular instructional units focused on topics that included robotics, transportation, weather, graphic communications, electronics, manufacturing, graphics and animation, research and design, energy, power, and mechanics, bridge engineering, rocketry and space, and flight technology. Each of the experimental participants was enrolled in a technology education course at the time of the experiment and had studied most modular units prior to the experiment.

### Pilot Study

A pilot study was conducted to determine if procedural changes were necessary before implementing the main study. It was conducted at the same facility and under identical conditions as the main study. Twelve students enrolled in the main study were randomly selected as pilot study participants and tested over the duration of one school day from 8:30 am until 3:00 pm in four sessions lasting forty-five minutes each. Three participants were tested during each of the four sessions. Six seventh graders and six eighth graders participated in the pilot study (nine males and three females).

The pilot study procedures were identical to procedures developed and used in the main study (see Appendix A) with the exception of task time constraints. Available time for each problem-solving task was adjusted throughout the pilot study to provide the greatest opportunity for each participant to complete all three tasks. The pilot study was

valuable in determining the estimated time required for participants to solve each of the problem-solving tasks and determining if participants were capable of solving the problems presented. The original experimental design called for each of the three problem-solving tasks to last ten minutes. During the pilot study, it was determined that the first problem, elevated load, was more difficult and time consuming than the subsequent tasks for two reasons. First, it took time for the participants to acclimate to the available materials and learn how to manipulate them to solve the problems. Second, the majority of the participants said the initial problem was more difficult than the next two tasks. Due to supply kit acclimation and difficulty of the initial problem, the time limit given to the first assignment was expanded from ten to twelve minutes. The two remaining problem-solving time limits were maintained at the initial ten minutes time frame due to the 100% completion rates that were well under the time constraint.

An additional concern discussed prior to the pilot study was the risk that students would share their problem solutions with future participants at the conclusion of the experiment. This concern would jeopardize the experimental results of problem-solving efficiency and result in decreased solution times and similar final solutions. In contrast to this concern, problem solutions created during the pilot study were different from one another in many respects. No solutions developed throughout the day mimicked previous solutions and participants used available materials in many different ways. For example, masking tape was used by one individual to bind a number of small pieces into multiple bundles that provided enough strength for a supporting structure. Another student used masking tape as a stabilization device for small pieces by taping them onto the work surface and then used the tape to create support lines similar to ropes lines used for stability. Some participants used a small number of objects contained in the supply kit while others used many pieces to solve the problems. The wide range of creative solutions developed throughout the pilot study indicated that solutions created in the morning sessions were not shared with other participants who participated in the pilot study at the end of the day.

Focusing throughout the forty-five minute duration of the experiment was anticipated to be difficult for the age group, but the opposite was true during the pilot study. Each of the twelve participants maintained focus throughout the test and enjoyed the experience. Following the test, a majority of participants commented about how much fun they had developing solutions to the problems even though some found them to be very challenging. One student commented that she had not thought that hard before and others said that they wished they had the opportunity to do similar problem-solving tasks on a regular basis.

## **Research Hypotheses**

As stated in Chapter One, two hypotheses were developed:

H1: Successful example solutions and unsuccessful example solutions influence technological problem-solving efficiency.

H2: Successful example solutions will enhance technological problem-solving efficiency more than unsuccessful example solutions, which in turn, will enhance technological problem-solving efficiency more than no example solutions.

## Experimental Design

Each participant completed three open-ended technological problem-solving tasks that included *elevated load*, *cantilevered weight*, and *energy absorption*. The total time required to complete each of the three problem-solving tasks was measured for each participant. Table 1 depicts the experimental design.

**Table 1.**

Experimental design of the study.

	Successful Example Solutions	Unsuccessful Example Solutions	No Example Solutions (Control Group)
Random assignment	R	R	R
Treatment	X <sub>1</sub>	X <sub>1</sub>	
Observation	O <sub>1</sub>	O <sub>1</sub>	O <sub>1</sub>
Treatment	X <sub>2</sub>	X <sub>2</sub>	
Observation	O <sub>2</sub>	O <sub>2</sub>	O <sub>2</sub>
Treatment	X <sub>3</sub>	X <sub>3</sub>	
Observation	O <sub>3</sub>	O <sub>3</sub>	O <sub>3</sub>

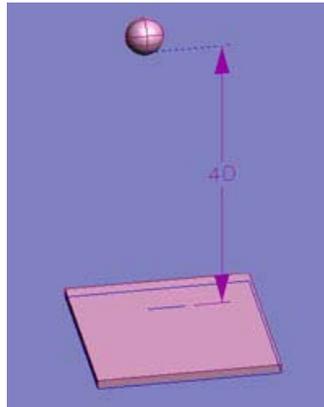
A random numbers table (Howell, 1997) was used to assign 51 participants to one of three experimental groups that included successful example solutions, unsuccessful example solutions, and no example solutions. Experimental research sample size suggested by Gall, Borg, and Gall (1996) recommended 15 subjects per group as a minimum standard. This study exceeded their sample size design recommendation with 17 participants per experimental group. Three participants assigned to the same experimental group were tested at one time.

## Problem-Solving Task Descriptions

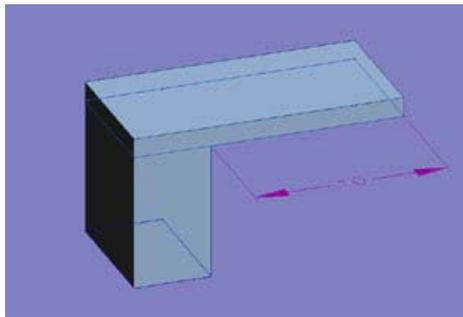
*Problem #1 Elevated Load.* The goal of the first task was to build a structure that supported a golf ball at or above 40 centimeters from the top of the table. A line drawn on each divider in black ink marked the designated 40 centimeter point so there was no need for participants to measure the specified height with a tape measure. The golf ball had to remain at the required height for at least 5 seconds to be considered a successful solution. See Figure 1 for an image of the elevated load task diagram.

*Problem #2 Cantilevered Weight.* The goal of the second task was to build a cantilevered structure with a length of 10 centimeters that supported a stack of five 5/16 inch zinc washers on the end. Each participant received a guide to determine the proper length of the cantilever made from a piece of plastic soda straw cut to 10 centimeters. The cantilevered structure needed to hold the stack of washers for at least 5 seconds to be considered a successful solution. See Figure 1 for an image of the cantilevered weight task diagram.

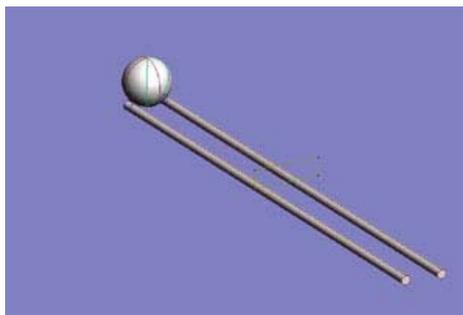
*Problem #3 Energy Absorption.* The goal of the third task was to build a structure that stopped a golf ball halfway down a designated track. See Figure 2 for an image of the track. Track dimensions consisted of a length of 47 centimeters, width of 2.54 centimeters, and inclined at an angle of 24 degrees. A 5 centimeter section of track was painted red to designate the area where the golf ball was required to stop. The golf ball had to be released from the top of the ramp and stop in some area of the red zone while remaining on the track in order to be considered a successful solution. See Figure 1 for an image of the energy absorption task diagram.



Elevated load diagram



Cantilevered weight diagram



Energy absorption diagram

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**Figure 1.** Task diagrams displayed on rear wall of dividers.



**Figure 2.** Energy absorption track.

### **Task Diagrams**

Diagrams were designed and displayed to provide visual clarification for objectives of each problem-solving task. Individual diagrams were attached to the upper rear wall of dividers while participants developed solutions to each task. Figure 1 shows the task diagrams.

### **Problem Ordering and Duration**

As seen in Table 2, each student began with the elevated load problem, followed by the cantilevered weight problem, then followed by the energy absorption problem. The elevated load problem time limit was 12 minutes while the cantilevered weight and energy absorption problems had time limits of 10 minutes.

**Table 2.**

Problem ordering and duration.

Successful	Unsuccessful	No
Example Solutions	Example Solutions	Example Solutions (Control Group)
Problem #1	Problem #1	Problem #1
Elevated load	Elevated load	Elevated load
12 minutes duration	12 minutes duration	12 minutes duration
Problem #2	Problem #2	Problem #2
Cantilevered weight	Cantilevered weight	Cantilevered weight
10 minutes duration	10 minutes duration	10 minutes duration
Problem #3	Problem #3	Problem #3
Energy absorption	Energy absorption	Energy absorption
10 minutes duration	10 minutes duration	10 minutes duration

## Construction Materials

Each participant received three identical supply kits that contained an assortment of common materials in a one-gallon plastic freezer bag. When each problem was completed, participants received a new supply kit for subsequent tasks. Supply kit contents were compiled in a manner that prevented example solutions from being mimicked. This was accomplished by selecting supply kit contents that contained dissimilar materials from example solution materials to prevent copying, but still enabled participants to solve the three tasks by using important aspects of the example solutions.

Supply kit contents included:

1. Twenty Popsicle sticks
2. Five tongue depressors

3. One plastic cup
4. Two aluminum film canisters with screw-on lids
5. Six small paper clips
6. Four .5 inch x .5 inch x 4 inches orange wooden blocks
7. Four .5 inch x .5 inch x 3.5 inches blue wooden blocks
8. Four .5 inch x .5 inch x 2 inches yellow wooden blocks
9. One golf ball
10. One .5 inch x 2.75 inches x 5.75 inches wooden block
11. One sheet of 8.5 inches x 11 inches graph paper
12. One 20 inch long piece of one inch wide masking tape
13. One 1 gallon plastic freezer bag
14. One stack of five 5/16 inch zinc washers taped together

### **Experimental Setting**

This study was performed in a middle school classroom that contained thirty student desks arranged in six rows and one 15 feet long worktable positioned against the rear wall of the room. Experimental participants worked on the table at the rear of the classroom to provide adequate room and participant spacing. Three chairs were placed at four foot intervals along the table for students to sit on while they worked through the three problem-solving tasks. The experimental setting was selected to provide an isolated area where participants would not be interrupted throughout the experimental procedure and was commonly used by students to create projects and attend lectures. See Figure 3 for a photograph of the experimental setting.



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**Figure 3.** Experimental setting and divider spacing.

## Dividers

Three dividers were constructed to allow privacy for participants and prevent solution mimicking. These freestanding dividers were designed with three walls and constructed from dark brown 1/8 inch pressboard with dimensions of 24 inches wide, 24 inches high and 20 inches deep. To eliminate the need for tape measures, a height line was placed on walls of the dividers to designate 40 centimeters required for the elevated load task. Criteria required for each problem-solving task were displayed on the rear wall of the dividers using computer aided drafting diagrams for each of the technological problem-solving tasks; elevated load, cantilevered weight, and energy absorption. Refer to Figure 1 for task diagrams. Dividers were placed on a 15 feet long worktable positioned in the rear of the classroom. Participants were seated behind their own divider and situated so that they were unable to view other students' work areas. The experimenter observed participants throughout the entire experiment and observed no discussion, peeking, or copying of design solutions from other participants.

## Procedures

Procedures implemented throughout the experiment were scripted in order to be equivalent across all conditions (see Appendix A). Following parental consent, randomly selected participants entered the experimental classroom in groups of three and were seated at one of three established workstations. Each participant was asked if they

maintained an interest in participating in the study and was given student assent forms to read and sign before beginning the study. Assent forms were collected and students were asked to turn their chairs away from the dividers and face the experimenter for an explanation of the experimental procedures. Participants were informed that the experiment would last approximately forty minutes and that each of them would build three structures in order to solve three problem-solving tasks. Participants were informed that they were required to work in isolation behind their divider, and were not allowed to view other people working or have any communication with them throughout the experiment.

Following a short discussion and display of supply kit contents, students were informed that they were not required to use all of the items provided if they did not feel they were necessary and that new supply kits would be provided for each of the three tasks.

Participants were informed about the three problem-solving tasks in the sequence of elevated load, cantilevered weight, and energy absorption. Computer aided drafting diagrams were used to clarify each task. Following the task explanations they were asked to turn their chairs around and begin task number one, elevated load. Participants assigned to successful or unsuccessful example solution groups received experimental treatments before beginning each of the three experiments in the form of one successful or unsuccessful example solution per problem-solving task.

The experimenter observed and timed the students with a stopwatch throughout the experiment. The experiment was terminated once the designated time limit had been reached for each task, or all participants had successfully completed one solution. Construction materials were placed in a collection box at the conclusion of each experiment and participants received a new supply kit for the next problem-solving task. After receiving new supply kits, problem-solving task number two, cantilevered weight, was re-explained and participants were asked to begin. At the completion of task number two, the third task, energy absorption, was explained again and students were asked to construct the final solution.

At the conclusion of the third task, participants were asked to turn their chairs around and answer a few questions (see Appendix B) concerning the difficulty of the problems and discuss any insight gained from the example solutions displayed (if they received them).

## **Examples**

Successful and unsuccessful example solutions displayed in this experiment were designed as worked example guides to promote the efficiency of problem-solving solutions. The experimenter and faculty advisor drew upon considerable construction knowledge and experience to develop example solutions based on simple construction principles that were suited for individual problem-solving tasks. The first set of example solutions, elevated load, were based on the need for a wide base in order to provide stability for a tall structure carrying a heavy load at the uppermost section (see Figure 4).

The second set of example solutions, cantilevered weight, exhibited the need to provide a counterbalance in order to maintain the stability and integrity of the cantilevered structure (see Figure 5). The third and final example solutions, energy absorption, were designed to display the advantage of increased surface area and properly positioned impact zone in order to stop the ball in the designated area and prevent it from soaring off the ramp (see Figure 6).

Successful and unsuccessful example solutions were designed to differ in only one aspect of height, length or width. This one difference in dimensioning changed successful example solutions adequately to transform them into unsuccessful example solutions. These differences included dissimilar base sizes for the elevated load example solutions, different counterweight lengths for the cantilevered example solutions, and different heights for the energy absorption example solutions. Refer to Figures 4 through 6 for images of the successful and unsuccessful example solutions for each task.

### **Elapsed Time Measurement**

Elapsed time was measured with a stopwatch for each experimental task. The timer started when students were asked to begin the procedure and stopped when they had successfully completed a solution. Final solutions were assessed by the experimenter and determined successful when the structure met the criteria designated in the problem statement. When a solution was deemed unsuccessful, the experimenter informed the participants why it did not meet the established criteria and they continued to work until a successful solution was developed or time expired.

Students completed tasks at different time intervals, so those who finished before the final person solved the problem were asked to solve the problem again in a different manner from their first solution. Additional solutions had no bearing on problem-solving efficiency and were not recorded as part of the experiment. Participants were asked to do this in order to keep them occupied and ensure that they did not disturb others still working on solutions. When all three participants had completed the task, or time had expired, the entire group moved on to the next task. If a participant did not successfully complete the task in the designated time frame, he/she received a score that was equal to the maximum time allotted for each problem-solving task.

### **Statistical Analysis**

Experimental data was analyzed using a 3 (example solution group, between subjects) x 3 (problem-solving tasks, within subjects) mixed factorial ANOVA. The design was selected to explore the two hypotheses developed for this study containing more than one independent variable. Howell (1997) stated, “an analysis of variance allows us to deal with two or more independent variables simultaneously” (p. 299). The hypotheses were answered by analyzing the three example solution groups across the three problem-solving tasks using a mixed factorial design. Howell (1997) explained, “a factorial design is one which we include all combinations of the levels of the independent variables” (p. 401). Following the above analysis, a chi-square and statistical power analysis were performed.

A chi-square analysis was used to determine if a significant difference existed between those who failed to solve the elevated load task (observed frequencies), versus the expected failure frequency for the elevated load task. As stated by Gall, Borg, and Gall (1996) “chi-square is a statistical test to determine whether research data in the form of frequency counts are distributed differently for different samples” (p. 400).

Finally, an analysis of power and sample size was determined. “Statistical power analysis shows the advantage gained by increasing the sample size by certain amounts” (Gall, Borg, & Gall, 1996, p.230). Power also displays how much the sample size needs to rise depending on the selected level of significance determined to reject the null hypothesis (Gall, Borg, & Gall, 1996). “Discussions of power are generally concerned with the effects of varying sample size” (Howell, 1997, p. 216). If the experimental sample size increases, then the statistical power also increases (Gall, Borg, & Gall, 1996). A statistical power analysis was used to determine sample size needed to establish a power of .80. The experimental sample size needed to establish a power of .80 at the .05 level was determined by using the equal sample sizes equation incorporating effect size and the noncentrality parameter (Howell, 1997).

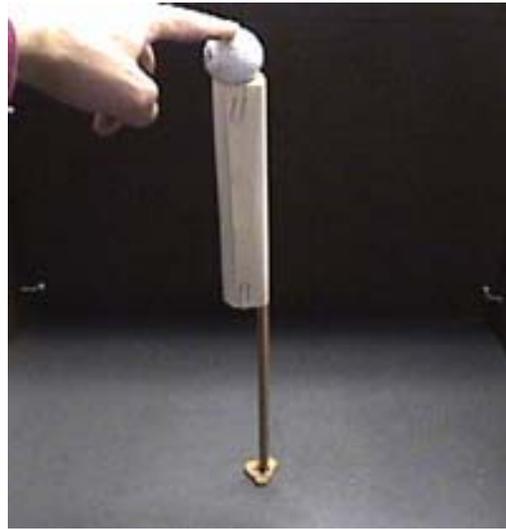
## **Human Subjects Review**

This study fit criteria that required inspection and approval by the Institutional Review Board, Office of Research Compliance. An expedited review process was submitted to the Institutional Review Board at Virginia Tech. The review process consisted of the submission of documents that contained an expedited review form, justification of the project, institutional informed consent agreement, parental consent form, participant assent form, and Institutional Review Board checklist. The Institutional Review Board granted approval to the study for a period of twelve months.



Successful example solution

Elevated load

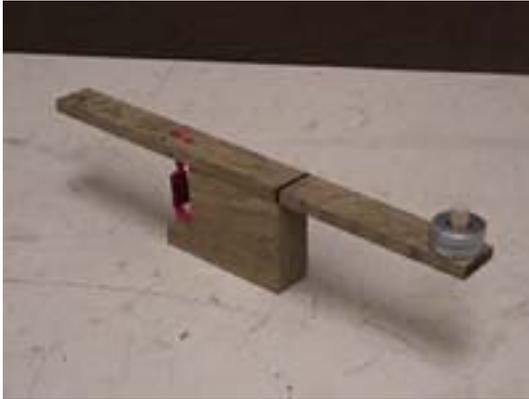


Unsuccessful example solution

Elevated load

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**Figure 4.** Successful and unsuccessful example solutions for the elevated load task.



Successful example solution

Cantilevered weight



Unsuccessful example solution

Cantilevered weight

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**Figure 5.** Successful and unsuccessful example solutions for the cantilevered weight task.



Successful example solution

Energy absorption



Unsuccessful example solution

Energy absorption

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**Figure 6.** Successful and unsuccessful example solutions for the energy absorption task.

## Chapter 4. Results

The first problem the students attempted was the elevated load problem. Overall, 14 of the 51 students (27%) failed to solve this problem in the time allotted. In the successful example solution group, two participants failed to solve the problem. In the unsuccessful example solution group, four participants failed to solve the problem. In the no example solution group, eight participants failed to solve the problem. Table 3 depicts the failed solution numbers for the elevated load task.

**Table 3.**

Number of participants from each example solution group who failed to solve the elevated load task.

	Successful example solution group	Unsuccessful example solution group	No example solution group
Number of elevated load solutions not completed	2	4	8

This pattern of results was expected based on the hypothesis that successful and unsuccessful example solutions would enhance problem-solving. However, a chi square analysis revealed that there was no significant difference in failure to solve the problem based on example solution group,  $\chi^2 (2, N = 14) = 4.0, p > .05$ . All students solved the cantilevered weight problem and the energy absorption problem within the designated time duration.

As predicted, regardless of the problem, students in the successful example solution group solved the problems fastest ( $M = 304.71$  seconds) followed by the students in the unsuccessful example solution group ( $M = 305.53$  seconds) followed by the students in the no example solution group ( $M = 364.22$  seconds). Table 4 depicts combined mean times for example solution groups.

**Table 4.**

Combined mean times for example solution groups.

	Successful example solution group	Unsuccessful example solution group	No example solution group
Combined mean time for three problem-solving tasks	304.71 seconds	305.53 seconds	364.22 seconds

However, a 3 (example solution group) x 3 (problem-solving task) mixed factorial repeated-measures ANOVA revealed no significant main effect for example solution group and a very small effect size,  $F(2, 48) = 2.19, p > .05, \eta^2 = .08$ . See Table 5 for descriptive statistics.

**Table 5.**

Descriptive statistics.

Problem	Example Solution	Mean	Standard Deviation	N
Problem #1	Successful	556.35	169.94	17
<i>Elevated load</i>	Unsuccessful	537.65	194.53	17
	No example	619.47	157.79	17
	Total	571.16	173.98	51
Problem #2	Successful	271.88	185.10	17
<i>Cantilevered weight</i>	Unsuccessful	246.71	144.92	17
	No example	299.65	153.96	17
	Total	272.75	160.46	51
Problem #3	Successful	85.88	49.16	17
<i>Energy absorption</i>	Unsuccessful	132.24	118.13	17
	No example	173.53	115.21	17
	Total	130.55	103.89	51

The same analysis showed a significant main effect for problem-solving task with a large effect size,  $F(2, 96) = 131.09, p < .001, \eta^2 = .73$ . The energy absorption problem was solved the fastest ( $M = 130.55$  seconds), followed by the cantilevered weight problem ( $M = 272.75$ ), followed by the elevated load problem ( $M = 571.16$ ). Refer to Table 6 for mean solution time for each task.

**Table 6.**

Mean solution times for individual problem-solving tasks.

	Elevated load task	Cantilevered weight task	Energy absorption task
Mean solution time	571.16 seconds	272.75 seconds	130.55 seconds

The analysis also revealed no interaction between example solution group and problem-solving task,  $F(4, 96) = 0.42, p > .05, \eta^2 = .02$ . As shown in Figure 7, it is evident that the elevated load problem took the most time in each of the three example conditions, followed by the cantilevered weight problem, and the energy absorption problem.

Because the above analysis revealed such a large difference in solution time due to the type of problem-solving task, the problems were then analyzed independently. The elevated load and the cantilevered weight problems showed no significant difference due to example solution type. However, time of the energy absorption task was significantly different due to example solution type. A univariate ANOVA showed that the effect for example solution type was significant although small,  $F(2, 48) = 3.31, p < .05, \eta^2 = .12$ . A post-hoc Tukey HSD test showed that the successful example solution group ( $M = 85.88$  seconds) was significantly different from the no example solution group ( $M = 173.53$  seconds). Table 7 depicts the mean solution times for successful example solution group and no example solution group for the energy absorption task.

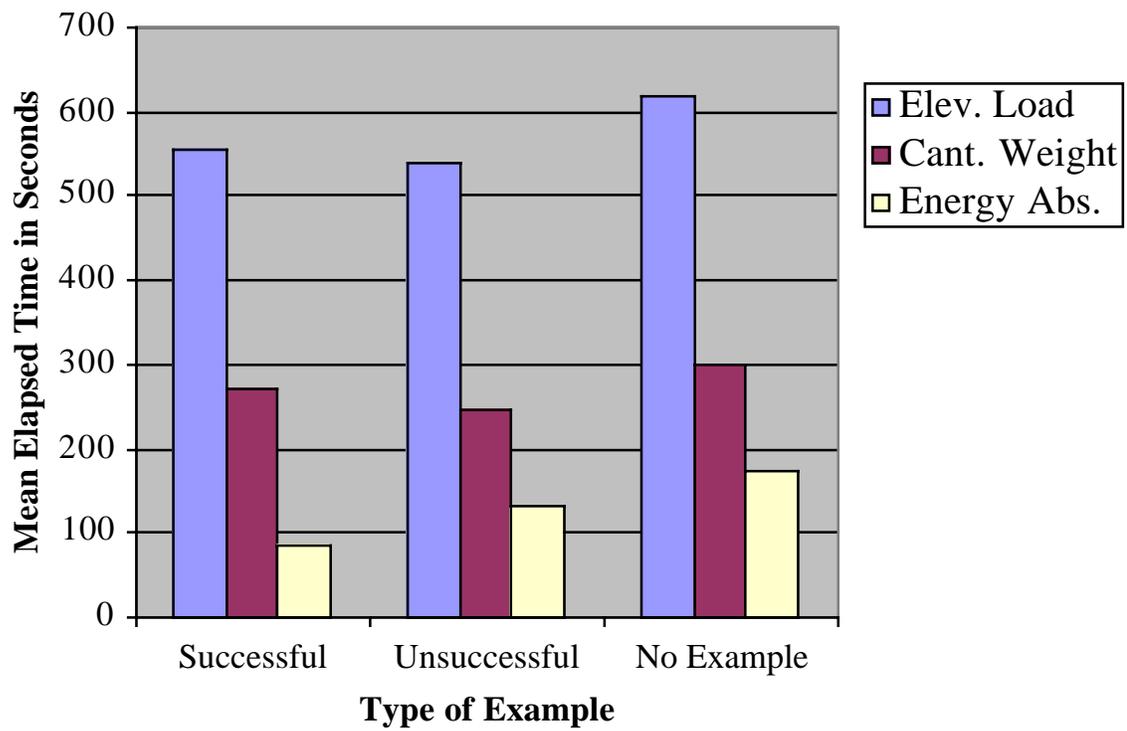
Power analysis was conducted and determined to be .426 at the .05 level. Based on the one-minute separation time between the successful and unsuccessful example solution groups when compared to the no example solution group, a significant difference among the groups was thought to be likely if the participant population were increased. A statistical power analysis was performed to determine how many participants were required in each group to obtain a power of .80 at a .05 significance level. Each experimental group contained 17 participants and the power analysis based on this sample size was determined to be .426 at the .05 level. In order to raise the statistical power level to .80 at the .05 level it was determined that each example solution group needed to contain 3,329 participants for a total sample size consisting of 9,987 participants.

Post experimental discussions with participants uncovered information that reflected their perceptions and solution strategies gathered from the presentation of example solutions. Participants briefly explained how the example solution information helped them or did not help them solve the three problem-solving tasks.

While the majority of participants said they were able to get helpful information from the example solutions displayed, others said that the examples did not help and one participant said that he was not interested in the examples because he wanted the task to be “more challenging.” Discussion concerning the cantilevered weight example solutions provided interesting feedback. Some participants mentioned the red tape used on the cantilevered weight examples and said that this triggered them to use the masking tape provided in the supply kit. This was surprising because the tape used on the example solutions was only used to prevent string from unraveling and had nothing to do with solving the problem. One participant said, “I saw the tape on the example and thought that would be something I should use.” One participant mentioned the lack of weight on the one side of the unsuccessful example solution for the cantilevered weight task and said, “I was able to see that an overhang on the other end would balance out the cantilever.” Another participant described the successful example solution for cantilevered weight and said, “The example showed me that there needed to be something on the other end holding up this end.”

Example solutions for the elevated load task were also mentioned. After seeing the successful example solution for elevated load, a participant said, “I saw the rolled paper and that looked like a good way to go.” After viewing the unsuccessful example solution for the elevated load task, some comments included, “I saw that it needed a bigger base to hold up the ball,” and “I knew that it needed another leg to hold it up stable.”

The third and final task, energy absorption, was solved much faster than the two previous tasks. Numerous participants had similar comments about their familiarity with the supply kit as described by one participant who said, “By the third problem I knew what I could do with the materials.” The successful example solution for the energy absorption task was said to be “very helpful” because it was such a “simple solution.” The unsuccessful example solution for energy absorption was also mentioned as helpful because they knew that the point of contact needed to be “higher” or the golf ball would “fly off” of the track.



**Figure 7.** Mean times of the problem-solving tasks for each example solution group.

**Table 7.**

Mean solution times for successful example solution group and no example solution group for the energy absorption task.

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	Successful example solution group	No example solution group
Mean time for energy absorption task	85.88 seconds	173.53 seconds

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## Chapter 5. Summary, Conclusions, and Recommendations

### Summary

The purpose of this study was to investigate the usefulness of different example solutions in enhancing the problem-solving efficiency of middle school students working on open-ended technological problem-solving assignments. The necessity to improve problem-solving in education has been emphasized by many organizations and curriculum standards (American Association for the Advancement of Science, 1990; International Technology Education Association, 2000; National Council of Teachers of Mathematics, 1989; National Research Council, 1996). Problem-solving efficiency must also be considered when students develop solutions to technological problems. Enhancing problem-solving efficiency makes more time available for the promotion of higher order thinking skills such as analysis and synthesis that enhance student technological problem-solving abilities and understanding. Denton and Williams (1996) relate efficiency to technological problem-solving design as, “the suitability of the design outcome compared with the time and effort put into the design process” (p. 15). Denton and Williams (1996) highlighted the importance of efficiency in education and problem-solving design by emphasizing the potential opportunity to enhance, develop, and refine solutions.

A comprehensive literature review in Chapter Two explored aspects of cognitive load theory, problem-solving, cognitive load, transfer, worked examples, and problem-solving speed and age. Research in these areas revealed improvements with schema acquisition, transfer performance, and problem-solving efficiency when worked example solutions were implemented and designed with minimal extraneous cognitive load and maximum germane cognitive load.

Experimental methods and procedures were explained and discussed in Chapter Three. This included a description of the participant pool, pilot study, experimental design, problem ordering and duration, construction materials, experimental setting, dividers, procedures, problem task descriptions, task diagrams, examples, elapsed time measurement, statistical analysis, and the two hypotheses described below:

H1: Successful example solutions and unsuccessful example solutions influence technological problem-solving efficiency.

H2: Successful example solutions will enhance technological problem-solving efficiency more than unsuccessful example solutions, which in turn, will enhance technological problem-solving efficiency more than no example solutions.

An expedited review process was submitted to the Institutional Review Board at Virginia Tech and this study was granted approval for a period of twelve-months.

Chapter Four described the results of the study based on the research data. Analysis of the data indicated no significant difference among the three experimental groups that included successful, unsuccessful, and no example solutions. The overall trend in example solution mean values appeared to support both research hypotheses but was not substantiated by the statistical analysis.

## Conclusions

The subsequent conclusions were based on the statistical analysis of the research data and the literature review. The conclusions communicate findings that relate to the two hypotheses and the problem statement established in Chapter One.

*Research Problem Statement.* The purpose of this study was to investigate the usefulness of different example solutions to enhance problem-solving efficiency among middle school students working on open-ended technological problem-solving assignments. Based on the statistical analysis, there appears to be marginal or no use for the implementation of successful and unsuccessful example solutions when working on technological problem-solving assignments.

Cognitive load theory and problem-solving experimentation have indicated that worked examples facilitate schema acquisition, increase transfer performance, and improve problem-solving efficiency (Kalyuga, Chandler, Touvinen, & Sweller, 2001; Paas & Van Merriënboer, 1994; Sweller & Cooper, 1985). Sweller and Cooper (1985) observed that worked examples, compared to conventional problems, decreased the amount of processing time needed to solve algebra problems. Participants solved the problems faster when viewing worked examples. Sweller and Cooper (1985) concluded that schema acquisition used for problem-solving is faster when using worked examples and suggested that by implementing worked examples, learners may focus limited cognitive resources on solution moves to solve problems.

Paas and Van Merriënboer (1994) studied the effects of worked example conditions versus conventional problem-solving on transfer performance, speed, and mental effort. The worked example group received problems presented with solutions, and the conventional group was only presented with the problems. Their results indicated that instruction using worked examples led to better transfer performance and decreased instructional time when compared to the conventional problem-solving group. As discussed above, this study does not reinforce the findings discovered by Kalyuga, Chandler, Touvinen, and Sweller (2001), Paas and Van Merriënboer (1994), and Sweller and Cooper (1985) that worked example solutions improve problem-solving efficiency.

*Research Hypothesis One.* The first research hypothesis predicted that successful example solutions and unsuccessful example solutions influence technological problem-solving efficiency. The results of this study indicate that successful and unsuccessful example solutions do not influence technological problem-solving efficiency. There was no significant difference among the example solution groups.

Mean completion time trends suggest that the implementation of successful and unsuccessful example solutions influence problem-solving efficiency when performing open-ended technological problem-solving tasks. However, the trends are not supported by the statistical analysis.

The results of the experiment do present encouraging results when comparing the unsuccessful and successful example solution group mean times. These two groups almost had identical mean solution times. These results augment the historical use and assumption that presenting unsuccessful example solutions is beneficial to technological problem-solving understanding and efficiency. The historical implementation of unsuccessful example solutions is evident in numerous textbooks presenting technological content such as carpentry and home construction (Graham & Emery, 1951), boat construction (Tolman, 1998), electrical wiring (Richter & Schwan, 1992), and engine repair (Roth, 1998). The results of this experiment provide some support for the employment of unsuccessful and successful example solutions to enhance technological problem-solving, but the statistical results were not significant.

*Research Hypothesis Two.* The second research hypothesis predicted that successful example solutions would enhance problem-solving efficiency more than unsuccessful example solutions, which in turn, would enhance problem-solving efficiency more than no example solutions. The results of this study indicate that successful example solutions do not enhance technological problem-solving efficiency more than unsuccessful example solutions, and unsuccessful example solutions do not enhance technological problem-solving efficiency more than no example solutions. The mean of combined task times for each problem-solving group indicated that the successful example solution group completed the tasks in 304.71 seconds, compared to 305.53 seconds for the unsuccessful example solution group, and 364.22 seconds for the no example solution group. Although there was no significant difference among the three experimental groups, the hypothesized trend appears to exist, although it is weak. Successful example solutions enhanced problem-solving efficiency slightly more than unsuccessful example solutions and 18% faster (almost a full minute) than the no example solutions group.

Nearly identical mean times for successful and unsuccessful example solution groups appears to indicate that the presentation of unsuccessful example solutions, as defined in this study, enhances problem-solving efficiency almost as much as successful example solutions. This outcome does, however, contradict cognitive load theory research supporting the use of germane cognitive load and reducing the amount of extraneous cognitive load (Bannert, 2002). Cognitive load theory research stresses the importance of reducing the amount of extraneous cognitive load, information that is not relevant to the learned information, and increasing the amount of germane cognitive load, information that is relevant to the information being learned (Van Gerven, Paas, Van Merriënboer, & Schmidt, 2002; Van Merriënboer et al., 2002). Unsuccessful example solutions would seem to increase extraneous cognitive load by introducing information that is indirectly related to the problem-solving solution which would ultimately detract from working memory capacity and problem-solving efficiency. Based on cognitive load theory and the experimental results obtained in this study, unsuccessful example solutions

may be similar enough to successful worked example solutions to provide beneficial germane load.

*Elevated Load Completion Rates.* The elevated load task appeared to be the most difficult. The mean completion time of the elevated load task was higher than the other two tasks. Comments from the participants during post-experimental discussion confirmed the difficulty as well.

Completion rates associated with the elevated load problem varied among experimental groups, but there was not a significant difference among the three groups. The overall completion rates from the elevated load task indicated that more students successfully completed it when they received successful and unsuccessful example solutions versus no example solutions. Within the maximum 12-minute time requirement, two participants did not complete the elevated load task in the successful example solution group, four participants did not complete the elevated load task in the unsuccessful example solution group, and eight participants did not complete the elevated load task in the no example solution group. These results suggest that the use of successful and unsuccessful example solutions were beneficial to participants and influenced successful solution rates for the most difficult task, elevated load. Higher completion rates using worked example solutions were consistent with cognitive load theory and worked example literature discussed above but not incorporated into this research study.

*Energy Absorption Task.* As described above, there was no significant main effect for example solution group but the same analysis revealed a significant main effect when only considering the energy absorption task. The energy absorption task was solved the fastest and showed a significant difference in problem-solving efficiency due to example solution type. The successful example solution mean was 85.88 seconds and was significantly different from the no example solution group with a mean of 173.53 seconds on the energy absorption task. There was no significant difference with the unsuccessful example solution on the energy absorption task. This study was not intended to test differences among each of the three problem-solving tasks, but the significant difference on this task supports the cognitive load theory literature that supports the use of worked example solutions in order to enhance problem-solving efficiency.

The energy absorption problem was the easiest of the three tasks based on the overall mean scores and post-experimental discussion with participants who ranked it as the easiest of the three tasks encountered. The relative ease of the task compared to elevated load and cantilevered weight tasks may indicate that the energy absorption task imposed low intrinsic cognitive load. Sweller and Chandler (1994) noted that the complexity of the subject matter induces high intrinsic cognitive load and Bannert (2002) suggested that high intrinsic cognitive load is imposed by the nature of the material, the amount of element interactivity, the method in which the material is presented, and lack of understanding of the material. Since the energy absorption task was identified as easier than the other two tasks and the mean times were the lowest across all experimental groups, the energy absorption task may have imposed a very low intrinsic cognitive load. Kalyuga et al. (2001) suggested that the “amount of guidance necessary decreases as the

subject material becomes easier and/or experience of the learner increases” (p. 4). The energy absorption task was the third and final task during the experiment so the knowledge and experience gained during the previous tasks may have influenced problem solving efficiency on this task. Additionally, knowledge of how to manipulate the materials in the supply kit learned from the previous two tasks may have influenced problem-solving efficiency when developing a solution to the energy absorption task.

*Post-Experimental Discussions.* Discussions were not part of the experimental design and should not be generalized nor receive undue speculation or recognition. Discussions were simply used to get a sense of what aspects of the example solutions attracted their attention.

Overall, the post-experimental discussion revealed that participants gathered useful information from both the successful and unsuccessful example solutions in order to identify a potential strategy and complete the problem-solving tasks. The type of information gained from each of the examples appeared to reinforce the basic construction principles used to develop the example solutions. These included the need for a wide base for the elevated load task, a counterbalance for the cantilevered weight task, and proper positioning of a large surface area for the energy absorption task.

*Power Analysis.* Power analysis revealed that roughly 10,000 participants were needed in order to obtain a power level of .80 at the .05 level. Based on these figures, the experimental sample size consisting of 51 participants was not adequate to obtain a power level of .80.

## **Recommendations for Researchers**

The subsequent recommendations are based on findings and conclusions derived from this study. Recommendations are intended for researchers exploring methods to enhance technological problem-solving efficiency. The utilization of successful and unsuccessful worked example solutions appears to marginally influence technological problem-solving efficiency. Consequently, based on the observable trend and prior problem-solving research, successful and unsuccessful example solutions involving technological problem-solving research may prove enlightening.

1. Adding a fourth problem-solving task to the experimental design may provide additional insight. Participants in each group would receive a fourth problem without viewing an example solution. The last problem would test the influence of example solutions over the entire experiment. This may answer an additional question: Did the participants who received example solutions over the first three tasks learn something from the earlier examples to help them solve the fourth problem more efficiently than the group that never received any example solutions?
2. Further research could include qualitative interviews to determine the characteristics of the examples that are most beneficial. Beneficial characteristics could be used to design future example solutions used to

enhance technological problem-solving efficiency. This may provide an opportunity to see what aspects of successful and unsuccessful example solutions are most useful to problem-solving participants.

3. The implementation of successful and unsuccessful examples could be explored and evaluated to determine effectiveness with a variety of technological problem-solving tasks. This study was limited to a narrow aspect of technological problem-solving. Additional studies could search for the effectiveness of example solutions with different types of technological problem-solving tasks in areas such as research and development, troubleshooting, invention and innovation, or experimentation.

### **Recommendations for Practitioners**

The subsequent practitioner recommendations are based on research findings and conclusions derived from this study and the review of literature. Recommendations are intended for all subject area instructors implementing technological problem-solving methods and formats.

1. Based on time differences among the example groups and participant comments, successful and unsuccessful example solutions may prove beneficial in the classroom environment. A typical 45-minute classroom period is dramatically reduced after considering problem-solving instructions, materials organization, and clean-up time. Instructors may find the use of worked example solutions helpful to student problem-solving completion rates and promote efficient use of valuable classroom time.
2. Post-experimental discussions revealed that students do gather information from example solutions. Based on these findings, it is believed that practitioners should ask students what aspects of classroom examples are helpful in developing solutions to technological problems and implement these aspects into future examples. Instructors should also ask students what aspects of current examples are most helpful and integrate them into future examples. This process would provide instructors with an indication of the relative strengths and weaknesses of current and future example displays used in the classroom.

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### Appendix A: Instructions to Research Participants

Three participants entered the experimental room at one time. They were asked to sit at one of the three experimental stations and read the student assent forms before beginning the study. Assent forms were signed and collected and the participants were asked to turn their chairs away from their workstation for the experimental instructions.

The experimenter conducted the study with the following script listed below:

Instructions to Participants	Experimenter Procedures
1. Thank you for participating today.	
2. Over the next 40 minutes each of you will build three structures to solve three problem-solving tasks.	
3. The three problems you will solve include elevated load, cantilevered weight, and energy absorption.	
4. Each of you is required to work alone and will not be allowed to look at other participant solutions or speak to each other during the experiment.	
5. If you have any questions during the experiment, raise your hand and I will answer them.	
6. Each of you will receive three construction kits to solve the three problems.	
7. These are the materials contained in the construction kits	(The experimenter displayed all of the construction materials and each piece was described.)
8. You will get a new construction kit for each new problem-solving task.	
9. When you complete the first task, I will take away all of the materials from the first kit and give you a new kit containing the same materials. After you complete the second task, you will receive a new supply kit for the third task.	
10. You can do whatever you want with the materials in the supply kit and are not required to use all of the supplies if you do not think they are needed to solve the problem.	
11. The first task to solve is called elevated load.	
12. The goal of the first task is to build a	

structure that supports a golf ball at or above 40 centimeters from the top of the table.	
13. This is a diagram of the problem and it will be displayed on your dividers during the task	(The task diagram was held up, see Figure 1.)
14. As you can see on your dividers, a line is drawn at 40 centimeters so there is no need to measure this height.	
15. The golf ball must be at or above the black line on the divider and the ball must remain there for at least 5 seconds to be considered successful.	
16. When you have completed the task, raise your hand and I will come over and check your solution to see if it is OK.	
17. The second task is called cantilevered weight.	
18. The goal of the second task is to build a cantilevered structure with a minimum overhang of 10 centimeters that supports a stack of five washers on the end.	(An identical stack of washers was held up and the task diagram was displayed. See Figure 1 for an image of the cantilevered weight task diagram.)
19. The cantilevered overhang can be more than 10 centimeters but must be at least 10 centimeters long.	
20. You will receive a guide like this one to determine the minimum length of the cantilever.	(The experimenter held up a 10 cm measurement guide.)
21. The structure must hold the stack of washers on the end for at least five seconds to be considered successful.	
22. When you have completed the task, raise your hand and I will come over and check your solution to see if it is OK.	
23. The third task is called energy absorption.	
24. The goal of the third task is to build a structure that stops a golf ball halfway down this track somewhere in the red section.	(The track was displayed along with the energy absorption task diagram. See Figure 2 for an image of the track. See Figure 1 for an image of the energy absorption task diagram.)
25. The golf ball has to be released from the top of the ramp and stop in some area of the red zone while remaining on the track in order to be considered a successful solution.	(The golf ball was released from the top of the ramp to show it rolling down the ramp.)

26. The golf ball has to touch some portion of the red zone.	(The ball was held in various sections of the red zone for clarification.)
27. The golf ball must remain on the track in the red zone for at least five seconds after it has stopped rolling.	
28. When you have completed the task, raise your hand and I will come over and check your solution to see if it is OK.	
29. Remember that you are not allowed to look at the other participants or talk to them during the experiment.	
30. Please turn your chairs around and we will begin task number one, elevated load.	
31. As mentioned earlier, the goal of the first task is to build a structure that supports a golf ball at or above 40 centimeters from the top of the table.	
32. I am going to give each of you your first supply kit	(Passed out supply kits.)
33. Do not open the supply kit until I tell you to begin.	(At this stage of the experiment, successful and unsuccessful example solution groups were shown one example. The control group did not receive any form of example solution.)
34. This is an example that displays a method of how to successfully solve the elevated load task.	(Successful example solution group.)
35. This is an example that displays an unsuccessful method to solve the elevated load task.	(Unsuccessful example solution group.)
	(The example solutions were displayed to the students and then placed behind them throughout the duration of the problem-solving task. Participants were able to turn around and look at the example solutions if they desired.)
36. OK, begin task number one.	(Timer was started.)
	(When each student successfully completed the task, time was recorded on the experimental sheet. If a participant completed the task faster than the other participants, they were instructed to develop alternative solutions to keep them occupied. If all of the students completed solutions under the designated

	time frame then all of them moved onto the next problem-solving task. This method allowed the group of three participants to progress from task to task together and begin the next experiment at the same time.)
37. Time for task number one has expired.	(Twelve minutes.)
38. Please slide all of your supplies and solutions into this box.	(A plastic container was used to collect the used materials.)
39. The next task will be cantilevered weight.	
40. As mentioned earlier, the goal of the second task is to build a cantilevered structure with a minimum overhang of 10 centimeters that supports a stack of five washers on the end.	(An identical stack of washers was held up and the task diagram was displayed. See Figure 1 for an image of the cantilevered weight task diagram.)
41. Each of you will receive a gauge to determine the minimum overhang of 10 centimeters. This is your gauge.	(Passed out three 10 cm gauges.)
42. Here is a new supply kit for the next task.	(Passed out new supply kits.)
43. Do not open the supply kit until I tell you to begin.	(At this stage of the experiment, successful and unsuccessful example solution groups were shown one example. The control group did not receive any form of example solution.)
44. This is an example that displays a method of how to successfully solve the cantilevered weight task.	(Successful example solution group.)
45. This is an example that displays an unsuccessful method to solve the cantilevered weight task.	(Unsuccessful example solution group.)
	(The example solutions were displayed to the students and then placed behind them throughout the duration of the problem-solving task.)
46. OK, begin task number two.	(Timer was started.)
	(When each student successfully completed the task, time was recorded on the experimental sheet. If a participant completed the task faster than the other participants, they were instructed to develop alternative solutions to keep them occupied. If all of the students completed solutions under the designated

	time frame then all of them moved onto the next problem-solving task. This method allowed the group of three participants to progress from task to task together and begin the next experiment at the same time.)
47. Time for task number two has expired.	(Ten minutes.)
48. Please slide all of your supplies and solutions into this box.	(A plastic container was used to collect the used materials.)
49. The next task will be energy absorption.	
50. As mentioned earlier, the goal of the third task is to build a structure that stops a golf ball halfway down this track somewhere in the red section.	(The track was displayed along with the energy absorption task diagram. See Figure 2 for an image of the track. See Figure 1 for an image of the energy absorption task diagram.)
51. Each of you will need a ramp to complete this task. You will find your ramp to the left of your divider. Locate your ramp and place it in front of you.	
52. Here is a new supply kit for the next task.	(Passed out new supply kits)
53. Do not open the supply kit until I tell you to begin.	(At this stage of the experiment, successful and unsuccessful example solution groups were shown one example. The control group did not receive any form of example solution.)
54. This is an example that displays a method of how to successfully solve the energy absorption task.	(Successful example solution group.)
55. This is an example that displays an unsuccessful method to solve the energy absorption task.	(Unsuccessful example solution group.)
	(The example solutions were displayed to the students and then placed behind them throughout the duration of the problem-solving task.)
56. OK, begin task number three.	(Timer was started.)
	(When each student successfully completed the task, time was recorded on the experimental sheet. If a participant completed the task faster than the other participants, they were instructed to develop alternative solutions to keep them occupied. If all of the students

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	completed solutions under the designated time frame then all of them moved onto the next problem-solving task. This method allowed the group of three participants to progress from task to task together and begin the next experiment at the same time.)
57. Time for task number three has expired.	(Ten minutes.)
58. Please slide all of your supplies and solutions into this box.	(A plastic container was used to collect the used materials.)
59. This is the end of the study. Thank you for participating. Please do not speak to your classmates about the procedures or the solutions that you created until everyone has completed the experiment.	(If additional time was available at the conclusion of the third task, a few questions were asked before students were dismissed. See Appendix B for post-experimental questions.)

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### **Appendix B: Post-Experimental Questions**

Post-experimental questions were posed to participants if the experiment was completed early and classroom time was still available. This occurred with approximately 50% of participants. Questions were asked to get a sense of which problem-solving tasks were most difficult and what aspects of the example solutions were most beneficial.

The following list of questions were answered by available participants:

1. Which of the problem-solving tasks was the most difficult?
2. Which of the problem-solving tasks seemed to be the easiest to solve?
3. Did the examples help you solve the problems?
4. What aspects of the examples helped you solve the problems?

## Appendix C: Participant Solutions



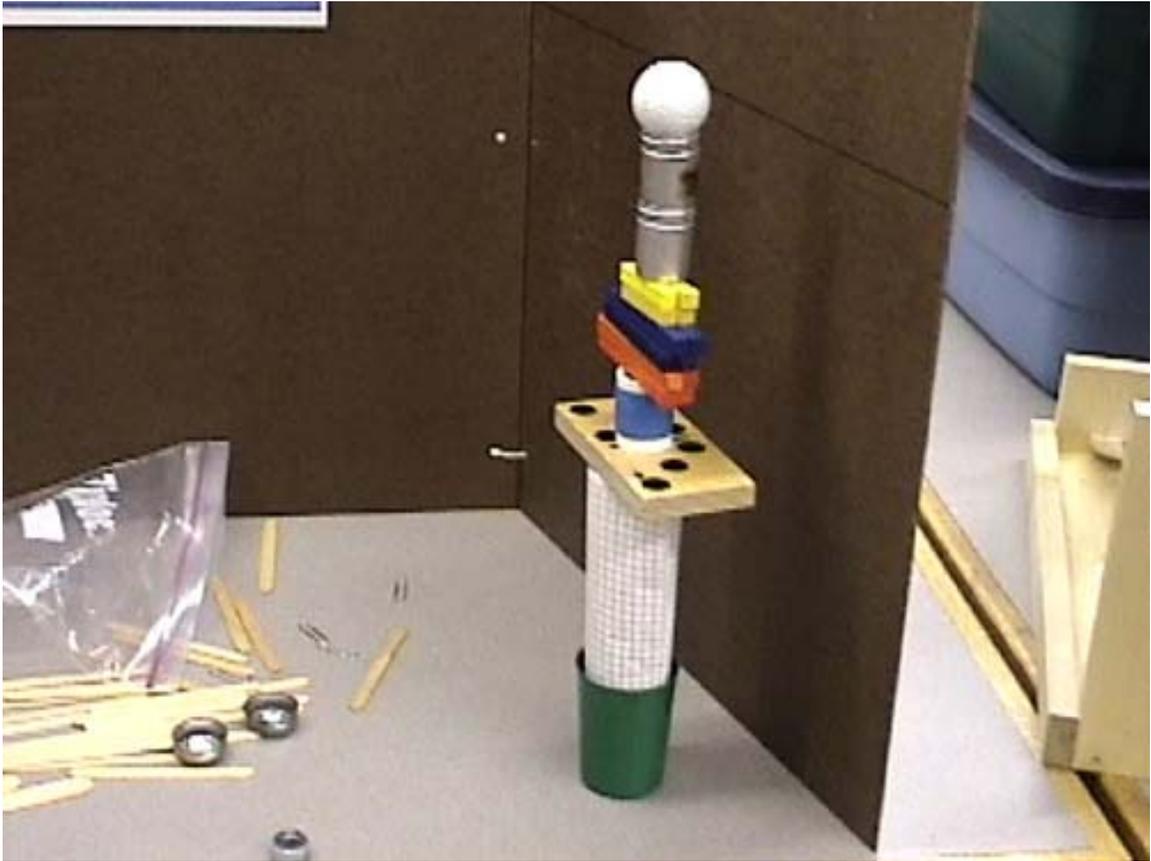
**Figure C1.** Elevated load participant solution (JPEG 36K).



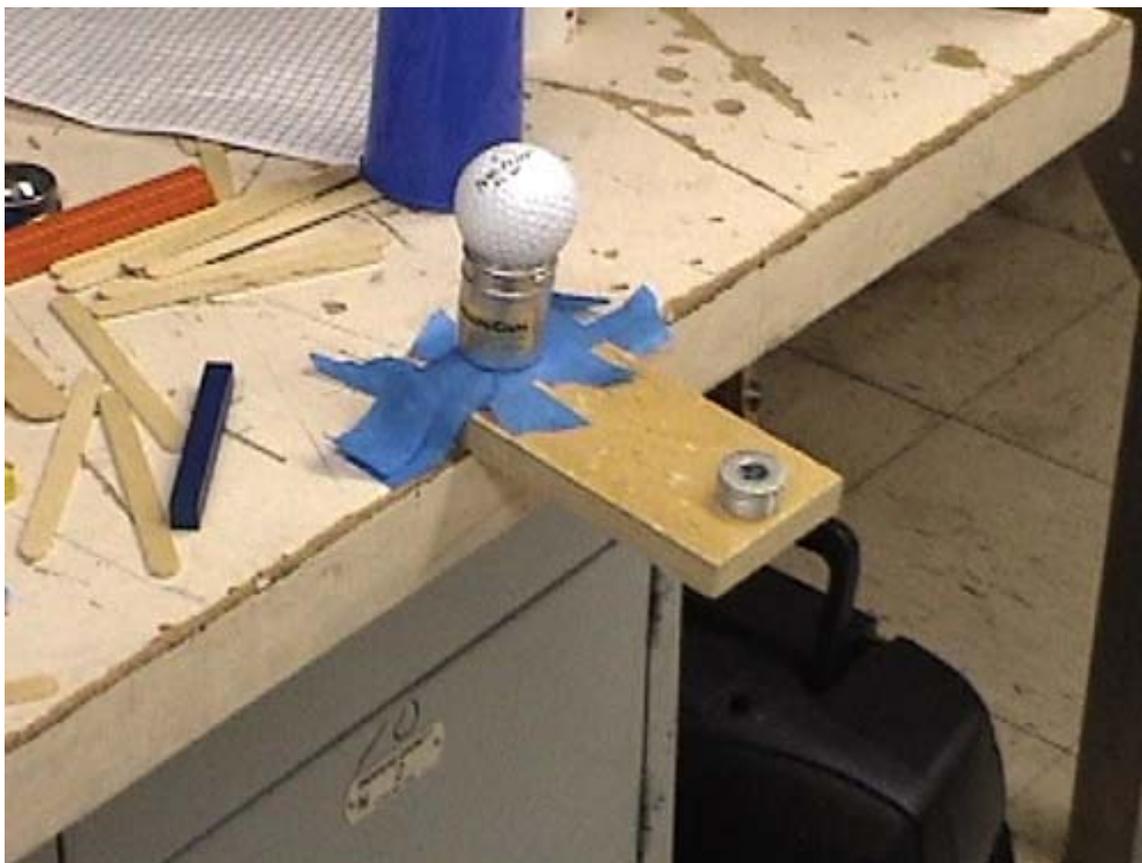
**Figure C2.** Elevated load participant solution (JPEG 36K).



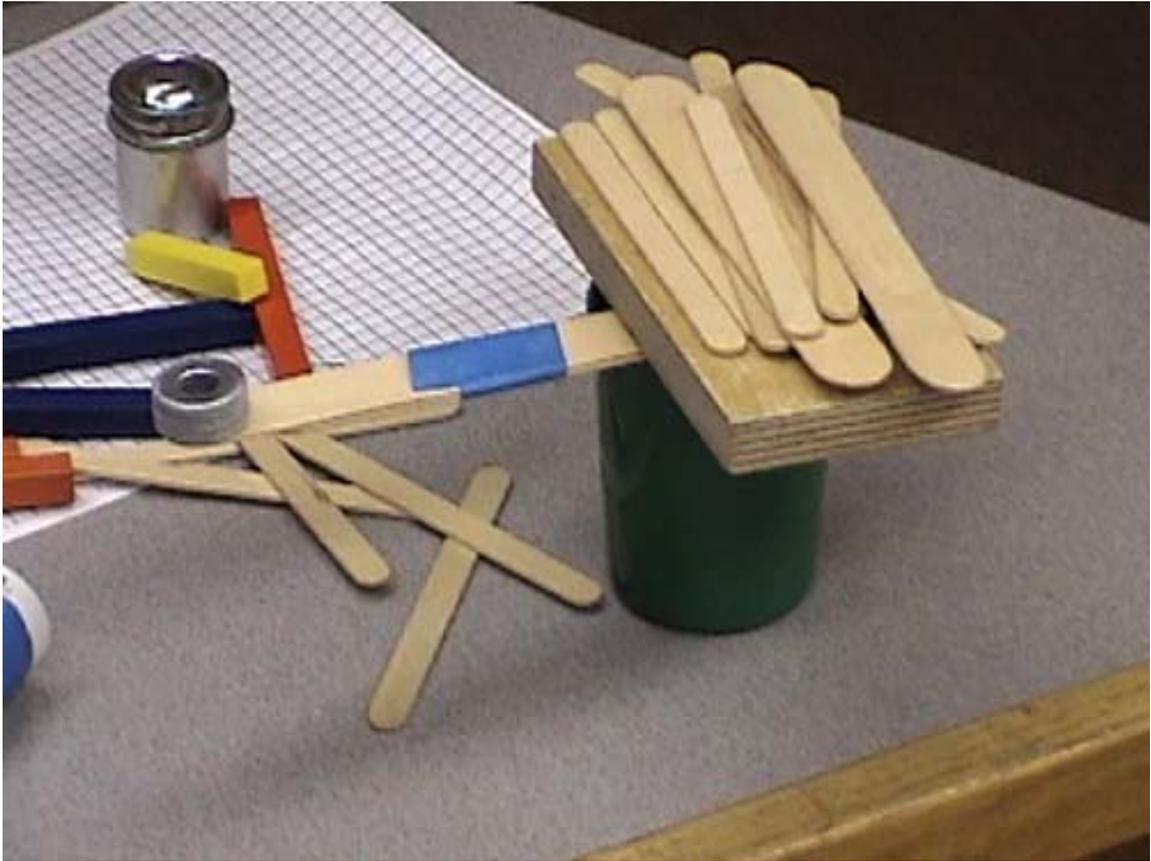
**Figure C3.** Elevated load participant solution (JPEG 36K).



**Figure C4.** Elevated load participant solution (JPEG 34K).



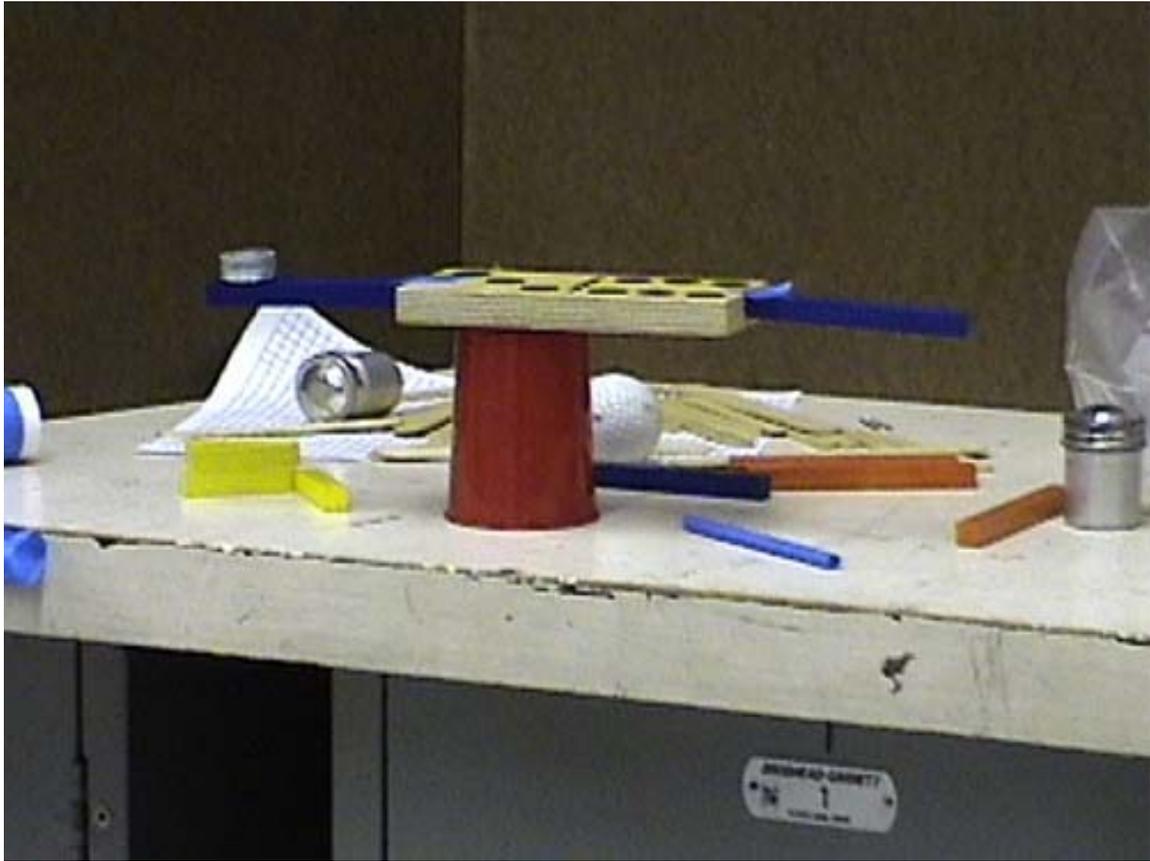
**Figure C5.** Cantilevered weight participant solution (JPEG 44K).



**Figure C6.** Cantilevered weight participant solution (JPEG 42K).



**Figure C7.** Cantilevered weight participant solution (JPEG 32K).



**Figure C8.** Cantilevered weight participant solution (JPEG 36K).



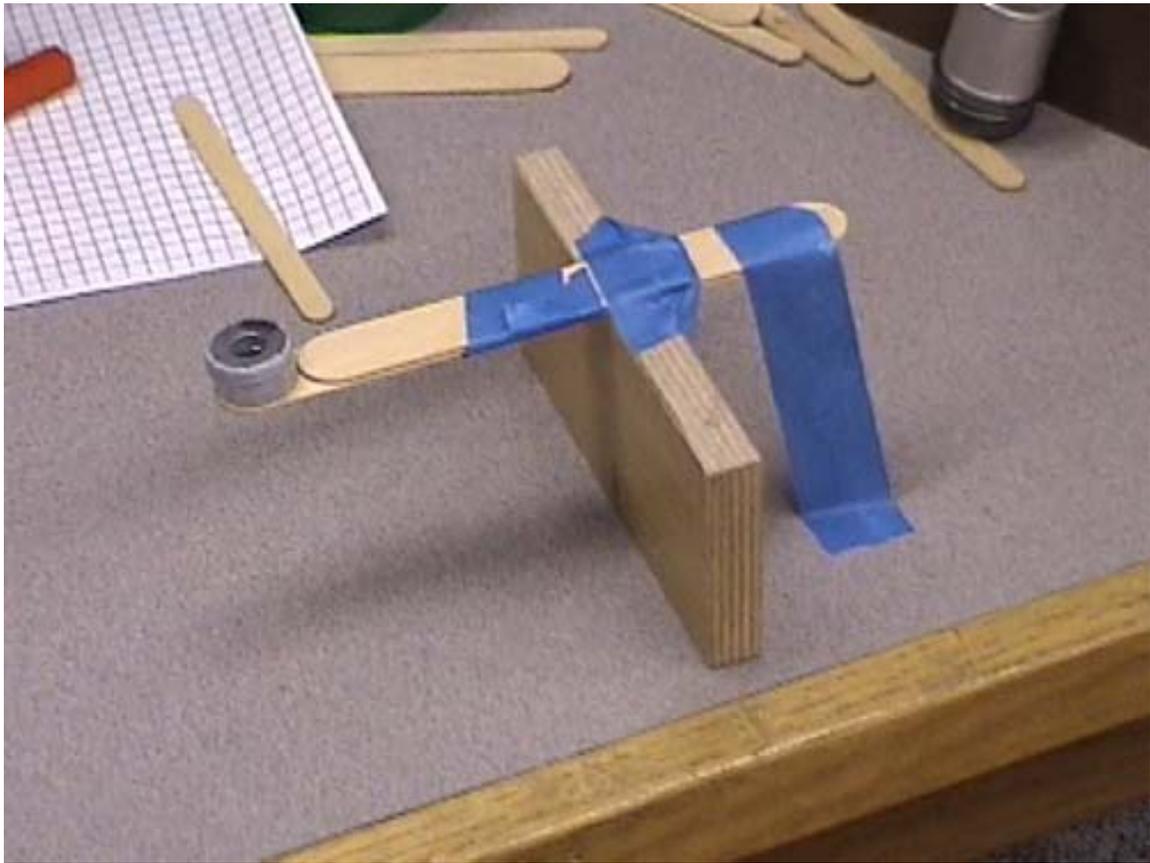
**Figure C9.** Cantilevered weight participant solution (JPEG 32K).



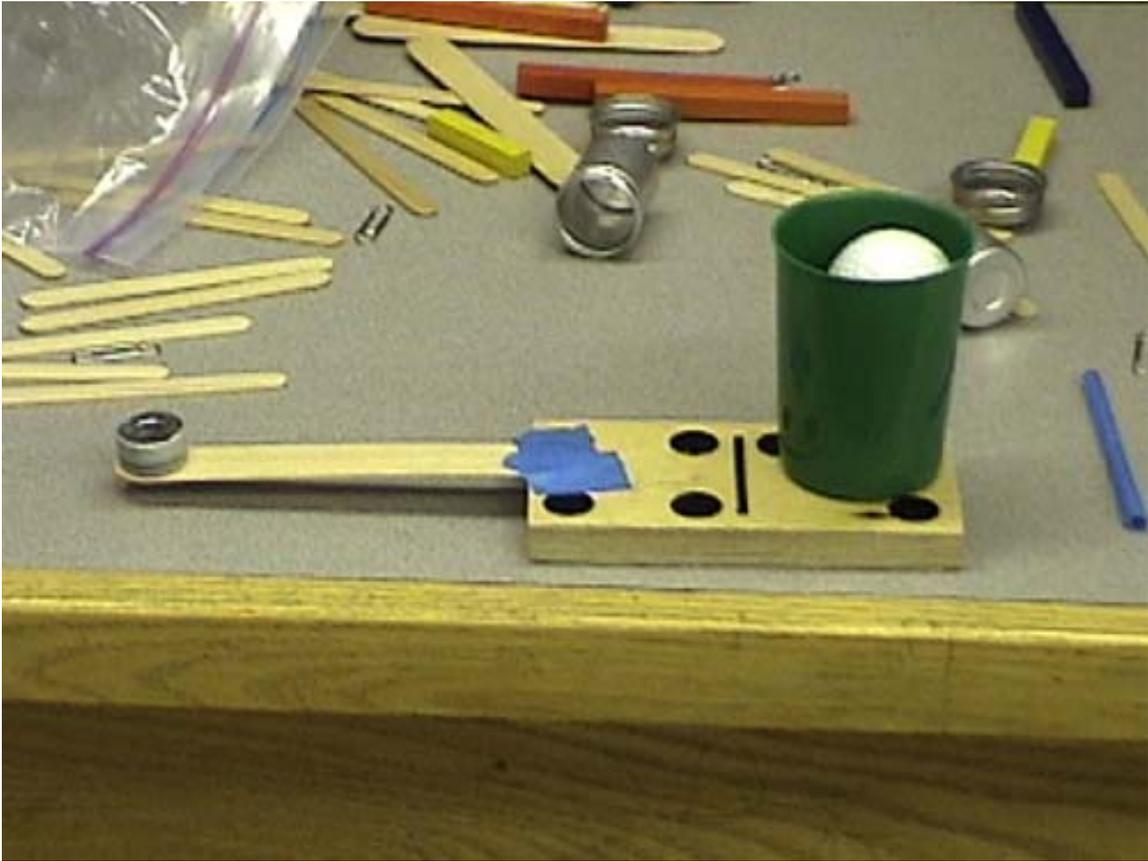
**Figure C10.** Cantilevered weight participant solution (JPEG 46K).



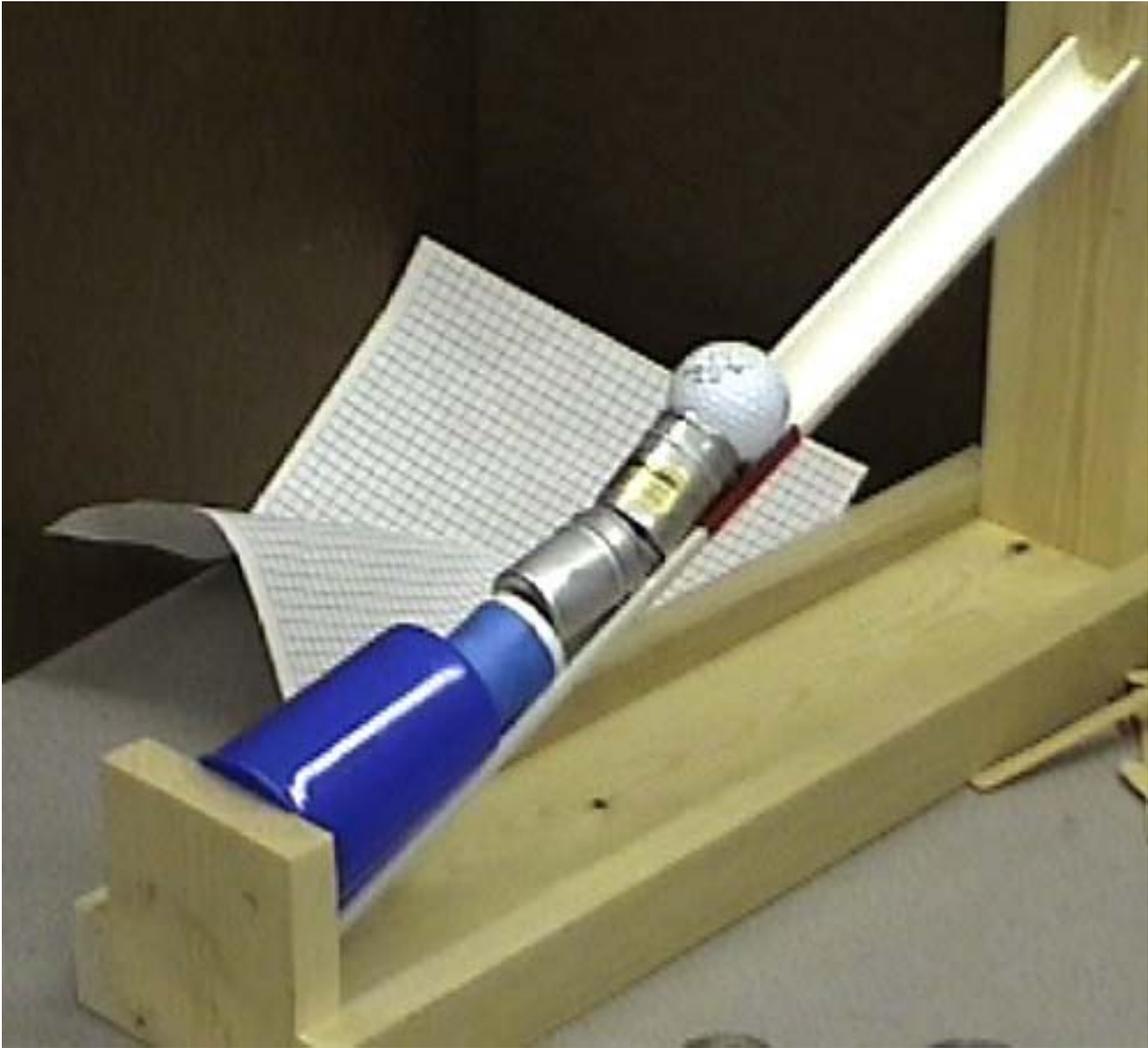
**Figure C11.** Cantilevered weight participant solution (JPEG 34K).



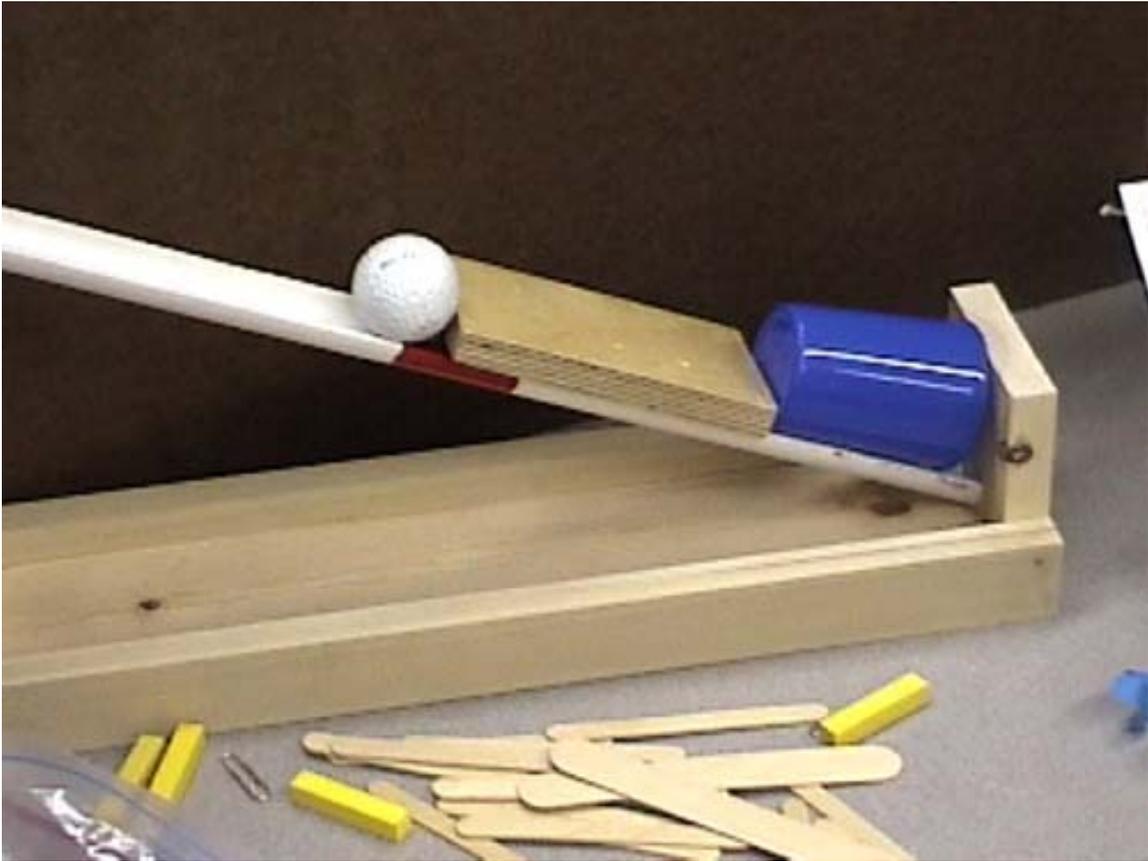
**Figure C12.** Cantilevered weight participant solution (JPEG 38K).



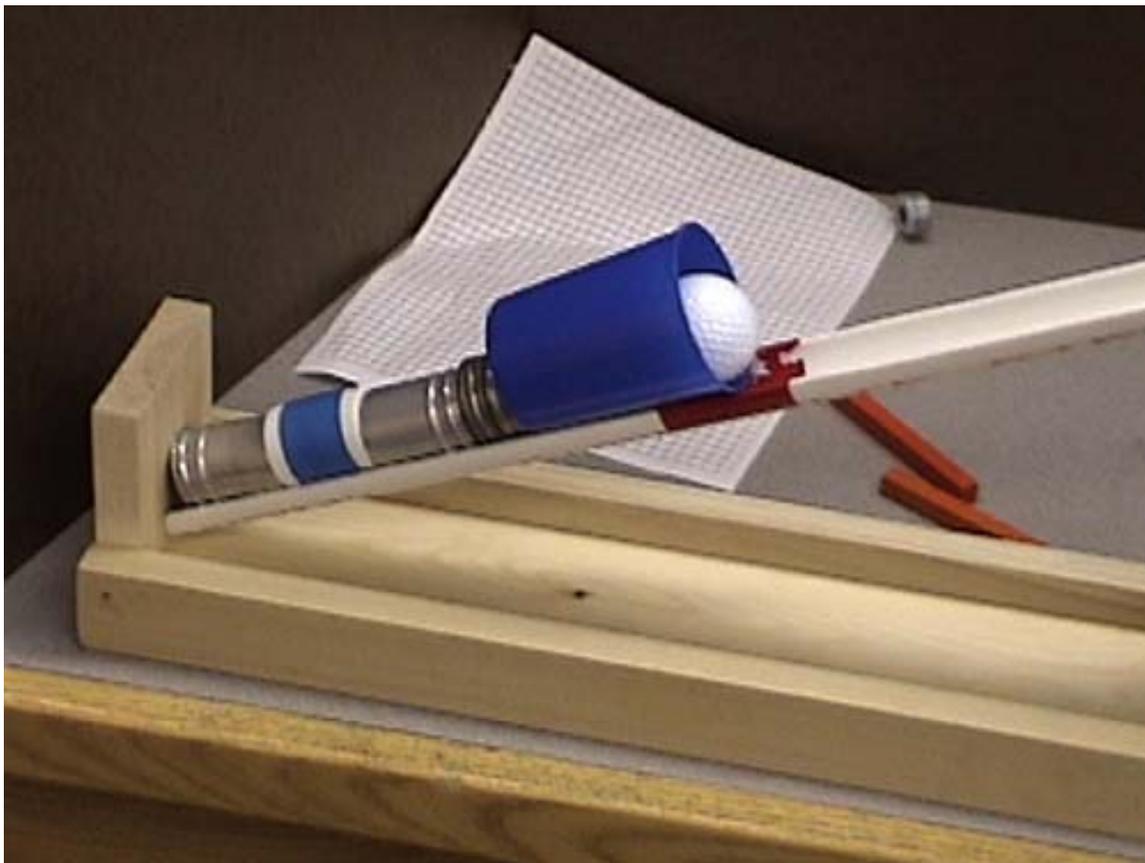
**Figure C13.** Cantilevered weight participant solution (JPEG 40K).



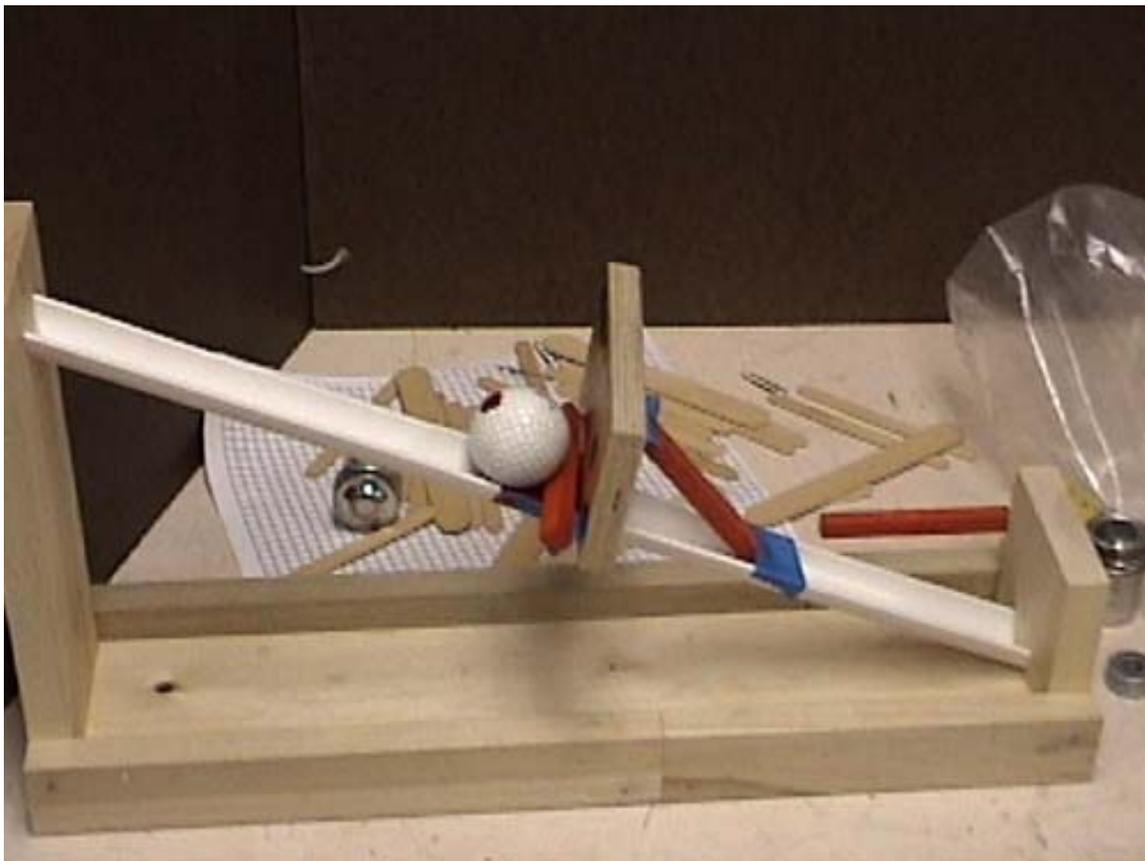
**Figure C14.** Energy absorption participant solution (JPEG 38K).



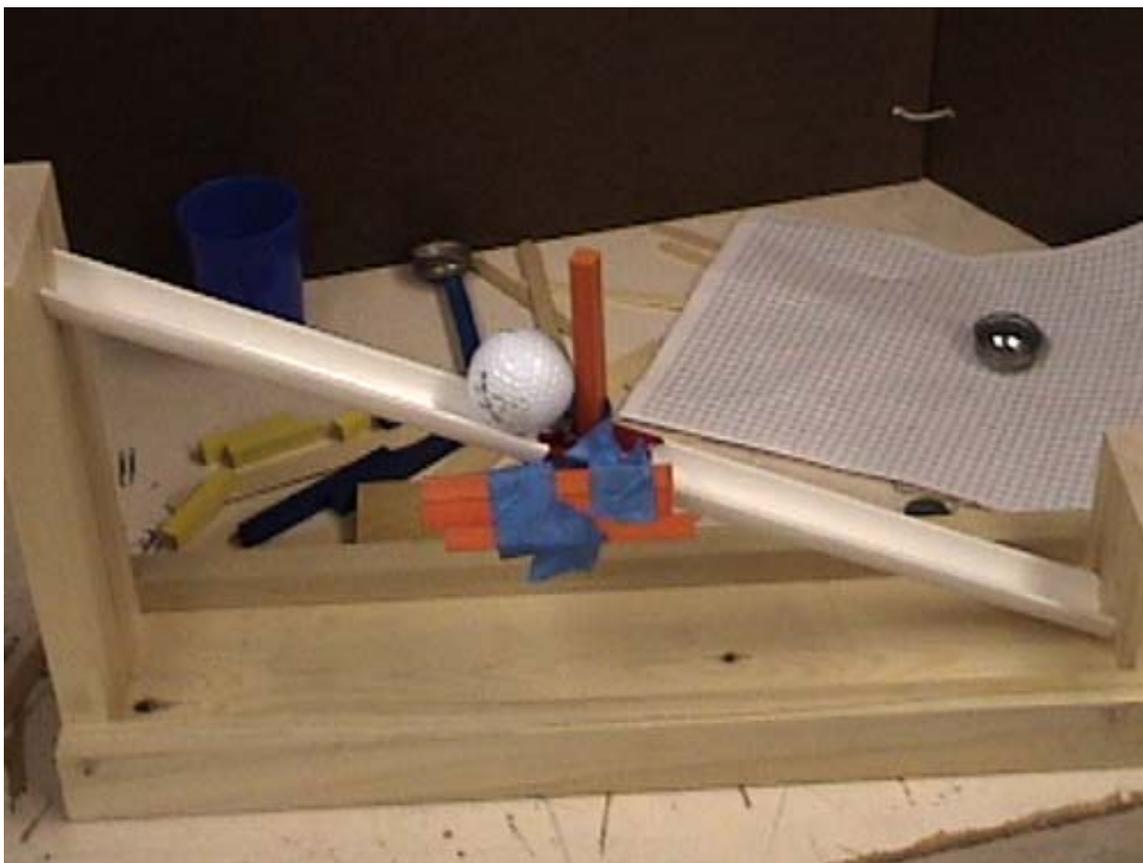
**Figure C15.** Energy absorption participant solution (JPEG 34K).



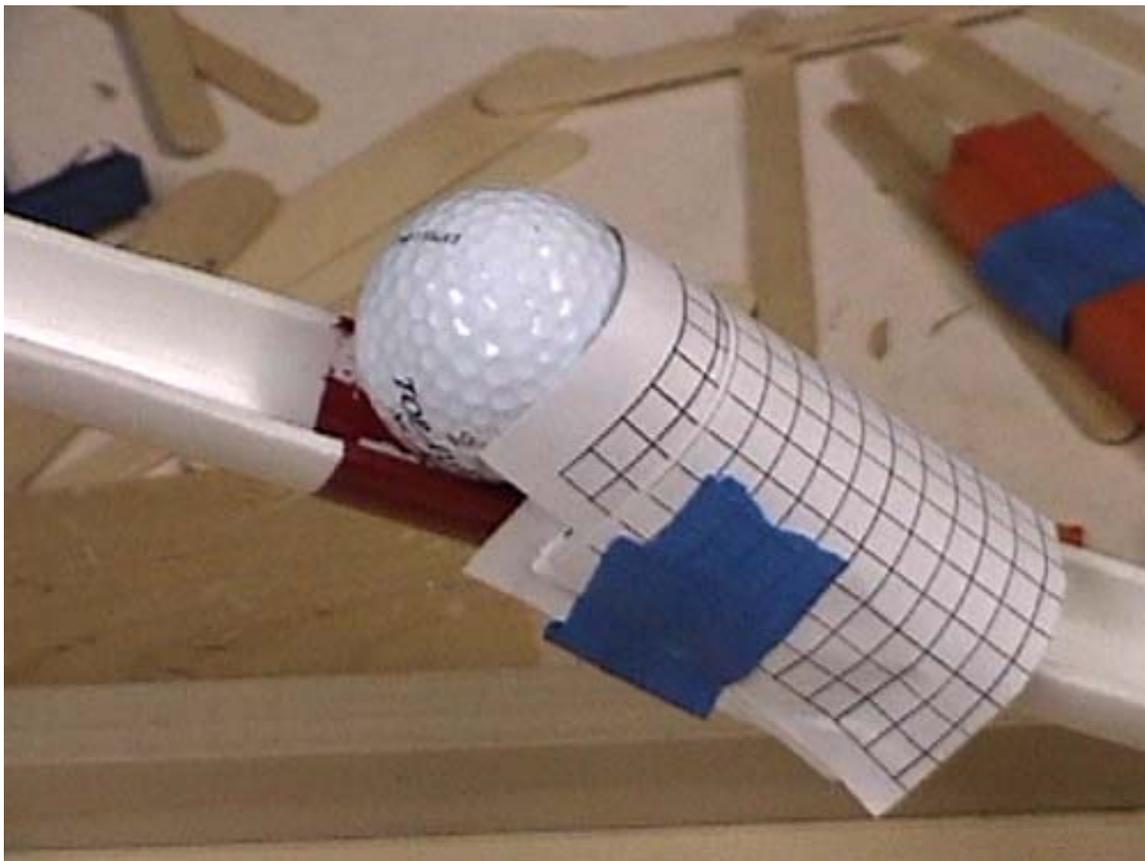
**Figure C16.** Energy absorption participant solution (JPEG 36K).



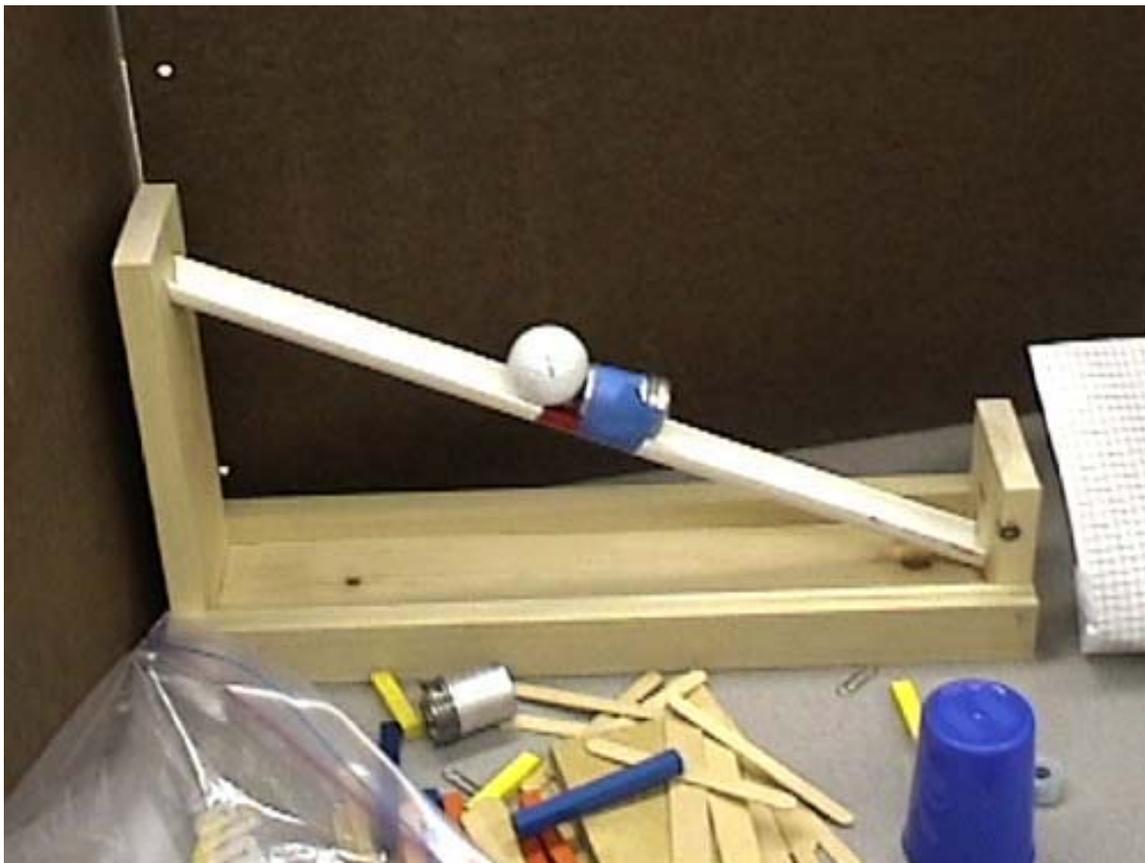
**Figure C17.** Energy absorption participant solution (JPEG 34K).



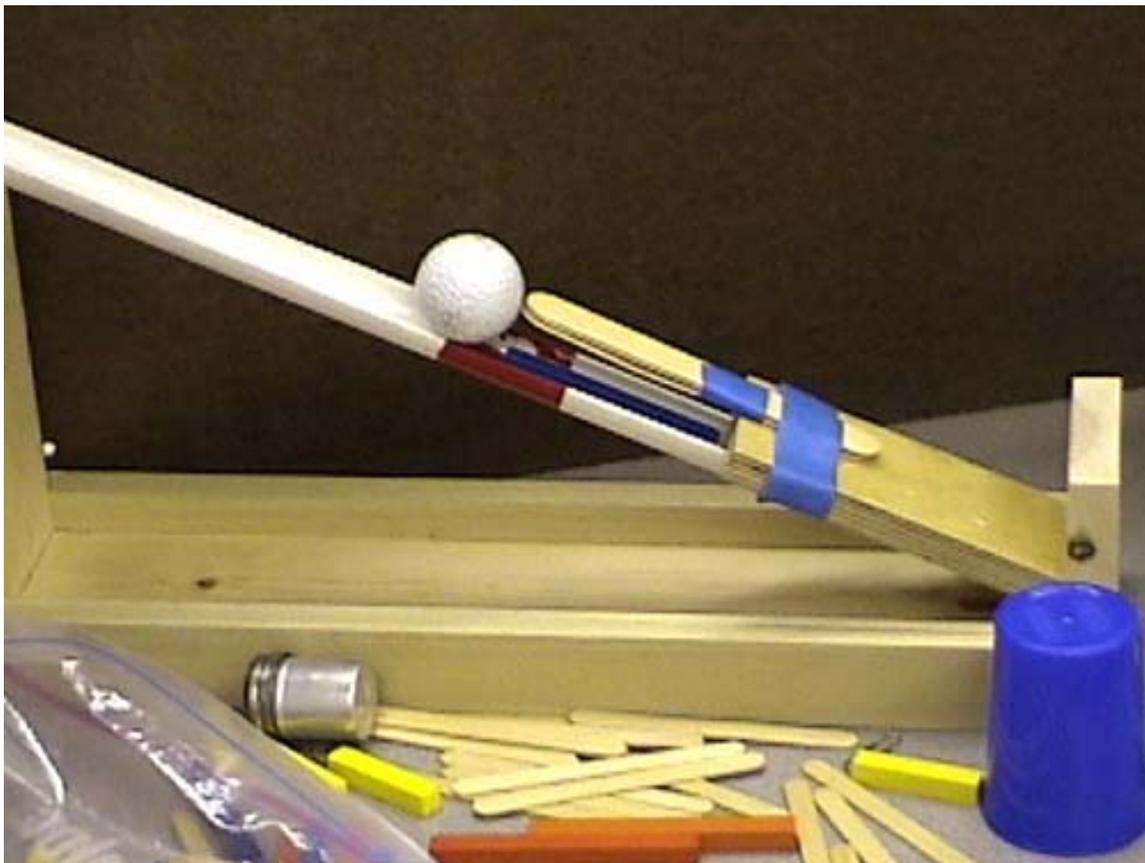
**Figure C18.** Energy absorption participant solution (JPEG 36K).



**Figure C19.** Energy absorption participant solution (JPEG 36K).



**Figure C20.** Energy absorption participant solution (JPEG 36K).



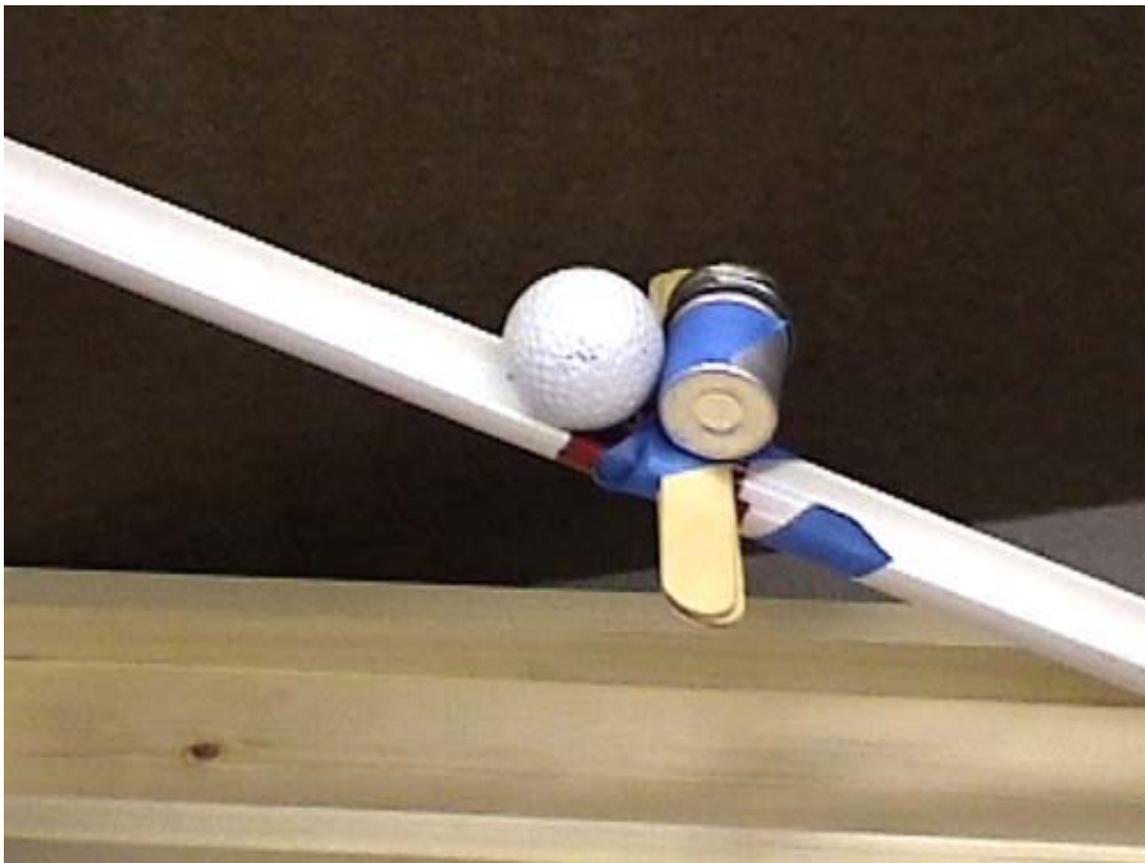
**Figure C21.** Energy absorption participant solution (JPEG 38K).



**Figure C22.** Energy absorption participant solution (JPEG 40K).



**Figure C23.** Energy absorption participant solution (JPEG 40K).



**Figure C24.** Energy absorption participant solution (JPEG 32K).

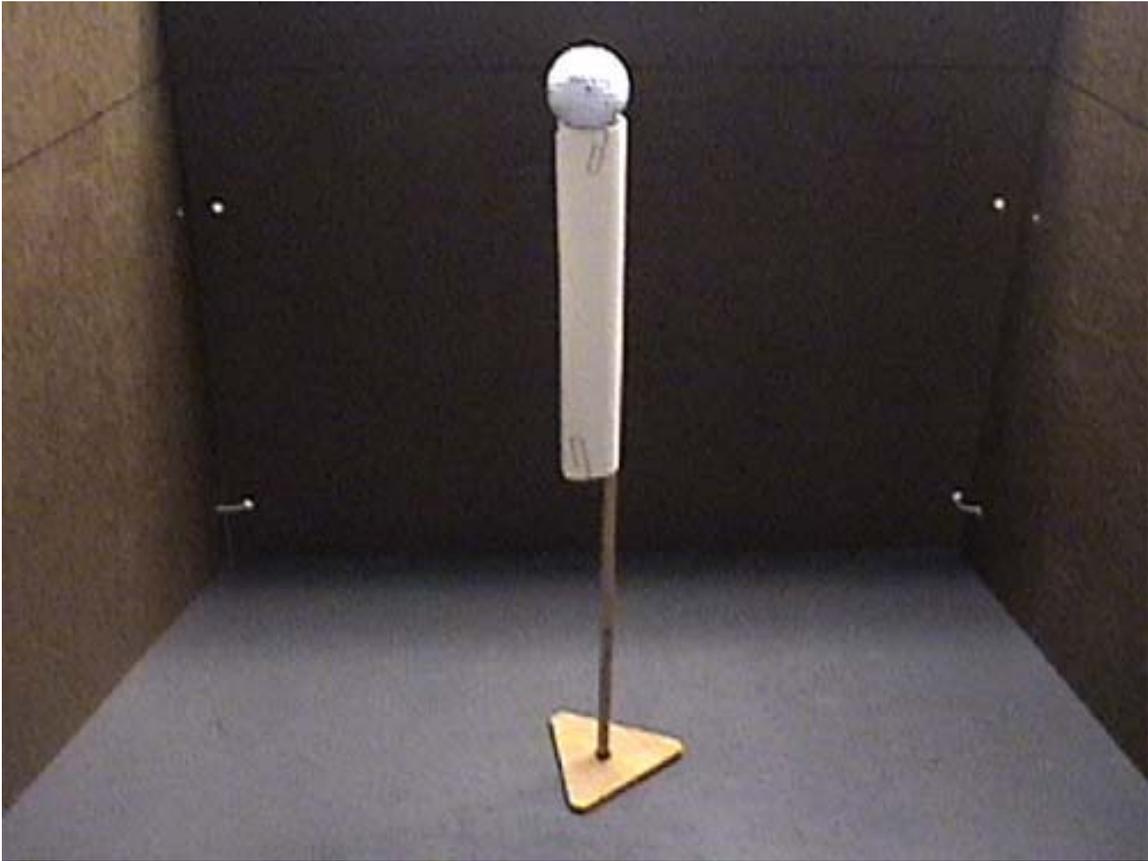
## Appendix D: Experimental Apparatus



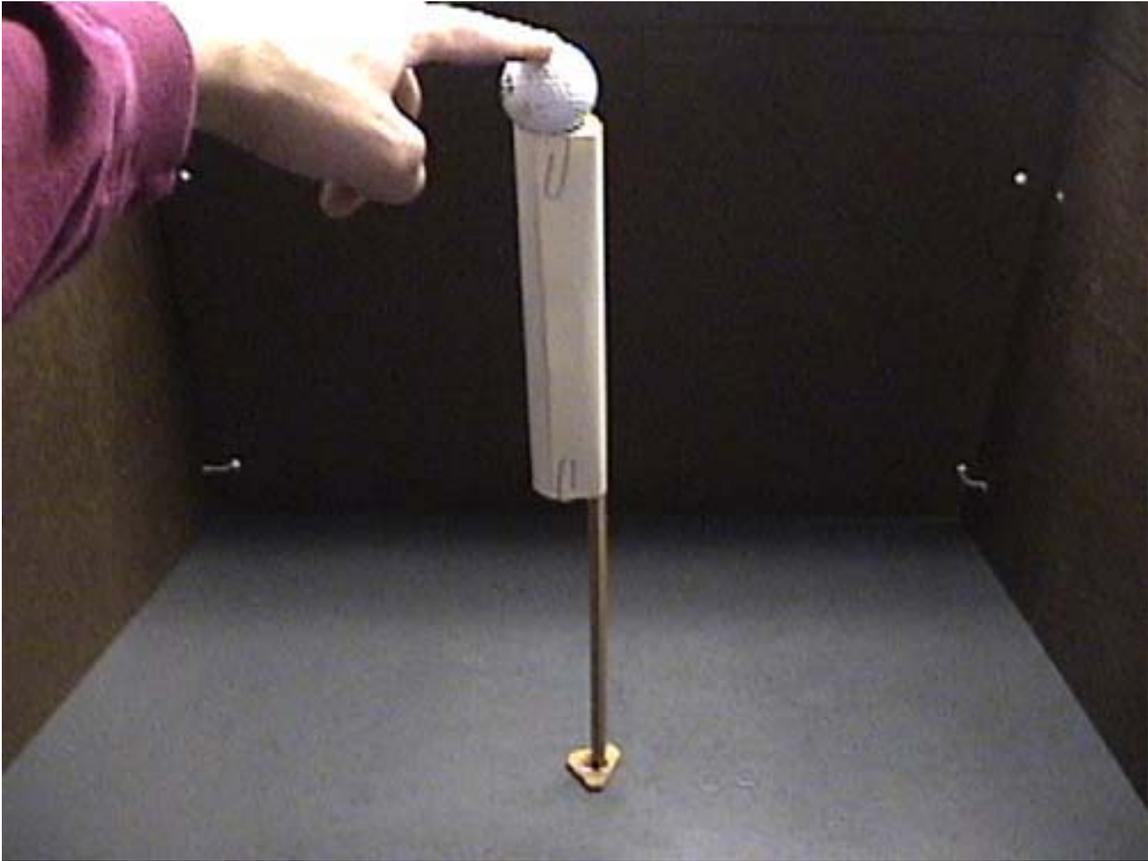
**Figure D1.** Experimental setting (JPEG 42K).



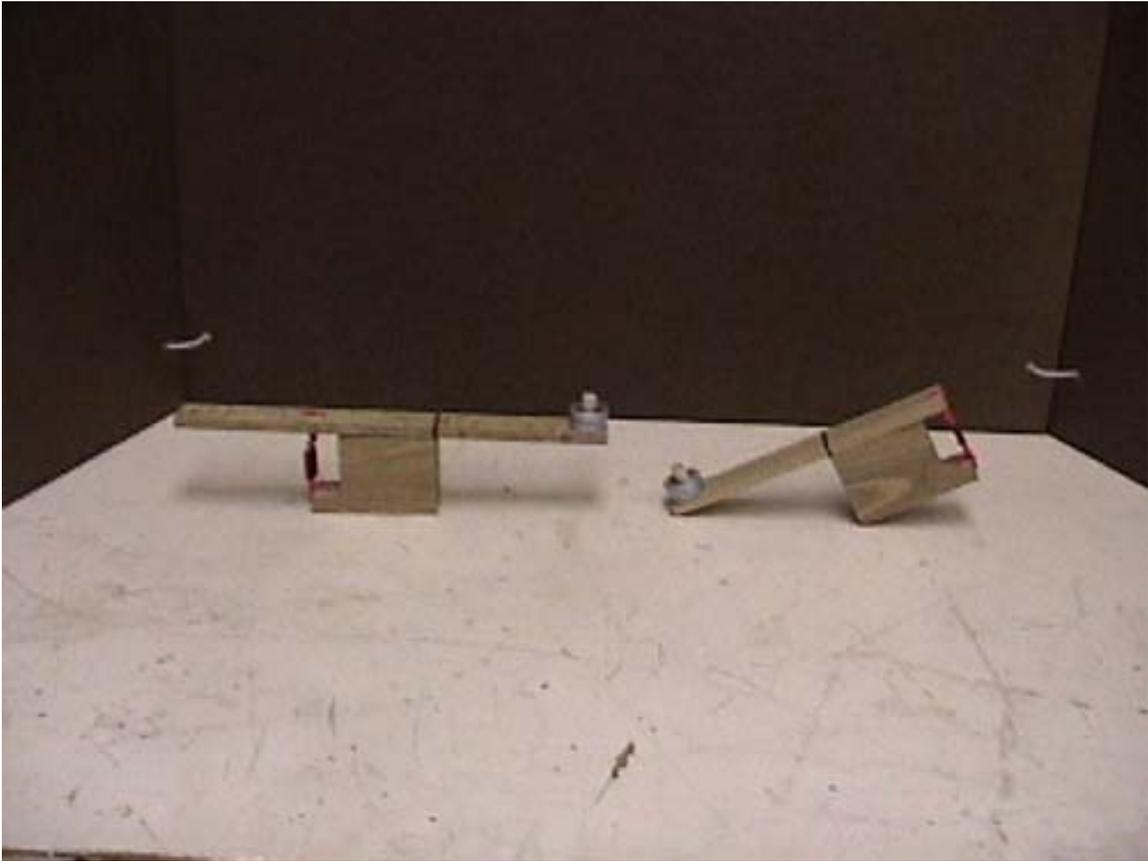
**Figure D2.** Construction materials contained in experimental supply kit (JPEG 36K).



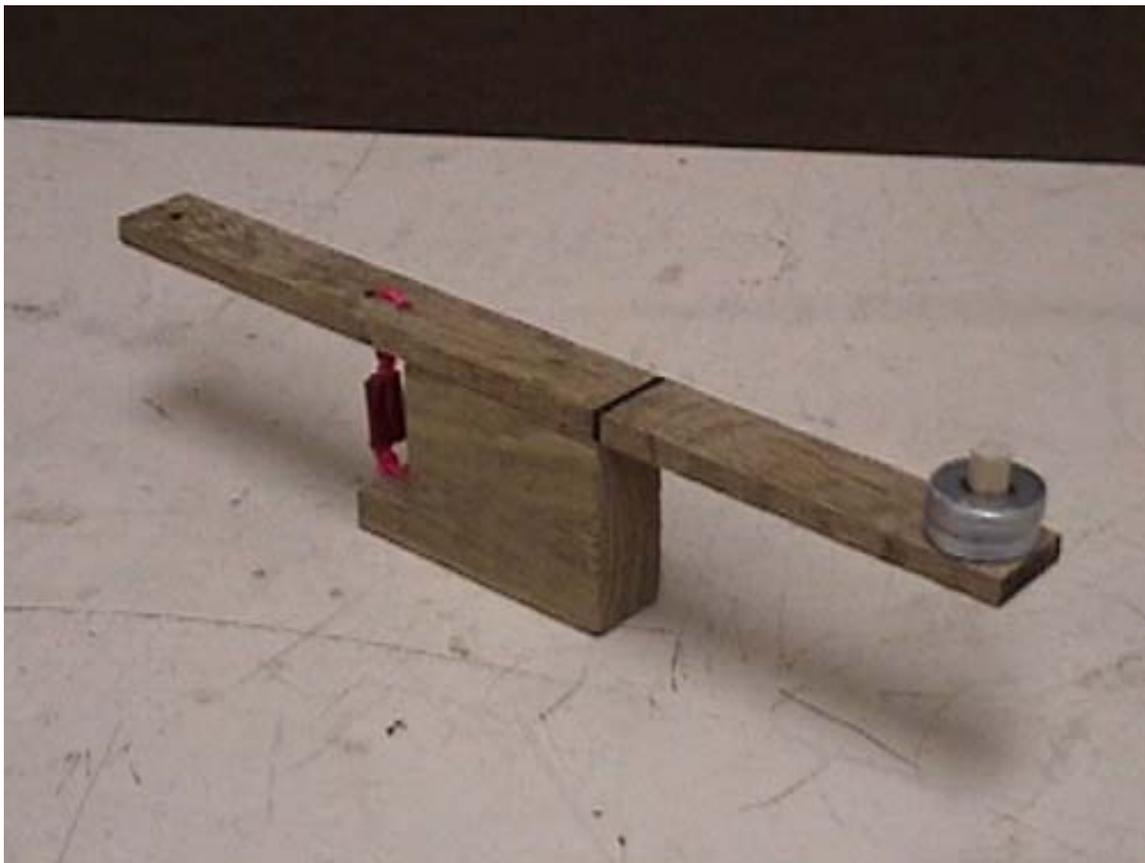
**Figure D3.** Successful example solution for elevated load task (JPEG 36K).



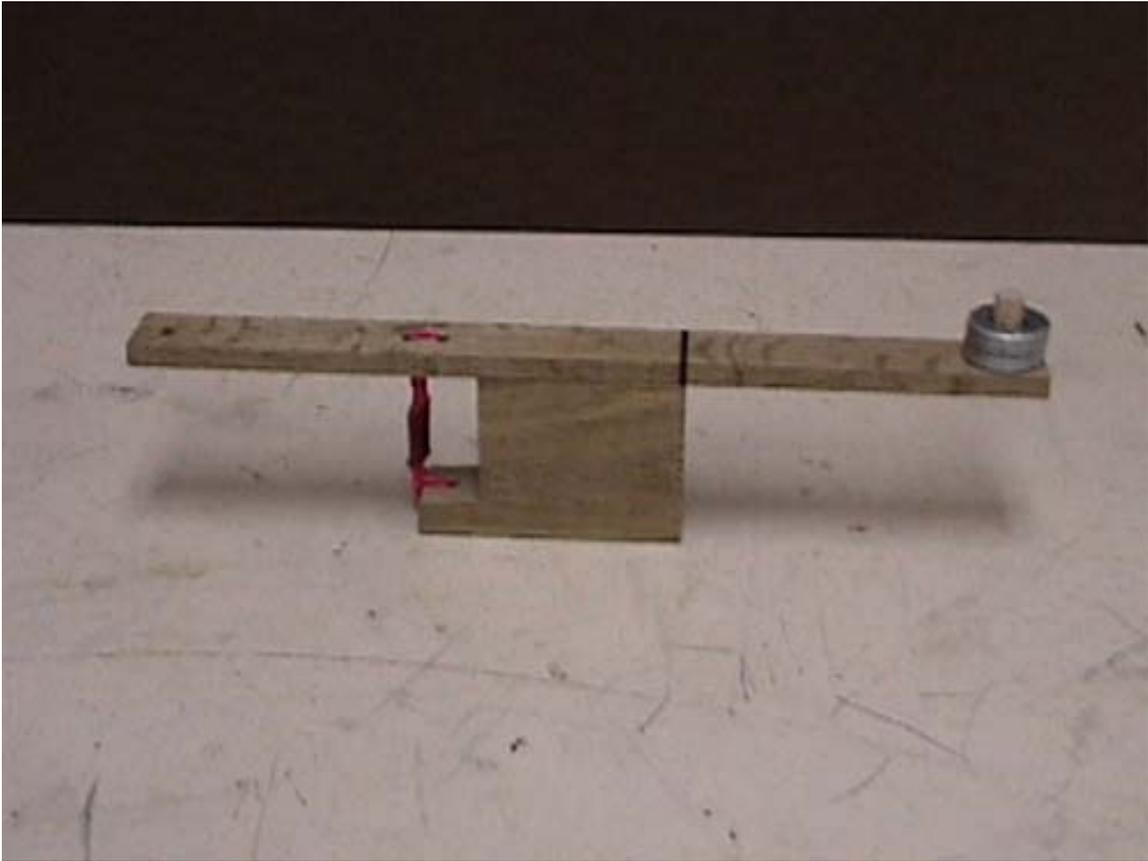
**Figure D4.** Unsuccessful example solution for elevated load task (JPEG 36K).



**Figure D5.** Successful and unsuccessful example solutions for cantilevered weight task (JPEG 36K).



**Figure D6.** Successful example solution for cantilevered weight task (JPEG 36K).



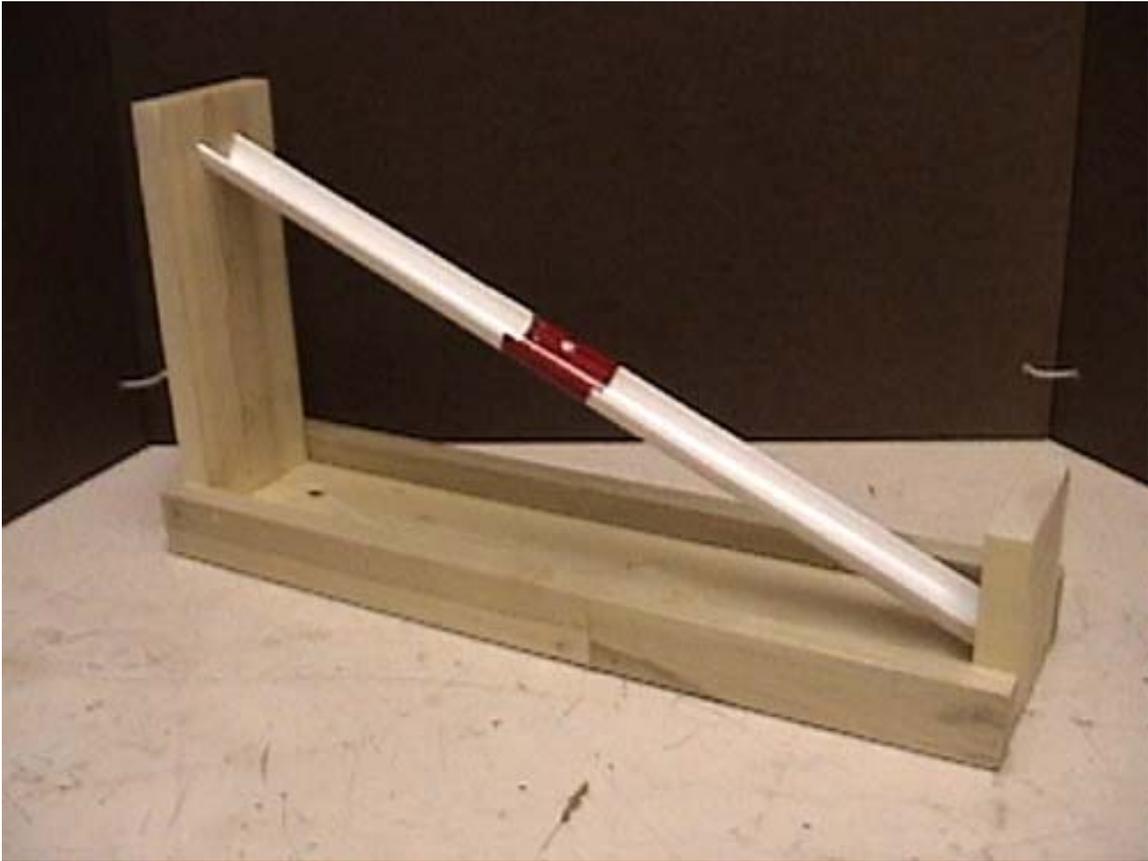
**Figure D7.** Successful example solution for cantilevered weight task (side view, JPEG 36K).



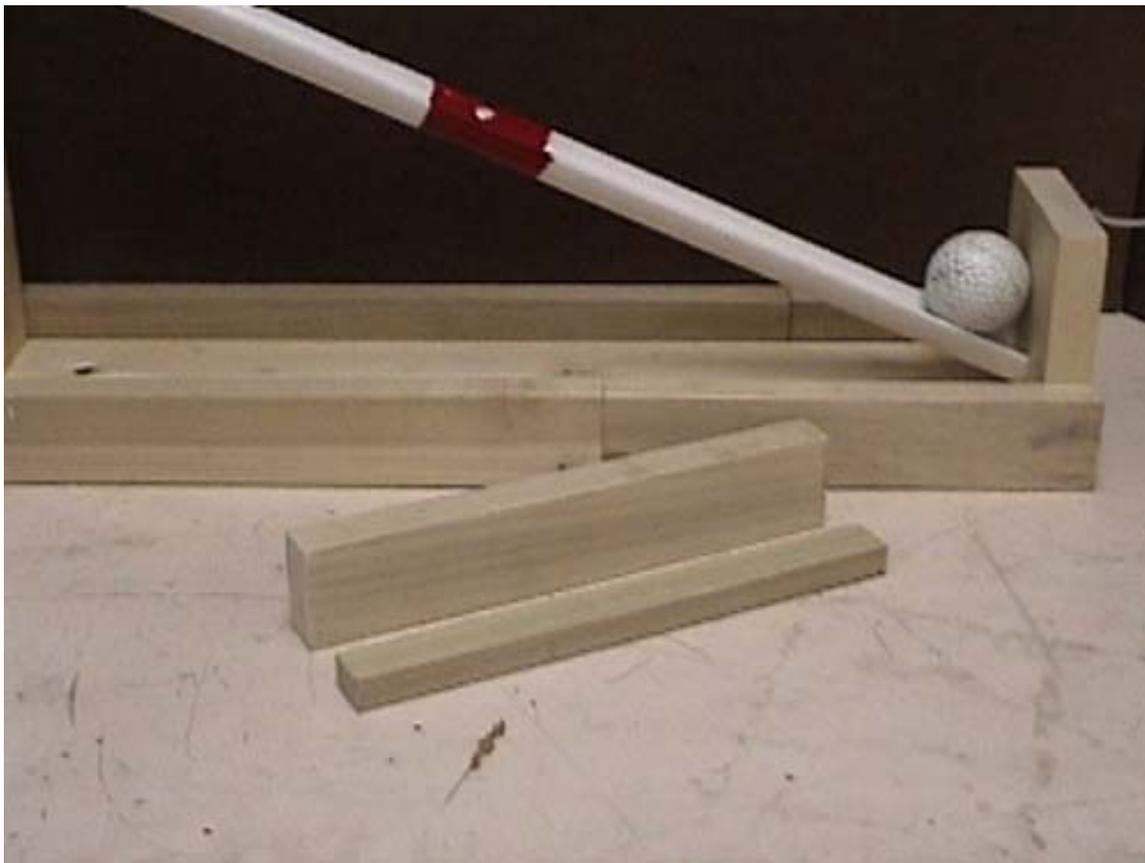
**Figure D8.** Unsuccessful example solution for cantilevered weight task (JPEG 33K).



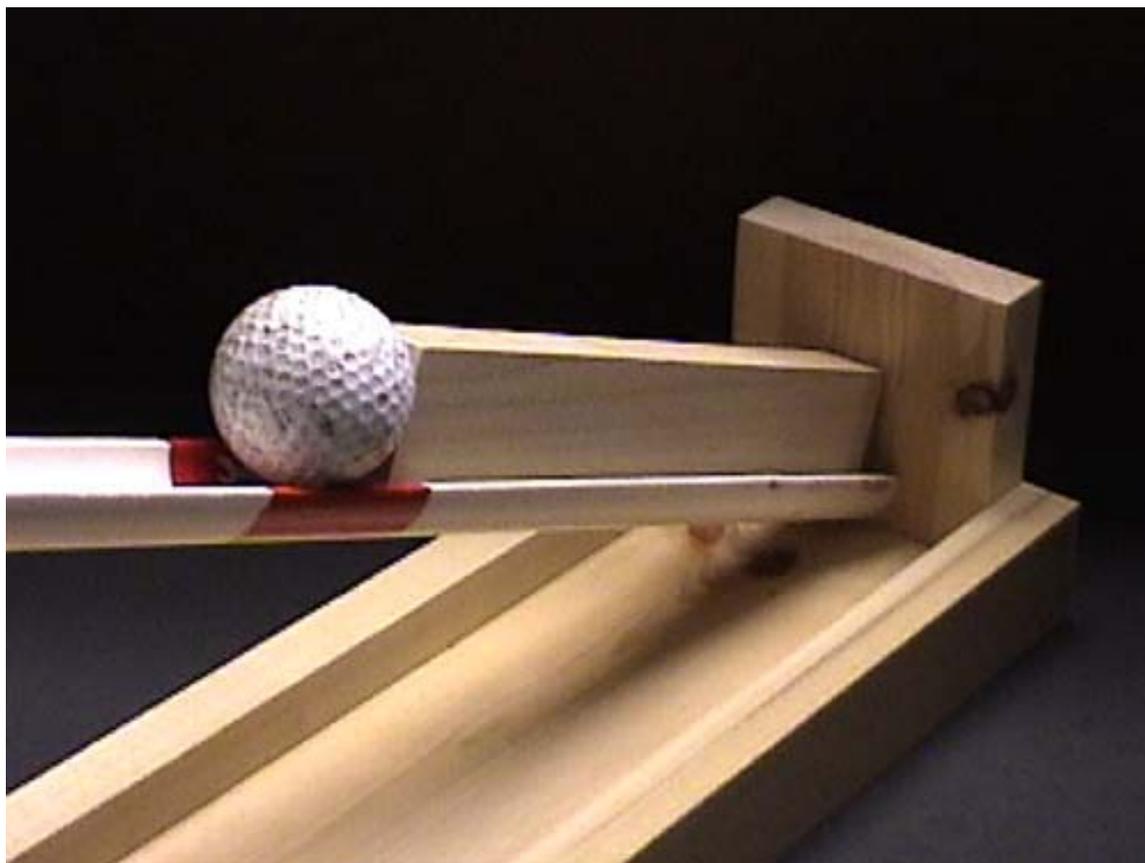
**Figure D9.** Unsuccessful example solution for cantilevered weight task (side view, JPEG 36K).



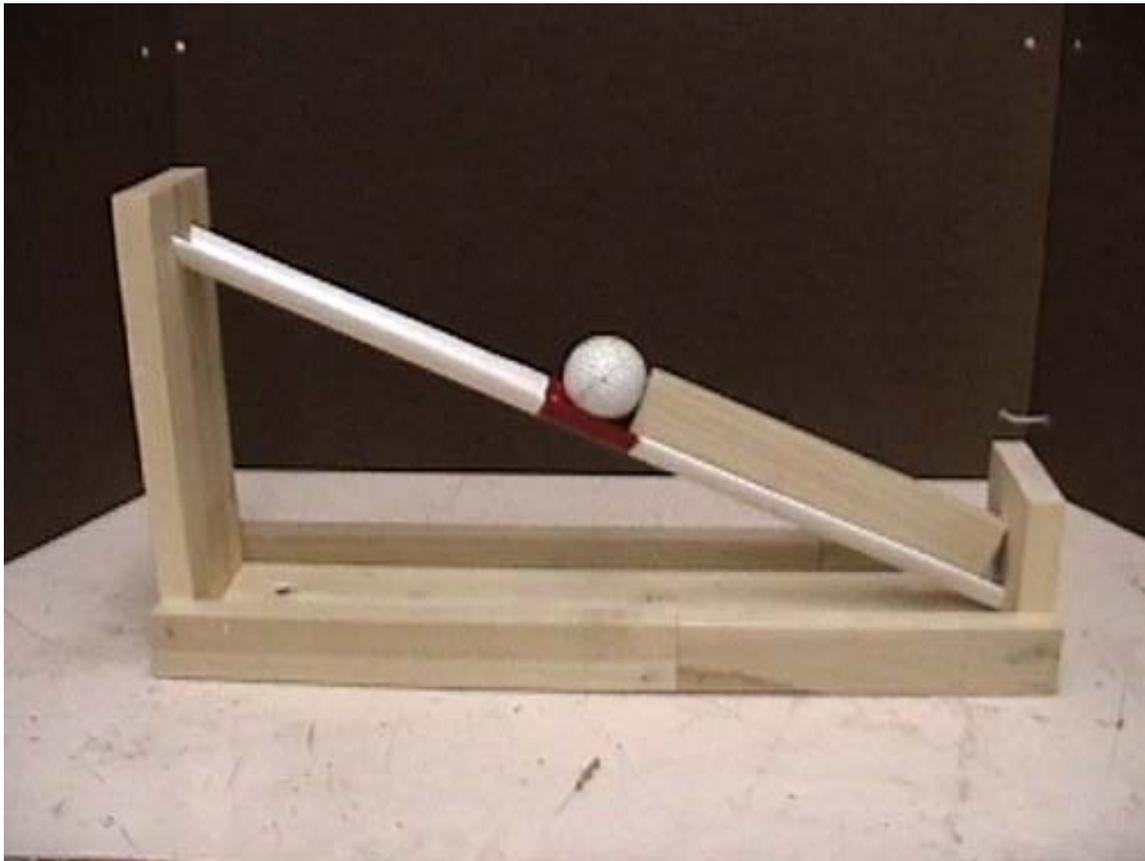
**Figure D10.** Energy absorption task experimental ramp (JPEG 32K).



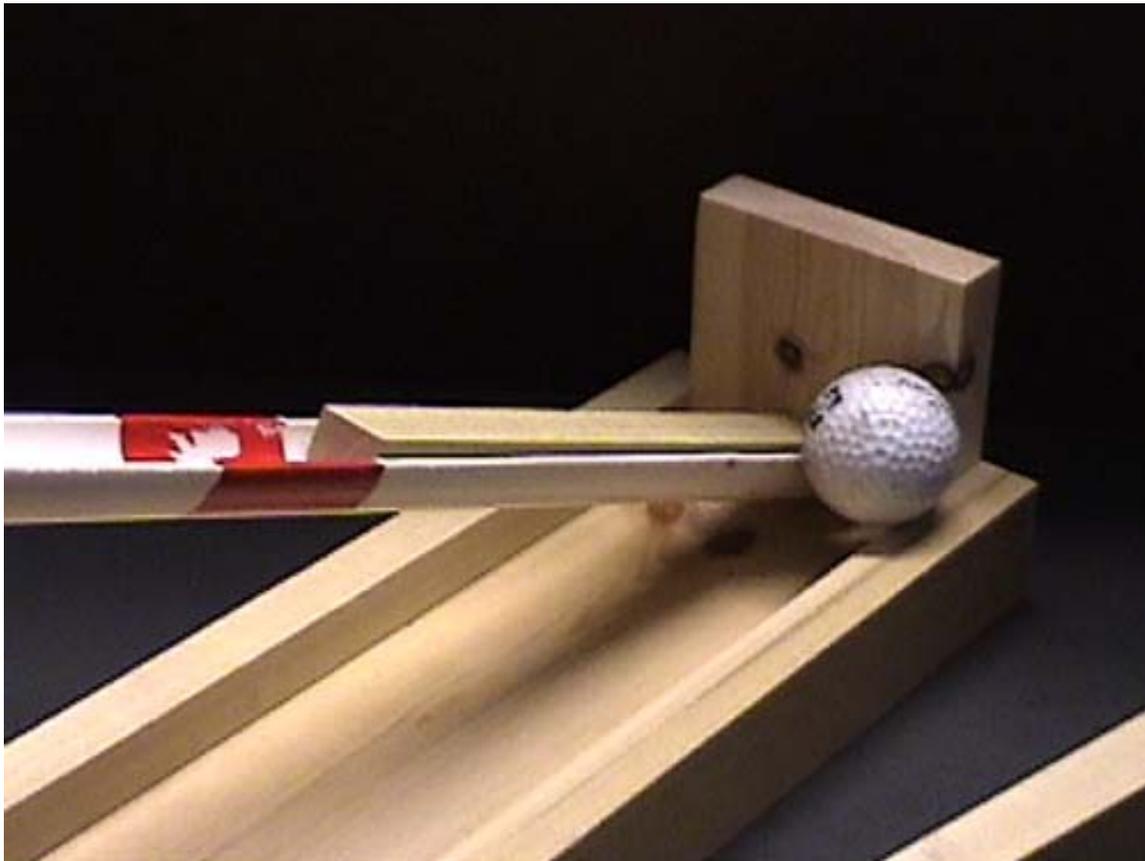
**Figure D11.** Successful and unsuccessful energy absorption example solutions (JPEG 36K).



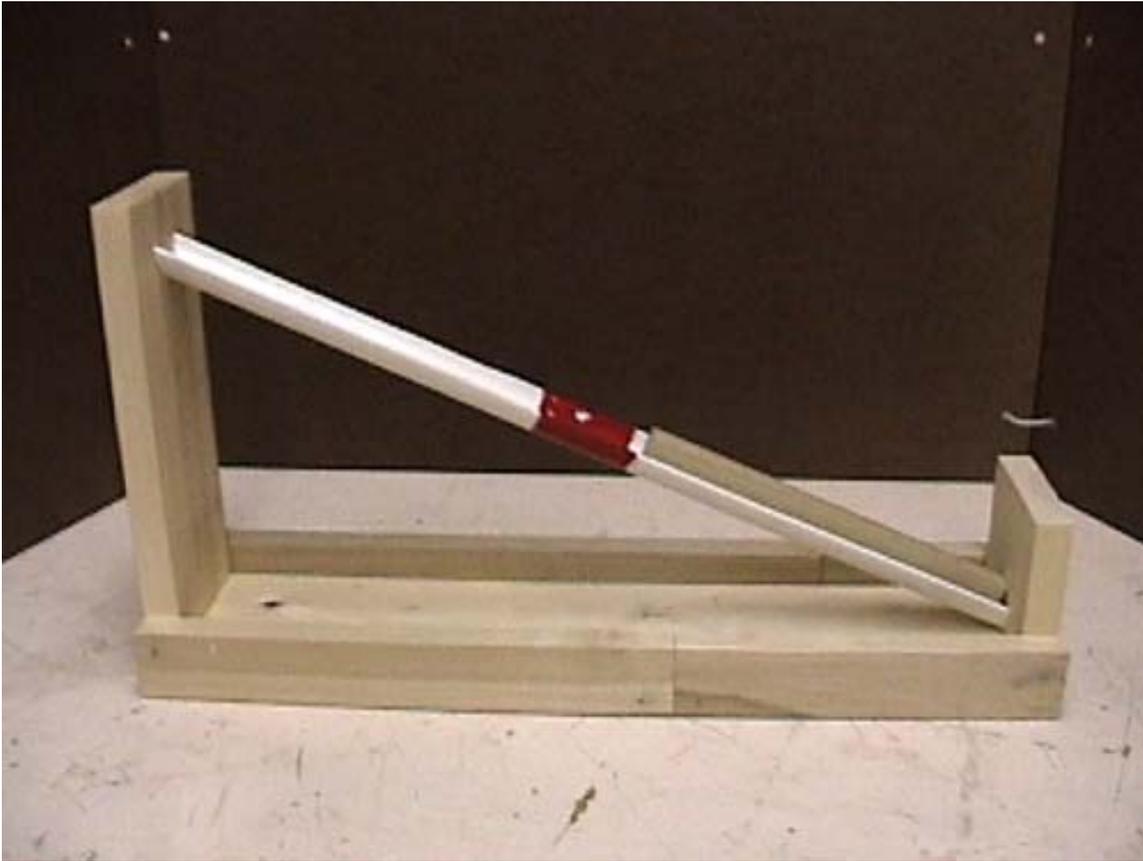
**Figure D12.** Successful example solution for energy absorption task (JPEG 36K).



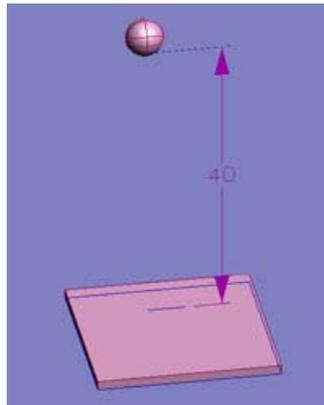
**Figure D13.** Successful example solution for energy absorption task (side view, JPEG 38K)..



**Figure D14.** Unsuccessful example solution for energy absorption task (JPEG 36K).

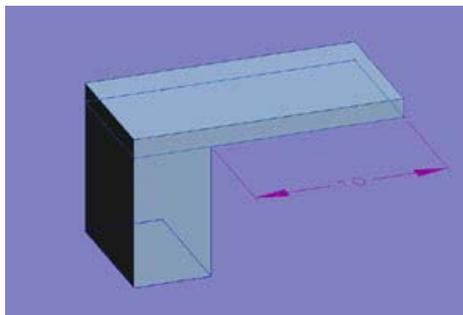


**Figure D15.** Unsuccessful example solution for energy absorption task (side view, JPEG 36K).



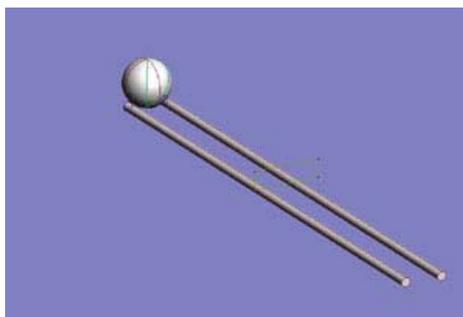
Elevated load diagram

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Cantilevered weight diagram

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Energy absorption diagram

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**Figure D16.** Task diagrams displayed on rear wall of dividers.

**Table D1.**

Example solution dimensions.

Task	Type of Solution	Dimensions
Elevated Load	Successful Example Solution	Height = 45 cm
		Tube Diameter = 4 cm
		Base Width = 10 cm
Elevated Load	Unsuccessful Example Solution	Height = 45 cm
		Tube Diameter = 4 cm
		Base Width = 3 cm
Cantilevered Weight	Successful Example Solution	Height = 7 cm
		Top Length = 25 cm
		Width = 3 cm
Cantilevered Weight	Unsuccessful Example Solution	Height = 7 cm
		Top Length = 16 cm
		Width = 3 cm
Energy Absorption	Successful Example Solution	Height = 4 cm
		Length = 20 cm
		Width = 2 cm
Energy Absorption	Unsuccessful Example Solution	Height = 1.5 cm
		Length = 20 cm
		Width = 2 cm