Teamwork Exercises and Technological Problem Solving with First-Year Engineering Students: An Experimental Study

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ABSTRACT

An experiment was conducted investigating the utility of *teamwork exercises* and *problem structure* for promoting technological problem solving in a student team context. The *teamwork exercises* were designed for participants to experience a high level of psychomotor coordination and cooperation with their teammates. The *problem structure* treatment was designed based on small group research findings on brainstorming, information processing, and problem formulation. First-year college engineering students ($N = 294$) were randomly assigned to three levels of *team size* (2, 3, or 4 members) and two treatment conditions: *teamwork exercises* and *problem structure* ($N = 99$ teams). In addition, the study included three non-manipulated, independent variables: team gender, team temperament, and team teamwork orientation. Teams were measured on technological problem solving through two conceptually related technological tasks or engineering design activities: a *computer bridge* task and a *truss model* task. The *computer bridge* score and the number of computer bridge design *iterations*, both within subjects factors (*time*), were recorded in pairs over four 30-minute intervals. For the last two intervals with the computer bridge, teams started construction of the truss model task, which created *low* and *high task load* conditions for the computer bridge: another within subjects factor.

A repeated measures ANOVA was used to analyze *time* (*computer bridge*) by factor interactions. No significant *time* by *teamwork exercises* or *time* by *problem structure* interactions on *computer bridge* scores were found [$F(2.31, 198.46) = 0.10$, $p = .928$; $F(2.31, 198.46) = 0.03$,

p = .984]. There was a significant interaction between the factors of *time* and *team size* [F(4.62, 198.46) = 2.75, p = .023]. An ANOVA was conducted with the between subject factors on the *truss model* task. A significant main effect was found for *teamwork exercises* [F(1, 86) = 2.84, p = .048, one-tailed], but not for *problem structure* or *team size*. Post hoc analyses were conducted for *team size* on *computer bridge* and *iteration* scores over time, as well as *teamwork exercises* effects for each *team size*. Findings and their implications were reported, along with suggestions for future research on technological problem solving in a team context.

DEDICATION

I dedicate this work to my two families.

To my wife, Patricia, and our child, who is “on the way.”

To my parents, Rex and Margaret.

To my sisters, Suzanne and Martha.

To my parents-in-law, Dagobert and Mery.

To my brothers-in-law, Greg, Mickey, Fernando, and Juan Carlos.

To my sisters-in-law, Beatriz and Adriana.

To my nieces, Brittany Marie, Bailey Cathlin, Noelle Ruth, and Maria Fernanda.

To my nephew, Carter Calloway.

To our child’s other cousin, who is “on the way.”

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File Name	Format	Description
02RegistrationWebSite	Zipped folder	This “zipped folder” includes the HTML version of the registration and information web site.
03AlternativeActivity	PDF	The design brief completed by students who were not in the research study.
04EngineeringWorkSpace	PDF	The engineering workspace plotted from a computer-aided design system. This file requires “zooming in” to approximately 300% to view.
05WPBDv4GUI	QuickTime Movie	A five-minute video that demonstrates some of the features in *West Point Bridge Designer Version* 4.1.
06TeamworkExercise1	QuickTime Movie	*Bandana Cup Marble*: An example teamwork exercise in which teams participated.
07TeamworkExercise2	QuickTime Movie	*Team Build-a-Word*: An example teamwork exercise in which teams participated.
08TeamworkExercise3	QuickTime Movie	*Hole Tarp*: An example teamwork exercise in which teams participated.

Note. All of the above files can be downloaded or viewed from the Web Site page for this electronic dissertation. If this document was obtained in hard copy from UMI ® ProQuest ®, a CD ROM should be included with the above files.

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Chapter 1. Nature of the Study

Overview

Technology educators are concerned with students' technological problem solving. Some technology educators advocate that technological problem solving in groups increases teamwork skills. In fact, it may. This study, however, investigates a converse proposition, which is whether teamwork exercises promote technological problem solving. If teamwork is important, then teachers typically do not want to leave this learning to chance. Teachers want to provide their students with a meaningful teamwork experience. Furthermore, the technology education classroom, with its breadth of content area, technical tools, classroom size, and material resources, may provide an ideal setting to implement team pedagogy, teamwork exercises, and team technological problem solving.

Books are being published, like *Team-Based Learning: A Transformative Use of Small Groups in College Teaching* (Michaelsen, Knight, & Fink, 2004), which suggest that team-based learning is superior to small group learning with some subject matter. Propositions such as these, however, have not been extensively researched in educational settings. As with all social science phenomena and educational research, it is unlikely that one variable only will account for a large portion of the variance. Therefore, this study includes several manipulated and non-manipulated variables to investigate possible impacts on team technological problem solving.

Importance and Need for the Study

Students are often placed in groups to work on class projects, and industry workers are placed in groups to solve problems. Although instructors or managers imply, or even explicitly state, "use teamwork," they often give little or no instruction on how to work together effectively. From a review of the research on individualistic, competitive, and cooperative education, Johnson and Johnson (1990) concluded, "Simply placing students in groups and telling them to work together does not in itself promote greater achievement" (p. 34). Many educators may not only value group work for a more productive end product, but those educators may also have improved teamwork skills as one objective. In addition to teamwork instruction, the processes that assist a team with problem formulation of a technological problem have not been investigated.

Team Pedagogy in Higher Education

The concept of teamwork and the practice of placing students into teams are probably increasing in educational settings. A portion of this increase may be, in part, due to the educational aim of preparing the next generation. The 1970s and 1980s saw a tremendous growth in the number of teams in the workplace (Wesner, 1995). Baker, Boser, and Householder (1992) suggest that the push toward problem solving and teamwork in education is partly stemming from occupational needs.

The concepts of teams and teamwork have increased in higher education course and curriculum descriptions. The 2003-2004 undergraduate course catalog at Virginia Tech uses the word *teams* or *teamwork* over 70 times. For example, in its curriculum description, the Biological Systems Engineering Department states:

> … emphasis on design and synthesis in a **team** environment … the program emphasizes computer, communication, and **teamwork** skills … Design and **teamwork** experiences are integral parts of the program … Students work in **teams** to design, build, and test a solution to an assigned problem [all emphasis added] … (Virginia Tech, 2004).

In addition, the undergraduate catalog uses *teams* in twenty-seven different course descriptions. For example, in *English 3084* "… students engage in collaborative exercises intended to sharpen their teamwork, editing …" (Virginia Tech, 2004).

Team experiences are now a part of the engineering curriculum in higher education. ABET, the Accreditation Board for Engineering and Technology, accredits over 2,500 programs at 500 universities and is the accrediting board for engineering and engineering technology programs at colleges and universities (ABET, 2004). ABET states in its 2004-2005 program evaluation criteria that “Engineering programs must demonstrate that their graduates have: … an ability to function on multi-disciplinary teams … [and] an ability to identify, formulate, and solve engineering problems” (ABET, 2003, p. 2). In addition, ABET states that technology programs must, “demonstrate that graduates have: … an ability to function effectively on teams … educational objectives … are typically demonstrated by the student and measured by the program at the time of graduation” (p. 5). It is unclear how students are measured on their ability to function in a team, but it should be safe to assume that if they are being measured on teamwork, then students must have been provided with educational experiences to help meet that objective.

Teamwork and learning experiences in teams may not have always been a part of the engineering and technology curriculum. In the 1999-2000 academic year, the Virginia Tech engineering section of the undergraduate catalog listed the objective of “an ability to function on multi-disciplinary teams” for the first time (p. 203). It seems that part of this objective is met through national competitive events, which are listed for the first time in the 2000-2001 course catalog, even though competitions started before this time:

> Virginia Tech aerospace students won top honors during the 1999 … design competitions … A cross-country cooperative team of students … won first place in the Undergraduate Team Engine Competition … A Virginia Tech team placed second in the Undergraduate Team Aircraft competition … The Tech chapter has won the region IV competition for nine out of the past ten years (p. 207).

Team experiences are also included in coursework requirements. In describing its curriculum in the 1996-1997 undergraduate course catalog, the Biological Systems Engineering Department includes teamwork experiences for the first time:

> Design and teamwork are integral parts of the program. … second year, students are required to complete a year-long design project. Students work in teams to design, build, and test a solution to an assigned design problem. …The senior year design sequence gives students a comprehensive design experience in which they utilize much of the knowledge they have acquired through their other courses. Students work, in teams or individually, on 'real-life' engineering problems (p. 196).

The academic year 1988-1989 was the first time the word *team* was used in a course description. For example, the Agricultural Engineering Department lists a senior team experience: "*4124: Design Project and Report:* Engineering Design Experience through independent team approach to solutions of design problems" (p. 214). Although the *Design Project and Report* course number (4124) did not exist in 1987-1988, its predecessor seems to be: "*4900: Project and Report*: Investigation and report on a supervised project. … May be extended over several quarters [ten week sessions; italics added]" (p. 188). Therefore, teams were not mentioned in the academic year 1987-1988. Also, in 1988-1989, the Industrial Engineering Department lists "working within teams" in one senior level course description (p. 214). The first academic year that a course description includes anything resembling a team approach is 1978-1979, though this was not referred to as a *team*: "[Mechanical Engineering Department section, undergraduate course catalog] *Complexity of Socio-Technological Problems*: … Includes readings, guest lectures, discussion, and project work in small groups on real problems [italics added]" (p. 217). In this year, it is not clear whether this resembled more cooperative learning or team-based learning, which will be described in Chapter Two.

During the same years described above, the Technology Education Program does not list *teams* in its curriculum or course descriptions found in the undergraduate catalog. However, the team approach at Virginia Tech probably began in 1982, with the introduction of a manufacturing course. For example, the Fall 2002 syllabus for *3454: Manufacturing in Technology Education* had a course goal of: “To provide problem solving opportunities using the team approach” (LaPorte, 2002). Syllabi from earlier years were not obtainable. As an undergraduate technology education major, the teamwork consultant, who is described in Chapter Three, took this manufacturing course in 1986.

Possibly, technology education, which was formerly known as industrial arts, was the first school subject to introduce a team approach into course content. College students preparing to be industrial arts educators were exposed to teams through manufacturing course content. Maley (1973), with his *Maryland Plan* curriculum, and Towers, Lux, and Ray (1966), with their *Industrial Arts Curriculum Project*, were the first professionals in the field to introduce formal curriculum documents that included such manufacturing course content. Maley had been experimenting with a manufacturing approach long before 1973. However, the manufacturing roles, which were representative of industry, may have been prescribed by the teacher, rather than developed by the students. For example, Maley (1973) stated, “This role-playing [of adult occupations] permits the teacher to observe the student in leadership activities and teamwork experiences. … The role-playing is a dynamic, complex experience” (p. 80).

Team Pedagogy in K-12 Technology Education

Currently, teams and teamwork are being promoted in K-12 technology education with great fervor. Today, the student team experience usually has less defined occupational roles than in Maley’s era. For example, the International Technology Education Association (ITEA) states that technology education involves “Working individually as well as in a team to solve problems” (ITEA, 2004). ITEA continues, “The International Technology Education Association is the largest professional educational association, principal voice, and information clearinghouse devoted to enhancing technology education through experiences in our schools (K-12).” There are over 5,000 members internationally in the ITEA, and the majority of members are from North American countries. As part of membership dues, every ITEA member is mailed the *Technology Teacher,* which is a trade journal that primarily includes classroom pedagogy articles.

In the September 2004 issue of *The Technology Teacher*, there is an article entitled *Robot Design Challenge.* This article describes a competitive event in which third through sixth graders are placed into teams of five and asked to design a robot which meets certain design constraints (Roman, 2004). Each team of students has the roles of team leader, design engineer, customer representative, human interface designer, and economist. In a section of this same article entitled *The Importance of the Challenge*, Roman states the following:

> This exercise is designed to foster teamwork and reinforce communication skills, teaching making a tradeoff between the roles they assume, and integrate their various roles and viewpoints together into a final design. … students must reach consensus … The team leader of this exercise should have good leadership skills, be articulate, and able to provide direction and counseling to the team to encourage them to reach their goals if they get stuck. … It also would be very helpful in this exercise if time were spent in the classroom beforehand discussing creativity techniques and how teams are much more creative than individuals. … The design challenge is a mirror on the world, very similar to how projects are managed and led in industry … People who can work in teams and know how to carry out a project are in high demand (p. 10).

After reading this article, a teacher may have many unanswered questions. For example, it is not clear how the team leader is designated or how he or she develops the skills to lead a team of five to complete a successful project. It is also unclear how having a leader promotes teamwork skills in the rest of the team members. In addition, it is not clear whether there is empirical evidence to suggest that teams are more creative than individuals.

Teamwork in the Standards for Technological Literacy

ITEA (2000) published content standards for K-12 technology standards in the *Standards for Technological Literacy (STL)*. These standards are to be implemented by technology educators, as well as teachers from all other school subjects. *STL* uses the words *team*, *teams*, or *teamwork*, a total of seventy-four times. For example, in relation to design projects, the authors of the document state, "Students generally work in teams when building their design proposals …" (p. 6). One vignette in the *STL* has an evaluation category of *teamwork*. The vignette states, "The students were evaluated in three categories: *Teamwork*—Did the team work together? Were they able to produce a completed product?" (p. 122). In this vignette, students are being assessed on both teamwork and the end product, but there is no indication that the students were provided with instruction on teamwork. If the teams were not able to produce a workable product, it may have been due to a lack of teamwork skills.

Brainstorming is another methodology promoted by the *STL* (ITEA, 2000). The document uses the words *brainstorm* or *brainstorming* a total of 23 times, typically in conjunction with teams or groups. The following four quotes from the *STL* illustrate this use in a group or team context:

1. Because it is particularly helpful for several people to **brainstorm** ideas, students will generally work in groups at this stage (p. 6).
2. Once the problem is determined, **brainstorming** becomes an important group problem solving technique for generating as many ideas as possible (p. 103).
3. **Brainstorming** is a group problem solving design process in which each person in the group presents his or her ideas in an open forum (p. 103).
4. Ms. C then divided the class into groups of four to five students, and they began **brainstorming** various design ideas (p. 122), [all emphasis added].

As will be discussed further in Chapter Two, quote number two clearly states a proposition that may have empirical evidence otherwise. For example, Stroebe, Diehl, and Abakoumkin (1992) state " … brainstorming, a method of idea generation in groups, is still widely used in business organizations … in spite of consistent empirical evidence that people produce many more ideas when they work individually rather in groups" (p. 643). Furthermore, quote number four states group sizes of four or five students, yet no empirical studies have been conducted in technology education with team size as a variable. In addition, many technology educators cite team practices in industry; however, this researcher was unable to locate empirical studies in technology education which included teamwork exercises as an independent variable. In other words, it is important to know potential liabilities and benefits from educational research, instead of merely accepting some model from industry that is not developmentally sound for students.

Statement of the Problem

This study investigates the utility of experiential teamwork exercises for promoting technological problem solving in the context of a team, which concerns whether or not teamwork exercises promote greater technological problem solving in student teams. It further explores the effect of problem structure and team size on two related technological tasks: a computer bridge simulation and a physical truss model based on the computer simulation. Finally, the study includes three non-manipulated, independent variables into the research design: gender, temperament, and teamwork orientation.

Purpose of the Study

The purpose of this study is to increase knowledge of some variables that may impact team technological problem solving. Up until now, most of the studies on teams have been with college students (National Research Council [NRC], 1994); however, most of these studies seemed to have the goal of generalizing their findings to industry. This study is designed with the upper-level technology education high school student in mind, especially the pre-engineering student, as well as first-year college engineering students. Any findings are meant to help educators and students gain knowledge of technological problem solving in a team context.

One goal of this study was to maintain the inferential power that an experimental research design affords, while at the same time presenting the student teams with a realistic classroom technological task that is also presented to student teams in extra-curricular competitions. In many ways, this research study resembles the competitive events that thousands of technology education students compete in during the academic school year through the Technology Student Association (TSA). The TSA is a national organization that gives students a chance to develop technological skills and knowledge as they compete against students from other schools. In addition, the TSA gives students the opportunity to experience problem solving in a team context. The following is a description of a high school TSA competitive event:

> **Technology Problem Solving Competition—**Participants (one **team** of two members per chapter) use problem solving skills and limited materials to develop a solution to a problem given on site. Participants are required to work as a **team** to provide the best solution, which is measured objectively (TSA, 2004), (all emphases added).

This competitive event is similar to the one presented to the participants in this study in that the team problem solvers do not know, in advance, the specific problem solving task. A final purpose of this study is to heighten the field's awareness of the lack of research on student teams. If educators are going to place students in teams, then it is important to begin to understand the potential benefits and liabilities of such a methodology.

Research Questions

This study investigates the following research questions, which are stated as hypotheses in Chapter Two:

1. Does the experience of participating in teamwork exercises impact team technological problem-solving performance?
2. Does providing instructional structure for student teams during the problem formulation stage impact team technological problem-solving performance?
3. What are the effects of varying team size on team technological problem-solving performance?
4. Do team gender, team orientation, and team temperament diversity account for variance in team technological problem-solving performance?

Definition of Terms

Human Problem-Solving Process	Alternately expanding and reducing the problem (search) space through integration and differentiation (combination and separation) of perceived concepts, strategies, relationships, elements, and resources, while evaluating potential solutions against the constraints of the problem context (environment and task). (Adapted from Newell, Simon, & Shaw, 1958; Simon & Newell, 1971).
Technological Problem Solving	"the process of understanding a problem, devising a plan, carrying out the plan, and evaluating the plan in order to solve a problem to meet a human need or want" (ITEA, 2000, p. 255). Activities in this process include design, research and development, trouble shooting, invention and innovation, and experimentation (2000). For purposes of this research study, an open-ended problem solving process that results in a technological artifact (e.g., clock) or a design for a technological artifact.
Mental Models	"mechanisms whereby humans generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future system states" (Rouse & Morris, 1986, p. 351).
Team Mental Models	"Team members' shared, organized knowledge about key elements in the team's relevant environment (e.g., teamwork, task work)" (Mohammed & Dumville, 2001, p. 102).
Team	"… a distinguishable set of two or more people who interact, dynamically, interdependently, and adaptively toward a common and valued goal/objective/mission, who each have been assigned specific roles or functions to perform, and have a limited life-span of membership"

(Salas, Dickinson, Converse, & Tannenbaum, 1992, p. 4). For purposes of this study, the roles do not need to be formal or even discussed by the team.

Student Teams — Two or more students who are assigned a project in which they are expected to contribute collaboratively to the finished product or design. The educational objective is to learn/discover/invent content knowledge, problem solving, and teamwork skills. Student teams will have a corollary team in industry that has a variety of names, such as work group, work team, or design team.

Teamwork — "Team processes aimed at facilitating team member interactions in an effort to promote successful task completion" (Rentsch & Klimoski, 2001, p. 108, interpreted from the work of Cannon-Bowers, Salas, & Converse, 1993).

Student Teamwork Exercises — Exercises designed specifically for the developmental level of students to help them learn how to contribute effectively in team problem solving and productivity. The exercises help students learn team coordination, cooperation, member preferences, and how to accurately interpret the behavior of teammates.

Teamwork Orientation — "An individual propensity for functioning as part of a team. The degree to which individuals prefer to work in group/team settings for task accomplishment. This construct is not team or task-specific but rather a general tendency to seek out opportunities to work with others" (Mathieu & Marks, 1998).

Keirsey Bates Temperament — A stable component of personality that gives an individual's preference for acquiring information, making decisions on information once acquired, and characteristic ways of engaging problems and interaction with others (Keirsey & Bates, 1984).

Homogeneous Teams — Teams with members who comprise a team, and all members have the same characteristic in common, such as age, gender, or personality.

Heterogeneous Teams — Teams with members who comprise a team, and not all members have the same characteristic in common, such as gender or personality.

Delimitations

The following delimitations were made to increase the focus of the investigation:

1. The research was delimited to first-year college and/or first-year engineering students. Some students may have sophomore or junior status, but they must be enrolled in the first-year engineering course entitled *Engineering Exploration*.
2. The research did not measure the psychosocial benefits of teamwork, except with the Teamwork Orientation Scale.
3. Due to the elusive nature of team functioning, which does not lend itself to direct observation (e.g., coordination processes), as described in Chapter Two, this investigation does not measure team viability.

Assumptions

The following assumptions were made with respect to this investigation:

1. Room proctors did not create significant confounding variables.
2. Room proctors accurately and consistently recorded team scores at the specified intervals.
3. Teams followed all prescribed contest restrictions (e.g., do not access the Internet, and use only the specified software).
4. Treatment and control group environments (e.g., space, lighting, room, and temperature) were equivalent, not creating confounding variables.
5. Participants accurately and honestly filled out all survey instruments.
6. Participants did not have prior knowledge as to the specific technological tasks that would be presented during the research study.
7. Teams did not assist other teams during the measurement period, nor did teams copy design ideas from other teams.
8. The Team Orientation Scale measures the propensity to want to work with others on group projects.
9. The Keirsey and Bates (1984) Temperament Sorter accurately measures temperament.
10. Participant prior knowledge was distributed evenly into both treatment and control groups.
11. Participants must understand the technological concepts in the bridge simulation program to change scores significantly. “Trial and error” problem solving can change scores over time, but this would happen at a slower rate than with learning or understanding the concepts.

12. With the assistance of written directions and examples, participants are able to construct a truss model.
13. Teams of two can comfortably construct the truss model within the time limits.
14. The technological task was complex enough to create team interdependency.
15. The intrinsic rewards of the technological task and the competition incentives (i.e., prizes) were sufficient motivation to cause the participants to give their best effort, regardless of treatment and control conditions. In addition, random assignment should balance conditions based on motivational and other differences.
16. Although an experienced teamwork consultant in a large group format conducted the teamwork exercises, all of the exercises were within the creative capabilities of any classroom teacher.

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Chapter 2. Review of Related Literature

Overview

Technological problem solving has evolved into one of the principal staples of the technology education laboratory and classroom. In addition, the team is often used as the context for technological problem solving. However, there is little research that investigates what influences technological problem solving for student teams. The first part of this chapter focuses on a review of individual technological problem-solving literature, which transitions into the team context for technological problem solving. During the second part of the chapter, team developmental theory is discussed, as well as a relatively new construct, team mental models. These models are an extension of individual mental models and are applied to teamwork and task work models for a team. The third part of the chapter discusses theory and research on process gain and loss as it relates to group production. The next part of the chapter discusses team composition factors, such as team temperament and team gender. In the last part of the chapter, before stating the research hypotheses, the learning concepts of the two technological tasks presented to teams in this study are discussed.

Quantitative Research Practices in Technology Education

Few experimental studies have been conducted to determine possible effects on student technological problem solving. Zuga (1994) found that 65% of the studies on technology education over a six-year period were descriptive. In a similar effort, Foster (1992) discovered that 54% of 503 quantitative graduate research theses in industrial education and related fields were of the survey type. Petrina (1998) found only one of ninety-six studies published in the *Journal of Technology Education* during its first eight volumes was experimental. In addition, Petrina (1998) found that of the human subject studies published in the *Journal of Technology*

Education only 12% had been conducted with university students, while 36% of the human subject studies investigated teachers or teacher educators. Furthermore, Haynie (1998) found very few experimental or quasi-experimental (12%) articles in the first seventeen issues of the *Journal of Technology Education*. Due to a lack of research on technological problem solving, Lewis (1999) lists a series of possible research questions in which he includes, "What tends to inhibit or enhance problem solving and creativity?" (p. 47). In addition, The *Technology Education Graduate Research Database (TEGRD)* has 5,260 technology education theses and dissertations that were completed between 1892-2000 (P. A. Reed, 2002). The researcher of this study performed a search of the *TEGRD*, finding only one master's thesis, which was by Topp (1990), which investigated student teams. Although not in the *TEGRD*, Denton (1992) conducted his dissertation work on student teams.

Models of Technological Problem Solving

In his study of technological problem solving, Sianez (2003) lists seven different problem-solving models used in mathematics, technology, science, and engineering. His analysis suggests that, regardless of the field, the seven different problem-solving models all included:

1. Recognition and understanding of the problem
2. Development of a solution
3. Solving the problem
4. Evaluating the solution (p. 12).

Furthermore, Sianez suggests that the outcome of technological problem solving is one that typically generates multiple prototypes and models in developing new products or tools.

Boser (1993) provides indirect support for Sianez's (2003) proposition that different fields approach problem solving with many similarities. For example, Boser (1993) found no difference between how technology educators, leading educators, and psychologists rank-ordered instructional procedures to develop problems-solving capabilities. Boser found that the highest rank-ordered procedure was "problem solving strategies are practiced in meaningful contexts" (p. 17). In addition, the ninth highest rank out of nineteen items was that "small group problem solving procedures are analyzed through inter-group discussion," which differed from the highest ranked by less than one on a ten-point Likert scale. However, Boser found that there was not agreement on teaching methods to promote problem-solving abilities. "With the exception of small group problem solving experience, panelists' ratings of techniques [teaching methods] appeared to reflect familiarity with practices" (p. 18). After small groups, the next highest rank-ordered items were: individual problem-solving experiences, simulation, and design-based problem solving (p. 19). Boser stated that there is little agreement among panelists for assessing program effectiveness for implementation of procedures to promote technological problem-solving capabilities. However, the top two ranked items from Boser's work were: outcomes from group problem-solving activities and performance samples of specific problem-solving phases (p. 20). Because the panelists identified additional procedures to promote technological problem solving, Boser compiled these items into an additional instrument. He found that "alternative ways of looking at the problem should be considered in the search for a solution" was the most highly ranked instructional procedure (p. 23).

Authentic Practice in Technological Problem Solving

Halfin (1973), using the Delphi method, a research process that synthesizes knowledge from experts, identified seventeen operations or mental processes used by technologists. The operations included: defining the problem or opportunity operationally; observing; analyzing; visualizing; computing; communicating; measuring; predicting; questioning and hypothesizing; interpreting data; constructing models and prototypes; experimenting; testing; designing;

modeling; creating; and managing. Lewis, Petrina, and Hill (1998) suggest that these operations become reduced into problem-solving steps, such as IDEATE (*I*dentify the problem, *D*efine the goal, *E*xplore possible solutions, *A*ssess the alternatives, *T*ake action, and *E*valuate), imposed by teachers on their students. For example, a high school technology education textbook entitled *Technology Systems*, literally writes its own set of problem-solving steps on an illustration with steps that humans construct for walking between floors, such as in a home (Wright, 1996). Moreover, McCormick, as quoted by Cajas (2000), states students sometimes use rigid classroom methodologies, which are far from actual practice. McCormick concluded that, "This can become a ritual…that does not affect the student's thinking" (cited in Cajas, 2000, p. 81). Rigid algorithmic thinking is far from what Halfin (1973) found in authentic technological practice. Williams (2000) advocates referring to processes, such as those identified by Halfin, as aspects rather than stages, because stages imply a sequential, linear practice. Sequential steps may not always be the case in a design problem-solving context.

Content vs. Process in Technological Problem Solving

Some technology educators have focused on content, while others educators have focused on process. DeVore (1964) thought both content and process were equally important. He recognized technology as an ongoing process, in which discovery and problem solving are integral components. Lewis (1999) suggests that the field of technology education tends to become polarized into content and process approaches. A major focus of Maley's research and experimentation program that would subsequently become part of his *Maryland Plan* (1973) was concerned with social processes, personal development, and problem solving. Maley (1963) stated, "America needs people capable of problem solving, capable of making decisions, and capable of using sound procedures in arriving at decisions" (p. 26). Over two decades later, Maley was still concerned with problem solving: "It [society] needs education that promotes … learning processes … that will enable the individual to … seek new solutions to problems …" (Maley, 1986, p. 1). Maley was concerned with process and social development, which is evidenced by his eighth-grade program. Maley's program used a group process approach to study modern industry utilizing the activities of a group project and a line production experience (Maley, 1973, p. 67). Apparently, Maley saw the group process as a context for problem solving.

The (IACP) Industrial Arts Curriculum Project (Towers, Lux, & Ray, 1966), on the other hand, focused primarily on the content of manufacturing and construction. Lux and Ray (Maley & Lux, 1979) concentrated on curriculum from the four domains of knowledge: formal, descriptive, prescriptive, and praxiological (p. 151). Similar to DeVore's taxonomy for technology, Towers et al. (1966) developed a structure for the study of industry. Bruner (1960) suggested that subject matter structure allows for discovery learning. In addition to the fundamental ideas of a field, Bruner states that the student needs "an attitude toward learning and inquiry … towards solving problems on one's own … with a resulting sense of self-confidence in one's abilities" (p. 20).

Towers et al. (1966) may have missed the importance of student discovery, when Lux stated, "it was thought … essential that both they [students] and teacher be in general agreement on what it [industry] is. Having settled that authoritatively …" (Maley & Lux, 1979, p. 152). Therefore, Maley's (1972) *Maryland Plan,* with focus on process, research, and experimentation, seemed to be more in line with Bruner's (1960) discovery learning than the IACP.

In 1990, Savage and Sterry declared that the field of technology education was moving from content to process:

> Process education using the technological method encourages major shifts from content or subject matter based teaching and learning to a variety of educational opportunities and experiences for students such as thematic learning, problem solving, modular instruction, integration learning and cooperative learning (p. 10).

Lewis et al. (1998) suggest that technology education is in fact moving away from content to the process of problem solving, but it is still important to understand the *why* to solutions. Lewis et al. also state that "The student who solved the problem of the longest bridge must know why her solution worked, or the exercise would have been meaningless" (p. 17). Sanders (1994) proposed that this is not typically the case in practice; unfortunately, students build bridges and test them, but they still do not understand why one bridge design is stronger than other designs. Moreover, Benenson (2001) stated that many current educational practices, which focus on one right answer, do not allow for students to learn how technological design is an iterative process.

In a similar appraisal, Zubrowski (2002) states that elementary student teams reach an impasse, not knowing how to proceed with a design:

> … students have arrived at a consistently functioning windmill, but they aren't sure how to go about making further refinements. In the video "Windmills," one team of students was lifting 120 nails while other teams barely lifted 40 (p. 59).

Zubrowski proposed that teachers can either consult with each team, or isolate variables, such as angle of attack in wing design, in other team projects to determine which factors are relevant to improving each team's own design. Lewis et al. (1998) also agree with Brown (1984) and Silver (1994), from mathematics education, that students do not solve problems in isolation, but rather, they can share their problem insights with classmates.

Peer interaction as a source of knowledge is highlighted by Twyford and Jarvinsen (2000), who stated, "Existing knowledge, direct observations, and practical experience clearly guide analysis and are a part of their interaction with peers" (p. 45). "No longer can any one person be expected to master a body of knowledge" (Braukmann & Pedras, 1990, p. 3). In a similar line of thinking, others have suggested depth should take priority in modern education, "Curricula that emphasize breadth of knowledge may prevent effective organization of knowledge because there is not enough time [left] to learn anything in depth" (NRC, 2000, p. 49).

Current and Past Practices in Technological Problem Solving

Secondary technology education classrooms across the United States primarily utilize "hands-on" problem-solving activities. According to P. N. Foster (1994), problem solving was voiced as an integral part of technology and industrial arts education as far back as the 1920's; however, the field rarely realized this ideal (Browning & Greenwald, 1990). Sanders (2001) conducted a national survey of public school technology educators, comparing his results with two earlier studies with similar purposes: the 1963 Schmitt and Pelley Survey and the 1979 *Standards for Industrial Arts Program Project* (Dugger, Miller, Bame, Pinder, Giles, Young, and Dixon, 1980). In the two earlier studies, "develop skill in using tools and machines" ranked as number one, while Sanders (2001) found this ranked eleventh in 1999. Sanders found that by 1999, "developing problem-solving skills" and "use technology (knowledge, resources, and processes) to solve problems and satisfy human wants" ranked as the first and second purposes, respectively. According to Sanders, in contrast to this, the two previous studies during the 1960's and 1970's ranked "problem-solving" as only the fifth most important purpose for the field.

Sanders' (2001) research found that more than half of the technology instruction (56.9%) delivered engaged students in problem solving. Although his study did not include information regarding group or team problem solving, it seems likely that student teams worked on many of the problem-solving activities. The field of technology education tends to use the phrase or term technological problem solving; however, terms such as product design, invention, and troubleshooting may be more concise (Custer, 1995; Flowers, 1998). Custer further suggests that not all problem solving involves the same amount of creativity.

Jonassen (2000) identified eleven problem types, including trouble shooting, algorithm, and design problems. Each problem type varies in terms of structuredness, complexity, and abstractness. For example, in the area of structuredness, algorithmic problems have predictable procedures, while design problems are usually the most complex and "ill-structured" problems a professional encounters. Jonassen classifies design problems as not having a right or wrong answer, "… only better or worse" (p. 75). Jonassen also proposes that the artifact or product is important in evaluating design problem solving.

Finnish technology educators also ranked "hands-on" problem solving highly (Alamaki, 1999); however, they found that problem solving ranked second to creativity. In addition, the Finish technology educators ranked student self-image, social skills, and cultural heritage as the third, fourth, and fifth general goals, respectively. All the categories mentioned above, except for problem solving, are difficult to compare to the Sanders' (2001) findings in the United States, because the survey areas are not equivalent. However, both countries rated problem solving as high in importance.

From their research with middle school Finnish students, Autio and Hansen (2002) suggest that technical thinking as human ingenuity can be measured. In addition, by measuring the psychomotor component of technical thinking, Autio and Hansen propose that the mind and body must be exercised concurrently, which is congruent with their definition of technology: synthesizing the "seeing, touching, thinking and doing" is technological activity (p. 6). Alamaki (1999) states that the Finnish people have a "general belief that the design and build approach used in contemporary technology education programs enhances the pupils' creativity, dexterity, diligence, initiative, problem solving, self-image, and preparation for work" (p. 5). Unlike the United States trend to eliminate Industrial Arts programs, Alamaki states the Finnish education system added content areas, but they did not eliminate their traditional *sloyd*, which is known as craft and design.

Technological Problem-Solving Style

Wu, Custer, and Dryenfurth (1996) compared the university majors of humanities, engineering, and technology on both personal problem-solving style and technological problem-solving style. Heppner (1988) operationalized problem-solving style as an inclination to respond in certain ways toward problems. His construct is measured through the dimensions of problem-solving confidence, approach/avoidance, and personal control. Wu et al. (1996) adapted the personal problem-solving style, which is a perception survey used in counseling psychology, to focus on technological problems. The original instrument on personal problem-solving style focused on such items as relationship problems or selecting a career, while the technological problem-solving style by Wu et al. posed scenarios, like "lights that do not light, doors that stick, and a car that does not start" (p. 61).

With the three different majors, Wu et al. (1996) found no significant differences on personal problem-solving style. However, they found significant differences for all three majors on technological problem-solving style. Wu et al. found that technology majors scored the highest in this area, followed by engineering majors, followed by humanities majors. In addition, the technology and humanities students had significant differences on the personal and technological problem-solving scores, while the engineering students did not. Wu et al. found engineering students perceived themselves equally competent on both constructs. From the applied nature of the examples above, Wu et al. concluded that since engineering has traditionally been more abstract and theoretical, and technology has provided students with "hands-on" experience, the technology students' higher scores were not surprising. However, the "trouble shooting" nature of the examples may be different from the technological problem solving required in design activities. With the technological problem-solving style instrument, none of the examples provided by Wu et al., quoted at the end of the previous paragraph, ended in a new design.

Technological Problem Solving from Worked Examples

In a recent study, Sianez (2003) presented students with three technological problems: elevated load, cantilevered weight, and energy absorption. He found that presenting students with successful and unsuccessful examples of work reduced the time participants needed to solve the three technological problems. The successful and unsuccessful examples presented to the students were different on only one dimension, so even the unsuccessful examples had some components of a correct solution. For example, the elevated load may have had all the components of a successful example, except that it had too small a base to stand upright.

Sianez (2003) found that middle school students presented with successful (M = 304.71 seconds) or unsuccessful (M = 305.53 seconds) technological solutions needed, on average, just over five minutes to solve three technological problems; the control group, which was not presented any solutions, required over six minutes (M = 364.22 seconds). Unfortunately, Sianez had only 17 participants in each of these three experimental conditions. Therefore, although the treatment effect for worked example on solution time was medium, it was statistically insignificant. This power analysis by Sianez revealed less than half a chance of rejecting the null hypothesis, if in fact it was false.

TSM Context for Technological Problem Solving

DeVore (1964), arguably the first technology educator, used ideas from science, technology, and the society fields, to analyze that technology is a discipline, just like science or math. Regardless of the soundness of DeVore's argument, it is difficult to debate that there are no relationships among the disciplines of science, math, technology, and social studies, even though a student may only have a vague sense of these connections. Secondary schools, especially high schools, may have a tendency to artificially compartmentalize subjects.

To address this issue, LaPorte and Sanders (1995) created the *Technology, Science, and Mathematics Connection Activities* (*TSM*) in the first half of the 1990s. These are curriculum materials for middle school students and their teachers. The goals of LaPorte and Sanders were consistent with Bruner's (1960) proposition that subject matter structure creates the conditions for discovery and transfer to different domains. Sanders (2001) found that technology educators ranked "applying mathematics and science" as the fourth most important purpose for their field. The *TSM* activities did not focus on social studies, but rather highlighted technological problem solving, using math and science as tools. LaPorte and Sanders (1995) suggest, " … activities that integrate technology, science, and mathematics are essentially engineering activities, which, are inherently laboratory-based investigations with which technology teachers are quite comfortable" (p. 184). The *TSM* connection activities, unlike the technological problems presented to students in Sianez's (2003) research, result in a somewhat recognizable technological artifact, which also has a more relevant, holistic function. For example, in the *TSM Power Boat* activity, students design a model boat with a propulsion system, testing both the hull design and the boat with the installed propulsion system. Many times the solution effectiveness is compared against other solutions, such as how fast different boat systems were able to travel two meters (LaPorte & Sanders, 1992, cited in Childress, 1994).

Using a LaPorte and Sander's *TSM* connection activity entitled *Capture the Wind*, Childress (1994) compared the impact of two methods of implementing the activities on the technological problem-solving ability of middle school students. Childress compared students who were taught the activity concurrently by their science, math, and technology teachers, with students taught the activity solely by their technology teacher. Both implementation methods increased participant scores on technological problem solving between pre and posttests; however, there was not a significant difference between the two methods. Childress measured technological problem solving by the amount of electrical power produced, paralleling what the goal is in maximizing alternative energy sources by the electrical industry. Once again, the activity has a recognizable design in the "real" world. Neither this technological problem-solving study by Childress nor that by Sianez (2003) investigated student teams; however, students often do work in teams on engineering design activities.

The integration of math, science, and technology is also occurring in elementary schools through design technology activities (Koch & Burghardt, 2002). A master's program is currently available for experienced elementary school teachers who want to integrate the three subject areas. In teacher action research, one graduate of the program, as quoted by Koch and Burghardt, commented:

> Hands-on problem solving and decision making through design and construction have enabled my students to make many real life connections and become part of the world of math, science and technology that exists in the world outside of our classroom (p. 26).

Furthermore, teachers commented that this approach had allowed their students to become active learners, with the teacher as a source of information, but not the only resource. Student peers become an important part of the learning process. Koch and Burghardt found one area of agreement from the research, and this is that integrating the subjects promotes higher-level thinking, dialogue, and problem solving.

Technological Problem Solving in Teams

Over fourteen years ago, Denton (1990) suggested that the field of technology education was omitting the competency of children being able to work productively as team members. He suggested, in authentic practice, that teams rather than individuals design artifacts and technological systems. Denton continued, “I do not suggest that a knowledge base is unimportant, only that it should be recognized that teamwork and the management of a task are equally important.” In 1994, Walker stated, “The skills and abilities to share and work in multi-functional teams are key underpinnings and goals of current technology education.” Baker, Boser, and Householder (1992) suggest that the push toward problem solving and teamwork in education is coming partly from occupational needs. However, teamwork is not a content area included in the *Standards for Technological Literacy* (ITEA, 2000), even though an economic imperative is made: “In the long run, improved engineering will strengthen the technological base of the economy and of society” (ITEA, p. 203).

Similarly, Reid (2000) states that many secondary technology education programs are not updating instruction to reflect modern societal practices:

> The curriculum did not encourage teamworking. In today’s work environment it is likely that a professional will have to work in a group relationship to solve a problem or operate a system (p. 36).

For example, the international company IDEO produces over 90 new patents a year using the processes of teamwork. A *Nightline* commentator (Koppel, 1999) stated, “IDEO is possibly the most influential product development company in the world.” During an interview on *Nightline*

IDEO's manager, Dave Kelly, claimed, "We have no content experts, only experts in the process." IDEO uses the following principles to design new products:

- One conversation at a time
- Stay focused on the topic
- Encourage wild ideas
- Defer judgment (don't criticize ideas)
- Build on the ideas of others
- They had a system where "Anyone who starts to nail an idea gets the bell"
- They use what they term "focused chaos"
- The idea must be cool, plus constructible
- The team (not one person) judges the best idea [this is different than traditional "top down" management]
- Enlightened trial and error succeeds

Denton (1988) also suggests that a reluctance of educators to embrace teams is the perceived difficulty in assessing teamwork. Denton's research, however, led him to believe that students identify with teamwork and put forth much more effort in task management than with traditional classroom work.

Dunham, Wells, and White (2002) mention teams and problem solving together when discussing instructional strategies in biotechnology. Under the collaborative approach, they state:

> As a part of a team, students interact, discuss, investigate, and create unique solutions … Teams are expected to discuss, negotiate, and collaborate as they build a novel photobioreactor … (p. 73).

The previous quote is consistent with Dyer's (1987) definition of a team as "a collection of people who must collaborate, *to some degree*, to achieve common goals … (p. 24)." Similarly, Denton (1990) suggests that teamwork is a form of group work; however, teamwork is more than students sharing a learning experience. Denton realized that, with group work, all students go through the same learning task, while a team manages a task and members may have varied learning experiences in pursuit of an end product. Moreover, Davis, Ginns, and McRobbie (2002) propose that it is the problem solving to produce an end product, process, or artifact that allows students to gain deeper understanding of design and technology. Cooperative learning, tutoring, and team training are closely related (NRC, 1994). The NRC goes on to state that: 1) in cooperative learning, students work together to gain knowledge and skills, 2) in tutoring, one of the participants has the status of expertise, and 3) teamwork is concerned with enhancement of the team, not individual outcomes. Denton (1990) states that the team task *demands* discussion and interaction for success.

Dunham et al. (2002) state that biotechnology teams create a context for Bruner's (1960) problem solving, investigation, and discovery. In addition, Dunham et al. suggest that biotechnology teams engage in the Knowles' (1984) problem-solving approach through discovery, which consists of three concurrent processes:

1. acquisition of new information;
2. transformation, or the process of manipulating knowledge to make it fit new tasks; and
3. evaluation, or checking whether the way we have manipulated information is adequate to the task (p .25).

Knowles' work grows out of Bruner's (1960) ideas on discovery and problem solving. Dunham et al. (2002) suggest that student teams engage in the discovery, problem-solving process:

> Teams gather information that illuminates the issue: *What are the impacts of BST on food safety? What are the economic impacts* …(p. 71).

Furthermore, Dunham et al. suggest that students make sense of their experience through others in a context, and biotechnology activities used in the technology education classroom occur in a team context. Furthermore, they suggested that activities encourage teams towards thoughtful reflection. Dunham et al. stated:

> they [teams] continually engage in a process of evaluation by reflecting on the solution … [when presenting] each **team** [emphasis added] is given the opportunity to revisit the context, challenge, design, and construction processes in order to assess the adequacy of their solution in addressing the challenge (p. 75).

Dunham et al. drew on the work of Jonassen (1994), who proposed that thoughtful reflection is important for a meaningful learning environment. Similarly, Kolb (1984), when drawing on the work of Lewin (1951) in social science, included Lewin's "observations and reflections" in his experiential learning theory.

Many of the technology education courses employ students working in pairs or teams. Modular instruction, in which students work on a media instructed technological unit, is commonly used in technology education. Modules almost always have students working in teams of two, and sometimes teams of three, rather than as individuals. Many times, the modular activity may have the students make only one design, problem solution, or model, instead of one for each participant in the module. If students are responsible for a collaborative design, the instructional activity has created shared responsibility suggestive of a student team, rather than solely collaborative work. If the students are graded on their project as a unit, then they are dependent on each other for success; however, it is not clear whether a vendor-developed modular environment is designed to promote teamwork.

The modular approach is employed extensively in technology education. Brusic and LaPorte (2000) surveyed technology educators in Virginia, finding that 25% teach using a purely modular approach and 25% teach using a combination approach of modular and conventional laboratory. However, Sanders (2001) found these numbers were not as high nationwide, with only 16.4% of technology education programs surveyed utilizing a modular laboratory approach. This is not to suggest that the modular approach is the only technology education method utilizing student teams. For example, the Virginia high school course entitled *Manufacturing*

Systems has two competencies related to teamwork: 1) "Use experiences to participate in Technology Student Association (TSA) as a leader, manager, or team member" and 2) "participate in an organized classroom and laboratory personnel system" (Virginia Career and Technical Organization [CTE], 2004). In addition, it is important to note that design and technology courses many times group students into teams to design solutions to problems.

Team Processes in Technological Problem Solving

In a quasi-experimental descriptive study, nine high school student teams, each having three team members, were presented with a "futuristic locker" design brief (Custer, Valesey, & Burke, 2001). This research study piloted a Student Individualized Performance Inventory (SIPI). The SIPI is an observational instrument with four different dimensions: problem and design clarification; develop a design; model/prototype; and evaluate the design (Custer et al., 2001). Each dimension has three different behaviors, which are rated on a scale from one to five: novice, beginner, competent, proficient, and expert. Although the students are working in design teams, the instrument used by Custer et al. is designed to measure individual performance.

Custer et al. (2001) described relationships between the SIPI and several variables, such as program type (project vs. design brief), years in technology education, grade level, math and science achievement, personality type, problem-solving style, and gender. They found moderate correlations between "individual science achievement" and the dimensions of "model/prototype" and "evaluate the solution." Four dimensions of the Myers-Briggs Indicator were used: action-oriented innovators (extraverted-intuitive); action-oriented realists (extraverted-sensing); thoughtful innovators (introverted-intuitive); and thoughtful realists (introverted-sensing). Custer et al. found that while more than half of the sample (n = 28) was action oriented, the performance averages were identical on all four dimensions. While the researchers concluded that problem-solving performance is not a function of personality type, it is important to note that, due to a small sample size, no inferential statistical tests were possible. The authors, Custer et al., suggest that further research is needed on homogeneous and heterogeneous teams. In addition, the researchers found that student performance improved with grade level. Concerning gender, the investigation found that males tended to score higher on the model/prototype dimension, while females scored higher on evaluating solutions.

Table 1
Group Evaluation Rubric

1. As a whole, the group was flexible and adaptable
2. All members of the group contributed actively to the process
3. The group was able to incorporate diverse personalities and ideas
4. The group had the ability to resolve adversity (ideas that didn't work, frustration, etc.)
5. There was a good balance between group and individual work
6. All members contributed creative ideas to the process
7. The group was able to re-energize when the energy level dropped off
8. The group was able to critique its own work
9. The members achieved an appropriate balance between leadership and followership
10. The group generated many new ideas rather than prematurely selecting a single solution
5 – Absolutely true of this group
4 – Described the group for the most part
3 – Description fit the group about half of the time
2 – Only marginally describes the group
1 – Does not describe the group at all

Custer, R. C., Valesey, B. G., & Burke, B. N. (2001) An assessment model for a design approach to technological problem solving, Table 9, p. 18. *Journal of Technology Education*, *12*(2), 5-20. Reprinted with permission of J. E. LaPorte (Ed.).

Custer et al. (2001) also studied team processes using a group rubric (see Table 1). The highest team averages on the group rubric were for all members contributing actively and flexibility to diverse personalities/ideas, while team averages were lowest for lack of brainstorming and prematurely selecting a single solution. In regards to group process, Custer et al. concluded that more research is needed on how group process contributes to or hinders not exploring alternative solutions. Furthermore, they proposed:

> The findings of the study indicate that, while some areas of performance are strong, other areas could benefit from additional intervention and focus. While the generalizability of these results is limited, the findings suggest that the profession [technology education] could benefit from more instruction and assessments on teamwork and group processes. This is especially important given the emphasis on group process in the *Technological Literacy Standards* (p. 17).

Moreover, Custer et al. suggest that more extensive studies are needed that will allow inferential statistics.

In a case study of icon-oriented programming with fourteen year olds, Lavonen, Meisalo, and Latu (2001) stressed the importance of the group process in creative problem solving. They used the features of a creative group outlined by Runco and Okuda (1988), some of which include:

> 1. Trust one another and believe in the power of group work.
> 2. … [Have] motivated, active participants … apply their creativity to the problem.
> 3. Have a positive and constructively critical attitude about the ideas presented by other group members.
> 4. Appreciate the ideas of others and can provide positive feedback, resulting in further development of the ideas (pp. 211-219).

Lavonen et al. (2001) cite the problems with traditional syntax programming for younger students; however, with the icon-oriented programming the students still worked mostly by trial and error. Furthermore, the researchers observed that the groups showed little evidence of sufficient planning or reflective thinking. Lavonen et al. concluded that the visual programming tool of the icon-oriented programming language promoted individual ideation.

Technological Problem Solving in Team Competitions

The TSA is the student organization for technology education, and according to national estimates, has over 160,000 K-12 student members, with the majority of membership occurring in secondary education (TSA, 2004). This organization offers secondary students opportunities to compete with students outside their school and leadership opportunities, such as becoming local or regional officers. Of the sixty-seven different TSA competitive events, more than half (56%) are competed in by student teams. The team size for these competitive events ranges from two to six. Both the high school and middle school levels have a structural competition. The high school structural engineering event, competed in by a team of two, is described as: “participants (one team of two members per chapter) work as part of a team on site with supplied materials to build a model of a structure that is destructively tested to determine design efficiency” (TSA, 2004).

Team competition is also commonly used in the technology education classroom, which Barak and Maymon (1998) claim is similar to methods for cooperative learning. One method is called Student Teams-Achievement Divisions (Slavin, 1990), which encourages “healthy” competition between teams while encouraging cooperation within a team. Teachers may also have the teams dependent on one another at some point in the problem solving, not allowing the “in group” and “out group” structure to become overly polarized. For example, if there are two manufacturing teams in one course, on production day, each team may recruit members of the other team as production workers for their final production run.

Robotics is another technological problem-solving competition which is growing in popularity (Verner & Hershko, 2003). For example, the FIRST Robotics Competition for high school students has grown to have more than 20,000 high school participants (LaPorte, 2002). LaPorte continues that the First Lego League is a similar competition but for younger students. In addition to other benefits, such as problem solving and systems thinking, Verner and Hershko (2003) suggest that robotics problem solving leads to teamwork skills. In a case study of a robotics high school design team, the students created a project report, in which Verner and Hershko noted:

> The report presented a range of experiences including the teamwork overview, the group collaborative work and its results, and the personal contributions of the students. In the teamwork overview the students described the structure and functions of the robot system and the principles behind its development (p. 44).

After the contest, Verner and Hershko reported that each of the students evaluated themselves on seventeen criteria or subjects, such as computer communication, robot kinematics, and teamwork. Teamwork is the only criteria that had an interpersonal dimension. The students evaluated both their practical and theoretical progress for each subject. These student evaluations were compared with that of the teacher, finding that, "Substantial progress was mainly achieved in programming, robot kinematics, sensors, data analysis, control and teamwork" (p. 50). The researchers state that the students made significant progress in engineering subjects, as well as technological and teamwork skills. Robotics, as well as manufacturing and design briefs in technology education, is considered to be project-based learning. Project-based learning is commonly used in technology education (Barak, 2002), and the learning goals of such projects are cognitive skills and teamwork abilities (Barak & Dopplet, 1999; Cross & McCormick, 1986).

Teamwork as a Goal for Technology Education

Raizen, Sellwood, Todd, and Vickers (1995) list five goals for technology education. They state in goal four, "When undertaken in groups, design projects assist in developing collaborative behavior and communication skills" (p. 42). In addition, Raizen et al. (1995) state in the fifth goal for technology education:

> Goal five acknowledges that technology education should provide a context for developing personal skills and self-confidence. The processes of designing and making something and then modifying the design in response to user feedback provide an ideal setting in which to develop teamwork, the collaborative problem

> solving, and communication capabilities that are as eagerly sought by industry as they are valuable for personal and civic life (p. 43).

Citing Katzenbach and Smith (1993), the technology educators Barak and Maymon (1998) stated: “Teams outperform individuals acting alone … especially when performance requires multiple skills, judgments, and experiences” (p. 9). However, Katzenbach and Smith do not cite any research to support their proposition. Furthermore, it appears that the impact of teamwork exercises as an independent variable within engineering design activities or in technological problem solving has not been investigated.

Team Technological Problem Solving in the Classroom

Barak and Maymon (1998) conducted one of the largest research studies to date with technology education student teams. There were 172 students, who for the most part, self-selected into teams (*n* = 45 teams), ranging from three to five members each. With the seven schools that allowed self-selection of teams, only four in forty teams (10%) formed co-ed teams. Barak and Maymon concluded that with this age group, students did not group in a way that would lead to a diverse team with the varying skills needed to perform the task. Both the teachers and researchers noted a high degree of involvement in the team workshop in which teams designed and tested a hot air balloon. Interviews with the participating students and teachers found four principal sources for the high level of involvement:

1. The intrinsic interest the subject held for the pupils.
2. The challenge with which they were presented.
3. The practical work, leading to an attractive product.
4. The change in classroom atmosphere, pupil-pupil and pupil-teacher relations (p. 11).

Barak and Maymon noted that, in some cases, the high motivation led to cooperation among team members, while in other cases the high motivation led to competitiveness toward other teams. In addition, Barak and Maymon noted that female teams displayed less argumentation and aggressiveness within groups, while male teams were more competitive.

Barak and Maymon (1998) used Tuckman's group research as a framework for studying how teams progress through a technological task. Tuckman (1965) found that groups, regardless of duration of team life, transition through the four developmental stages of forming, storming, norming, and performing. For example, even groups in short laboratory experiments develop to reach the problem-solving stage quickly (Bales & Strodtbeck, 1951), while longer-term groups spread the developmental stages over greater time periods (Tuckman, 1965). Barak and Maymon further described how the teams' tasks of problem presentation, planning, construction, and testing & evaluation, manifested themselves during Tuckman's stages of group development (see Table 2). Barak and Maymon summarized the stage in which the teams actually functioned as a team: that is, 11.1 % problem presentation, 47.6% planning, 35.5% constructing, and 4.4% during testing and evaluation. One team (2.2%) in the study failed to function as a team. Contrary to commonly held view that teams need strong leadership, few of these teams had a dominant leader (11.1%), while the majority of the teams used consensus decision making (44.4%), followed by random decisions (24.4%) and teacher intervention (20%). Barak and Maymon found that teacher intervention was needed in teams that digressed into lengthy arguments and were unable to reach a decision.

Barak and Maymon (1998) concluded that spontaneous leadership should not be expected and that students needed "hands on" experience if educators wanted them to function as leaders of teams. However, in her research with college engineering and computer science teams, Hayes (2003) found that teams with strong emergent leaders did not predict technological problem-solving performance. With secondary student teams simulating industrial design companies,

Table 2
Teamwork Development Matched to Progress on the Technological Task

Stage	Pupils' activity on task	Teamwork characteristics
a	*Problem presentation*: Pupils receive their first information concerning the envelope task, project targets and restrictions. They review the theoretical background.	*Forming*: Pupils do not yet know how much they must work with others. Pupils need encouragement from the teacher to begin to work as a group.
b	*Planning*: Each group makes decisions about their envelope's colors, dimensions, and number of sections. They prepare the template from paper board.	*Storming*: The task requires several joint decisions. The group has its first experience in decision making and joint problem solving.
c	*Construction*: The team selects paper sheets, connects them in layers, cuts, glues and assembles the envelope. This is hard to achieve individually.	*Norming*: Pupils work together, share tasks, help each other, and exchange information. Each pupil has a role in the teamwork, but cooperation is essential.
d	*Testing and evaluation*: All teams fly their balloons, comparing their envelopes.	*Performing*: The team presents its product jointly. Outwardly, the team appears cohesive. Each member has a place in the team.

Barak, M., & Maymon, T. (1998). Aspects of teamwork observed in a technological task in junior high schools, Table 3, p. 13. *Journal of Technology Education 9*(2), 3-17. Reprinted with permission of J. E. LaPorte (Ed.).

Denton (1994) found that almost all student teams believed that they had adopted a cooperative system, rather than a traditional hierarchical management system. Furthermore, Denton found that most simulation teams suffered in the early stages, because they had to establish a teamwork structure. Denton also learned that the simulation had a heightened effect of making teams consider time efficiency in relation to design and the necessary task work. Denton cites the Cognitive Acceleration through Science Education (CASE) project, which is thought to develop confidence and thinking skills by requiring students to establish control over approaching deadlines (Adey, Shayer, & Yates, 1990). Finally, Barak and Maymon (1998) found that teams sometimes had members stand to the side (42.2%), and some teams (20%) even had members who showed no interest at all. However, Barak and Maymon also found that many teams (37.8%) cooperated so that their team would succeed against other teams.

In a case study of a high school technology education manufacturing program using problem-based learning (PBL), which had a teacher identified favorably by recent graduates, Hill and Smith (1998) found that current students viewed teamwork and problem solving as integral components of the program. Hill and Smith found that students frequently mentioned the value of working in teams on design projects. A team of female students in the study mentioned how their interpersonal compatibility made task work easier. From the perspective of one tenth-grade female in the Hill and Smith study, teamwork made the task work more interesting: "[working in a team is] better than working by yourself, because it's kind of boring working by yourself" (p. 34). One male student in the study was initially cautious about working in a team, but later discovered working alone was not interesting. An eleventh grade male in the same Hill and Smith study viewed the team process as creating an environment for interpersonal development: "It [project work in a team] teaches you how to work with other people and how to resolve conflicts by yourself without having someone step in all the time" (p. 34).

In a case study on program evaluation, Verner, Waks, and Kolberg (1997), investigated student attitudes towards a high school matriculation course for students interested in engineering. The practical course in the study by Verner et al. (1997) includes "electronics, computers, mechanics, control and design in the robot system context" (p. 67). According to Verner et al., one reason this course is different from conventional high school courses is it employs "creative individual and team tasks vs. routine exercises binding for all" (p. 71). They found that attitudes toward both the course creativity and acquired technology background explained a large portion of variance in attitudes toward the course (42.6%). Moreover, attitude towards course creativity explained the most variance (32.8%). Verner et al. discovered that students believed team cooperation with classmates was important. "They [students] appreciated the experience of teamwork cooperation they [students] had acquired in the course" (p. 75). Furthermore, Verner et al. state that a "High correlation between individual contribution to team success and personal benefit derived from team cooperation, was indicated" (p. 73). However, Verner et al. fail to mention the magnitude of the correlation. Before the course, the majority of students (88.4%) responded that they lacked any technological background, and several students had feelings of fear in relation to technology (18.6%). By the end of the course, Verner et al. found that the majority of students (86%) believed that they could have a successful career in a technology-related profession, such as engineering.

In a quasi-experimental study with technology education college students, Gokhale (1995) investigated the difference between individual and collaborative learning, which is similar to cooperative learning, on two type types of test items: "drill-and-practice" and "critical thinking." The students were using Ohm's law to solve for unknown values in parallel and series dc circuits. Gokhale found no difference on student drill-and-practice test scores, based on collaborative or individual classroom environment; however, there was a difference on the critical thinking items. Students in the collaborative group scored significantly higher than students in the individual learning classroom. The majority of collaborative learning students identified four process benefits for this type of learning: helped understanding; stimulated thinking; pooled knowledge and experience; and received helpful feedback. In addition, Gokhale found a majority of these same students identified two social benefits: the relaxed atmosphere made problem solving easier and it was enjoyable. Less than ten percent of the students involved felt the collaborative learning experience had been a waste of their time. Gokhale states that future research needs to address group composition (heterogeneous/homogeneous), preference for collaborative learning based on gender, and group size.

Although the teaching strategies are related, Fink (2004) draws some distinctions between problem-based learning (PBL) and team-based learning (TBL). These two strategies are related in that both give groups of students challenging assignments (Duch, Groh, & Allen, 2001; Wilkerson & Gijselaers, 1996); however, Fink suggested that TBL focuses on having students apply prior knowledge and acquired skills, while PBL focuses on students learning new material. Therefore, PBL requires the use of tutors to keep the group functioning, whereas with TBL, teams are expected to function more autonomously and perform. With TBL, Fink proposed that teamwork abilities and team functioning may be more important to success, especially without the teacher to facilitate the team.

Cooperative learning is similar to PBL. In a cooperative learning context, students work together to learn material and are made responsible for their teammates learning (Slavin, 1990). Referring to the student-learning group as a team may lead to some confusion for classroom teachers on whether a teaching methodology is cooperative, PBL, or TBL. A teacher may even transition between these methodologies, making TBL sequentially more appropriate later in the semester, once students have had a chance to learn pre-requisite skills and knowledge.

Cooperative, Problem, and Team Based Learning

Examples of cooperative, PBL, and TBL may help compare and contrast the methods. Computer Aided Design and Drafting (CADD) content, the way it has been traditionally taught in technology education, is not open-ended or design based. Students typically all work on the same drawing, making this more of a cooperative learning situation. Toward the end of the year, students might be paired with the task of taking apart a mechanical object (reverse engineering) and then creating the working drawings for it: a case of PBL. However, if students are paired with a partner for the purposes of designing a solution to an identified problem or developing a prototype, then this is more similar to TBL. That is, students would be furthering their prior knowledge and skills in creating a new design. In addition, they would also be working on task coordination and management. Furthermore, the human resources that the team perceives would need to be coordinated in order to lead to efficient learning and problem solving.

In a quasi-experimental study with post-secondary students, Seymour (1994) compared individualistic, cooperative, and combined (individualistic and cooperative) learning methods in CADD. CADD is a technical subject that is many times taught by a technology teacher in the high school. Pre-service technology education teachers also take CADD at universities. Seymour found that students in the cooperative learning situation had higher scores on drawings, quizzes, and the posttest; however, there was not a statistically significant difference between treatment groups. In addition, Seymour did not find any attitude differences in level of student understanding and enjoyment of the course. Since Seymour's research design was counterbalanced, with every classroom receiving the three teaching methods, but at different points in time, she observed some differences of participant response to the sequencing of treatments. Seymour found that if students started the project individualistically, they "balked" at transitioning to working with a partner. Instead, if students began the semester together, they preferred staying with their partner, and the teacher had to remind them to work individually at a computer station.

Another example of cooperative learning is the Materials Science and Technology (MST) high school curriculum. "[MST] is a multidisciplinary course developed to replace much of the dreary, tedious atmosphere of many traditional classrooms with a stimulating environment conducive to learning" (Whittaker, 1994, p. 52). The MST curriculum utilizes problem solving with materials as an approach to studying technology and science. One student-learning objective is to “Work in a cooperative group setting for problem solving” (p. 56). Whittaker investigated students’ perceptions of the benefits of MST, and he found that students considered the learning environment stimulating. For example, one female senior in Whittaker’s study commented:

> The fact that you don't have to sit in a chair all day and just listen to a teacher say do this and do that. You get to pick out what you want to do and when you want to do it. It helps you too, [if] you can team up with someone (p. 60).

Whittaker states that the student has identified three important MST goals: active learning of material; participation in deciding what will be learned; and working cooperatively.

Although Whittaker (1994) identifies the previous quote as an example of teamwork, it may be more similar to cooperative learning or PBL, than to TBL. Whittaker reported that a male student, after peer teaching other students, reflected in his journal, “Today I helped three people invest [produce] their rings. I feel like a Materials Science genius!” (p. 63). Whittaker uses this quote as an example of peer teaching, which appears to be evident. In addition, the student’s journal reflection in Whittaker’s study is reminiscent of Maley’s (1973) *Maryland Plan*, which is illustrated in the following quote from that curriculum plan:

> Few, if any, knew more about his subtopic [a less academically inclined boy, who had presented his research on the Wright Brother’s aircraft, followed by a flurry of questions from his classmates], and thus, he achieved the recognition, the self-satisfaction, and the sense of participation provided for in the unit-seminar educational experience (p. 48).

In other words, it was also an esteem builder for the student. Although Maley published his *Maryland Plan* in 1973, the above observation took place sometime before this date. Maley was concerned with personal development, and he used the social experience and problem solving as the context for this development.

Hill and Smith (1998) observed that students recognized the importance of sharing and learning from a range of ideas presented in a team context. For example, one 11th grade female stated, "… when you have two or three people working they have lots of ideas" (p. 34). A 10th grade male, observed in the Hill and Smith study, discussed the progression of ideas that occur in the team process:

> You have, like here, we'll have three different ideas coming in. Like [a student] had some good ideas about how we should set up the seats, and then he worked on the coring spike, the front end of the coring spike to the steering. Got all that done. And then I had the idea of taking, cutting a handlebar in half and then taking those two and hooking them on to our original handlebars to make them longer (p. 34).

These student perceptions are clearly inconsistent with the social psychology findings that face-to-face brainstorming is less productive and that groups tend to share what the members have in common. It is important to note that the social psychology experiments, involving brain storming, have not measured technological problem solving in relation to the generated ideas; however, most technology educators think that brainstorming and alternative solutions are an important part of technological problem solving. However, consistent with the above mentioned social psychology findings, one 11th grade female in the Hill and Smith study commented: "… it's just easier to do designs when you are alone than having other people's ideas and trying to communicate without a drawing" (p. 34). This same student commented on how teamwork helped during the construction stage. From interviews with the student design teams, the researchers, Hill and Smith, discovered that the design was dynamic and evolving. "Teams that created sketches or models changed their creations from 6 to 10 times during the course of construction as they determined what did and did not work" (p. 35). Another finding of Hill and Smith was that:

> … meaningful design for most students began more as a lived, bodily experience than as a mental creation. Students needed to engage their senses in their planning (p. 35).

For example, one student in that same study, who was designing a garden table for a person with a disability, did her task work in a wheelchair to better understand the lives of wheelchair users. Finally, Hill and Smith suggest that further research is needed on how teamwork and subsequent social dynamics add to student learning.

In a case study, Wicklein and Schell (1995) investigated four different high schools and their curriculum efforts to integrate technology, science, and mathematics. Wicklein and Schell state that for one school using the *Principles of Technology* curriculum, the goal was to improve mathematics and science scores for students with below average abilities in these areas. In the study, the learning environment for the *Principles of Technology* program was student teams solving "real world" problems. Each student team consisted of a student supervisor, a mathematics expert, a technologist, and two laboratory technicians. According to Wicklein and Schell, this learning environment had several benefits:

> … the teamwork concept allowed for excellent cooperative learning, peer teaching, and teamwork responsibilities. The friendly competition between teams within the classes also heightened the interest and learning that was taking place. … [the experience in the] student learning teams was also a very positive experience for most students in this project. Students were able to perceive the importance of working together to solve a common problem as well as, exposure to occupational strategies … (p. 66).

An unanticipated problem with this project by Wicklein and Schell was many students only wanted to be accountable to one teacher, instead of one from each discipline: technology, science, and mathematics.

Jarvinen (1998) investigated a fifth grade class of design teams, which were given three open-ended design problems to solve using a Lego Dacta control kit. The classroom activities utilized a Mortimer's (1996, cited in Jarvinen, 1998) modern teamwork model, in which members must cooperate to accomplish a task, and a technology, science, and mathematics integration model. In addition, teams were allowed to decide and change roles, such as programmer and constructor, as needed (Jarvinen, 1998). Through an inductive interpretative process, Jarvinen's research findings resulted in several assertions:

1. The working of the pupils was controlled and guided mostly by themselves and the teacher's role was more like tutor and adviser as needed (p. 52).
2. Technological content spontaneously handled by the pupils consisted of the elements of control technology, system planning, and at least rudimentary programming skills; this content can be commonly understood and transferred among the pupils acting in the social interaction (p. 54).
3. Mathematical-scientific content appeared to be used as a tool in technological oriented problem solving and it was naturally applied by the pupils (p. 55).

Assertion one by Jarvinen was supported in that, the majority of the time (65.6%), student teams acted on technological and mathematical-scientific content, without suggestions or inputs posed by their teacher.

The social interaction and team process in arriving at a team decision is obvious in the following example quote that supports Jarvinen's assertion two:

> Lupu understands the meaning of touch sensor (input) in order to trigger the appropriate function (output). Hupu also understands the meaning of the sensors and, moreover, seems to be more aware of the possibilities of different sensors in this particular context. It was apparent that both Lupu and Hupu understand the principle of control technology and they were able to create a complete system (input-process-output) (p. 54).

The following quotes are examples of assertion three in relation to scientific and mathematical content:

> Marko looked toward the girls and said, "Hey...do you know what? Let's put more weight on this (Lego-car) and [it] will accelerate better while going down the hill (p. 55) .... Pirkko looks at the commands Marko has just written and stated, "Ten...you have programmed it (the motor) to operate for one second (ten equals ten tenths of a second or one second" (p. 56).

Overall, Jarvinen concluded that social interaction in student teams promoted technological problem solving and learning. In addition, Jarvinen concluded that with these student teams, knowledge transfer in the social interactions between members was both apprenticeship-like (expert-novice) and peer-to-peer, with neither phenomenon predominating.

Team Developmental Theory

As mentioned earlier, Tuckman (1965) reviewed most of the research on small groups to develop his theory that groups develop through the stages of forming, storming, norming and performing. Using grounded theory methodology, Gersick (1988) revisited Tuckman's model. She observed eight different groups or small teams, which all had some sort of task to accomplish. Three of the eight groups were comprised of graduate management students. Gersick's analysis of the data revealed that all the teams had varying ways of trying to accomplish tasks, but the timing of tasks was not different from team to team. Gersick found that every group went through two phases. The first phase was established during the first meeting, and it continued until exactly at the halfway point of the task deadline. From early on during the first meeting, every team had a unique approach to the task that continued through a period of inertia. This behavior is illustrated in the following quote from Gersick:

> Each group immediately established an integrated framework of performance strategies, interaction patterns, and approaches toward its task and outside context …. The most concise illustration of this finding comes from the student group, whose (1) easy agreement on (2) a specific plan for its work represented (3) a decision to ignore the outside requirements for its task—all within the same minute of group discussion (p. 21).

Gersick states that the power of the first meeting, in terms of process and content, is very important for half of the teams' life cycle. Furthermore, teams typically did not discuss task frameworks explicitly; rather, team members inferred these from typical behaviors displayed in the team.

Gersick (1988) found that at the halfway point, teams displayed an abrupt change in behaviors, characterized by a “concentrated burst of changes, groups dropped old patterns, reengaged with outside supervisors, adopted new perspectives on their work, and made dramatic progress” (p. 16). In the transition period, teams came to new agreements on the direction that each team should take to accomplish its task. Gersick’s findings suggest that the first meeting for a team is important, as well as the resources available to the team at the midpoint of the life cycle of a team. Gersick seems to use the terms team and group interchangeably.

Building on the research findings of Tuckman (1965) and Gersick (1988, unpublished manuscript in 1985), Morgan, Glickman, Woodard, Blaiwes and Salas (1986) developed a nine-phase generalized model of team evolution and maturation (see Appendix A: *Team Evolution and Maturation Model*, p. 227). Even before the team is formed, the pre-forming phase begins, which is the acting forces that necessitate a team instead of individuals acting separately. In the forming phase, the team orients itself to the task, and team members may test their dependence on one another. In the storming phase, the team adjusts to the emotional demands of the task and may display outward interpersonal conflict. Storming is characterized by an exploration of the situation. In the next phase, which is the norming phase, the team attempts to form functional roles and may develop group cohesion. In the performing one phase, the team may have initial solutions and may start to develop how the team members will coordinate their actions. During this phase, the team will experience inefficient patterns. For the next phase, reforming, the team reflects on past behaviors and makes adjustments from current understandings. This occurs at the mid-point of the life cycle of a team, which was identified by Gersick (1988). In the performing II phase, the team doubles its efforts to produce and may experience high levels of efficiency. Within the final phase, conforming, the team delivers its product. At this point, deforming members disband and move on with future tasks (Morgan et al., 1986). De-forming is similar to Tuckman and Jensen's (1977) revised model, which added adjourning as a final phase in the model.

Morgan et al. (1986) hypothesize two distinct tracks of activity in their model: operational team skills and generic team skills. For Morgan et al., the top track includes the team members' interaction with tools, machines, and technical aspects of the task. In contrast, the bottom track is focused on developing skills associated with improving teamwork skills. From this model, Morgan et al. proposed that the two lines of development for a team "must be separately enhanced, progressively focused, and ultimately converged so that all activities contribute to improved team viability and performance" (p. 17). From the earlier discussion on student team research, it is clear that students were and are being placed in teams and given a task (i.e., technological problem solving); however, it is not as clear whether the classroom teachers have given students separate teamwork experiences designed to enhance the team members' "ability to communicate, relate, and interact" (p. 17). For an example of this, refer to the technology education classroom research by Barak and Maymon (1998), which was described earlier.

Individual Mental Models

Cannon-Bowers, Salas, and Converse (1993) indicate individual mental models have been used in a variety of disciplines. For example, Johnson-Laird (1983) from the cognitive science field, viewed mental models as quasi-pictorial images that help people understand their current situation and the world around them. Similar to Laird, Alexander (1964) proposed that engineers and architects created mental models to help solve design problems. Alexander proposed that logic based on mental models can be more general than deductive logic, stating that " … [this logic] is concerned with the form of abstract structures, and is involved the moment we make pictures of reality and then seek to manipulate these pictures so that we may look further into reality itself" (p. 9). In contrast, Schnotz and Preub (1999) argued that mental models are not always images of an object, but rather, may also be more abstract concepts, such as "international trade relationships." In addition, Schnotz and Preub viewed concepts or cognitive schema as cognitive tools used to create mental models, which are orientation tools for understanding subject matter or current states. For Schnotz and Preub, mental models are temporarily constructed in working memory to solve specific tasks at hand, and they are not stored in long-term memory.

Norman (1983) views a person's mental model as evolving through interaction with a system. He states: "In interacting with the environment, with others, and with the artifacts of technology, people form internal mental models of themselves and of the things with which they are interacting" (p. 7). The purpose of a mental model is to provide a person with explanatory and predictive power during their interaction with a system. Although Norman gave examples of individuals interacting with different types of calculators, the above quote seems to illustrate his understanding that people also form mental models of interpersonal systems.

Similarly, Duffy and Jonassen (1992), in their discussion of constructivist knowledge, suggested that learners use mental models based on internal and social negotiation. They state that internal negotiation is similar to Piaget's accommodation and Norman's (1978) restructuring and tuning. The following quote illustrates Duffy and Jonassen's (1992) proposal that internal negotiation involves actively forming mental models: "Based on internal negotiation (a process of articulating mental models, using those methods to explain, predict and infer, and reflecting on their utility …" (cited in Jonassen, 1994, p. 37). In addition, Duffy and Jonassen (1992) proposed that social negotiation uses identical or similar processes to internal negotiation. Therefore, an individual uses mental models to explain, predict, infer, and reflect on interpersonal relationships and to explore his or her environment. In other words, Duffy and Jonassen saw mental models as what individuals use to explore and restructure their environment.

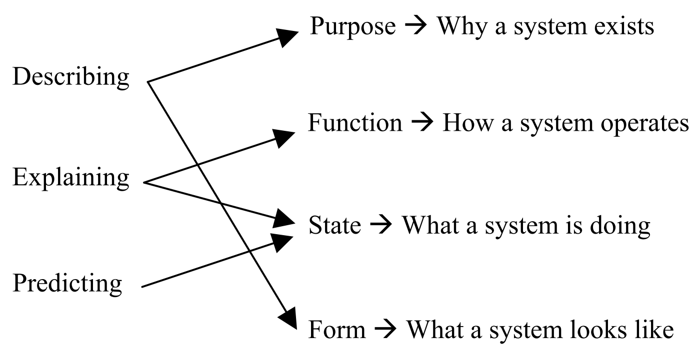

Figure 1. *Purposes of mental modes.*
Rouse, W. B., & Morris, N. M. (1986). On looking into the black box: Prospects and limits in the search for mental models, Figure 1, p. 351. *Psychological Bulletin, 100*(3), 349-363. Copyright © 1986 by the American Psychological Association. Reproduced with permission.

After reviewing a host of definitions of mental models from the manual control/supervisory community and cognitive science, Rouse and Morris (1986) proposed that differences are reduced between fields if the purposes of mental models are considered. In the field of manual and supervisory control, Rouse and Morris thought that mental models have served as assumptions that allow people to make calculations and predictions to help control machines and automated systems. On the other hand, cognitive science has concentrated directly on mental models as the way that humans understand systems. Rouse and Morris also stated that there is overlap between the two fields, "The common themes are *describing, explaining,* and *predicting*, regardless of whether the person is performing internal experiments, scanning displays, or executing control actions"(p. 350). Using Ramussen's taxonomy from 1979, Rouse and Morris developed an integrated view of mental models in 1986 (see Figure 1). The authors proposed a working definition of mental models as "… the mechanisms whereby humans generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future system states" (p. 351).

Types of Team Mental Models

Using Rouse and Morris' (1986) definition of mental models and from their experience in team training and research, Cannon-Bowers et al. (1993) developed four models important for team functioning (see Table 3). The teamwork and task work models proposed by Cannon-Bowers et al., seem to build upon the operational and general team tracks of development

Table 3
Multiple Mental Models in Teams

Type of Model	Knowledge Contents	Stability of Model Contents
Equipment Model	Equipment functioning Operating procedures Equipment functions Likely failures	High
Task Model	Task procedures Likely contingencies Likely scenarios Task strategies Environmental constraints	Moderate
Team Interaction Model	Roles/responsibilities Information sources Interaction patterns Communication channels Role interdependencies	Moderate
Team Model	Teammates' knowledge Teammates' skills Teammates' abilities Teammates' preferences Teammates' tendencies	Low

Cannon-Bowers, J. A. Salas, E., & Converse, S., (1993) Shared mental models in expert team decision making, Table 12.1, p. 233. In N. J. Castellan (Ed.), *Individual and group decision making* (pp. 221-246). Hillsdale, NJ: Lawrence Erlbaum Associates. Reprinted by permission of Lawrence Erlbaum Associates.

proposed by Morgan et al. (1986), which were discussed earlier. The different models Cannon-Bowers et al. (1993) developed are not independent. For example, according to Cannon-Bowers et al., if the task requirements change, the task model and team model will interact, as team members decide which members have the skills, knowledge, and motivation to work on the problem or sub-task.

With some modifications, the team mental models, proposed by Cannon-Bowers et al. (1993), may be applicable to technological problem solving within a TBL context. For example, suppose the general task presented to technology education students is technological problem solving. Depending on the technological problem constraints, Halfin's (1973) seventeen operations of a technologist fit well in the equipment and task models. Unlike in the Cannon-Bowers et al. equipment model, student teams, due to a lack of experience, may not have a highly stable equipment model. With student teams, resources should replace the equipment model with items such as knowledge of materials and processes, skill with technology tools, and different learning tools. It is important for team members to have different learning strategies. This model may have low stability as learners gain experience. In addition, with the task model, students must understand and define the problem. Differently than Cannon-Bowers et al. (1993), the team interaction model may be highly stable for student teams. That is, similar to Gersick's (1988) findings, student teams may establish norms in the first team meeting. Because of a lack of prior teamwork experience, these student teams may develop rigid team roles, based on some notion they have of work teams or even of sports teams. Furthermore, students may make unwarranted assumptions about their teammates' knowledge, skills, and preferences. It may be necessary to have separate teamwork exercises for students to develop a functioning team task model and team interaction model.

Team Mental Models and Performance

Due to the elusive nature of teamwork behavior, mental models are currently being used as an explanatory construct (Cannon-Bowers et al., 1993). For example, Hammond (1965) noted that ineffective teams had different mental models of the problem-solving task. Stout, Cannon-Bowers, and Salas (1996) state that research has tended to focus on observable teamwork factors, such as communication; however, observable behaviors may be inadequate for explaining teamwork elements like "adaptability and coordination of action" (p. 88). For example, Minionis (1994) found that the degree of shared mental model overlap had a significant effect on team performance and coordination, but it affected only one in seven communication categories.

In a similar study, Rentsch and Klimoski (2001) investigated work teams on teamwork schema agreement. Through interviews with teams of all types, their study asked open-ended questions, such as "How do you define teamwork?" or "Can you give specific examples of teamwork?" (p. 112). From this work, a fifteen item, paired-wise teamwork schema questionnaire was developed. The researchers found that teamwork schema agreement mediated the relationship between demographic variables, such as team experience and team effectiveness. Team effectiveness had three factors: team viability, client satisfaction, and member growth. According to Rentsch and Klimoski, an example of team viability is "Team members tend to carry their weight" (p. 22). Citing an unpublished research study (i.e., Jenkins & Rentsch, 1995 – Paper presented at the 10th SIOP), Smith-Jentsch, Campbell, Milanovich, and Reynolds (2001) suggest that it is not always teamwork schema agreement that is necessary, but it is necessary to be able to predict other teammates' teamwork schemas accurately.

Mohammed and Dumville (2001) suggested there are four sub-domains of team mental models: information sharing, transactive memory, group learning, and cognitive consensus. Each sub-domain is different in the areas of degree of sharing emphasis, general content, and specific content. In relation to group learning, there is an emphasis on sharing overlap, knowledge structures are the general content domain, and teamwork is the specific content domain. Mohammed and Dumville state that " … group learning plays a significant role in the development, modification, and reinforcement of mental models and can be viewed as a subset of the broader concept of team mental models" (p. 98). In addition, they state that in team learning all members will need to learn some material, with other knowledge certain members will need overlapping knowledge, and some knowledge will remain unique to individuals.

Orasanu (1990) investigated the ability of experienced pilot teams to problem solve when faced with adverse conditions, creating a situation in which alternative solutions had to be explored and decisions made. According to Orasanu (1990) by "articulating situation assessment and metacongnitive processes, the crew builds a shared model of the problem" (p. 4). Without a shared interpretation of the problem, the crew may be working towards different ends. Orasanu found it important that the crew share elements, such as, "definition of the problem, plans and strategies for solving the problem, interpretation of cues and information, and roles and responsibilities of participants" (p. 4).

In addition to shared mental models, Orasanu (1990) identifies three other cognitive components: situation assessment, metacognition, and resource management. Situation assessment is interpreting information to recognize problems and realizing the significance of those problems. Metacognition involves defining the problem and working out possible solutions. "One must develop a plan and strategies, set priorities, and decide what information is needed in order to make a decision" (p. 3), states Orasanu. She also refers to metacognition as "problem-solving talk." Resource management involves elements such as management of information, time requirements of various components, and the cognitive demands of problems. According to Orasanu, " … resource management assures that time, information and mental resources are available when they are needed" (1990, p. 4). Similarly, classroom teachers in technology education want their students to manage their resources.

Orasanu (1990) found that captains in high performing crews talked less during high workload situations, while the opposite was found with low performing crews. She found that high performing teams obtained more problem relevant information, while low performing crews increased information requests when the workload was high. Therefore, a lack of preplanning on the part of the low-performing crews was evident. Moreover, the timing of the crew did not match the task demands. Orasanu concluded, "Shared mental models assure all participants are solving the same problem and create a context in which all can contribute effectively" (p. 15). In similar research, Siskel, Lane, Powe, and Flexman (1965) found that as teams gained experience with each other they became better at expressing fewer ideas to achieve coordinated effort.

Team Mental Models and Task Load

Stout, Cannon-Bowers, Salas, and Milanovich (1999) investigated shared mental models as an explanatory construct for coordinated team performance. The participants included in the study were twenty male undergraduate teams of two each. The task for each team, along with two experimenters who also took mission roles, was to perform a surveillance mission in a helicopter simulation. Therefore, the helicopter team had four distinct roles, and the two participants were randomly assigned to one of two positions within the team of four. One independent variable in this study was pre-mission planning, which was identified by rating behaviors on nine dimensions, such as creating an open environment, clarifying roles and information to be exchanged, and exchanging work preferences. Stout et al. (1999) also manipulated the task condition into high and low demands on the team. The dependent measures were shared mental models, the rate of communication in advance, and the number of errors made during each mission (performance). Stout et al. found that teams rated higher on pre-mission planning had closer shared mental models, provided information before it was requested, and had less errors during high workload conditions. However, in this study, teams with greater shared mental models were not found to use more efficient communications during times of high workload. Therefore, planning was not found to have an effect on communication strategies acting through shared mental models. These findings of Stout et al. did not confirm the findings of Orasanu, as described above.

Team Mental Models and Team Process

In order to investigate the influence of team mental models on team process and performance, Mathieu, Heffner, Goodwin, Salas, and Cannon-Bowers (2000) conducted research with undergraduate teams of two (52 males and 60 females), having a mean age of twenty-one (M = 20.96, SD = 2.02). All the participants were randomly assigned to their team of two, and then they were trained to use a flight simulator. After this, the teams flew missions and were allotted points on a rubric for survival, navigation to waypoints, and shooting down enemy planes. During the missions, the teams were rated on three process dimensions: strategy formation and coordination; cooperation; and communication. After their mission, each team member filled out a task mental model and a team mental model. Subject matter experts developed the task mental model through a task analysis. The team mental model was based on previous taxonomic research on teamwork dimensions (Mathieu et al., 2000).

Mathieu et al. (2000) found that team processes had an effect on team performance. In addition, the team and task mental models each had unique effects on team process. Although the team mental model sharedness was significantly related to team performance, it was fully mediated by team processes. However, the task mental model did not have a significant relationship with team performance, but it did have an indirect effect on team performance through team processes. That is, task mental model did have an effect on team process. This finding by Mathieu et al. was the first empirical evidence that the team and task models are separate (2000). The researchers in this study did not manipulate any variables.

Although all the studies in this section are examples of problem solving, the teams do not produce a technological design. Nonetheless, there are some similarities. For example, many times in technological problem solving students are asked to work with technical tools and information. Similarly, in the Stout et al. (1999) study, teams used technical tools, such as a 360° instrument for calculating headings and a computer gauge that shows a small picture of the map mode. Interpreting the measurements from these tools requires some of the same skills as using a multimeter, a GPS system, or vernier calipers. In addition, the teams in the study had to make both calculations and hypotheses, based on the information they gathered. Furthermore, planning was an important part of the problem solving. Finally, just like the teams in the study, students in TBL must share information, coordinate action, and hypothesize. Salas, Dickinson, Converse, and Tannenbaum (1992) suggest that team members need to learn how to combine teamwork and task work skills. Furthermore, Stout, Salas, and Folkes (1997) state that team interaction training studies have been unsuccessful, because they tended to focus on the individual level rather than bringing about team level change. Furthermore, Stout et al. (1997) concluded that team interaction training is especially needed in novel environments. Although these researchers wanted to generalize their findings to military situations, many student teams may also find technological problem-solving tasks as novel situations.

Team Training and Team Mental Models

Marks, Zaccaro, and Mathieu (2000) investigated whether or not team interaction training and leader briefings influenced the development of mental models. The participants in this study were 79 three-member teams (145 males and 92 females), with an average age of twenty (M = 19.83). Each team member was assigned to one of three tanks with the goals of shooting ten enemy targets on the simulated battlefield and of constructing pillboxes. The teams made decisions about their strategic routes and how to hide from enemies. Both the control and treatment groups watched a ten-minute video that gave task information; however, the team interaction treatment group video included how to interact effectively as a team. The leader briefing treatment consisted of a five-minute audiocassette of a leader telling his or her intentions during the mission (e.g., identification of significant battleground risks). Unlike the studies mentioned earlier, this Marks et al. study had two manipulated variables.

Marks et al. (2000) measured the teams on mental model similarity, mental model accuracy, communication processes, and team performance over short intervals. Mental model accuracy was measured through a comparison of the team's mental model and that of an expert to that particular team task. Communication was rated on quality rather than quantity. During measurement, the students were presented with environments in which they had trained, as well as novel environments. Marks et al. found that the quality of communication was positively related to team coordination performance in routine environments, and it had an even stronger relationship in novel environments. In addition, team mental model similarity had a significant effect on the quality of the communication processes; however, team mental model accuracy did not. Furthermore, Marks et al. found that the team mental model accuracy and similarity showed a multiplicative effect on team communication processes, but it failed to be significantly greater in novel environments.

As Marks et al. (2000) predicted, team interaction and leader briefing treatments had significant effects on team mental model similarity and accuracy. However, a significant multiplicative effect was not found, indicating that both treatments together did not enhance the treatment effect. One important finding of this study was that mental model similarity was more important than accuracy, especially when teams were confronted with novel environments. In a sense, when student teams are presented with new technological problem-solving tasks, they experience a novel environment. In contrast to the Marks et al. (2000) findings, Hayes (2003) found that whether teams had strong emergent leaders did not predict technological problem-solving performance. In addition, Hayes (2003) found only that team mental model accuracy, not similarity, significantly predicted team technological problem solving. Hayes' findings with team mental models are the reverse of those by Marks et al. (2000), who found that similarity was more important than accuracy. It is important to note that both Hayes (2003) and Marks et al. (2000) were measuring team performance, but the teams in each study had different tasks.

Evolution of the Concepts of Teams and Team Building

Depending on the time era, the team concept has been viewed and defined in different ways. One team definition that is often quoted in research studies is "an interdependent collection of people who must rely on the efforts of each other in order to be successful in achieving group goals" (Dyer, 1977). In the second edition of his book *Team Building: Issues and Alternatives*, Dyer (1987) differentiates teamwork based on the amount of collaboration required to achieve common goals. He conceptualizes that greater collaboration equates to greater teamwork. For example, in teamwork requirements, Dyer views a golf team as low, an accounting team as medium, and a NASA space team as high. Although his definition seems to focus on the level of collaboration, Dyer's examples seem to make no distinction between collaboration and coordination. For example, a golf team, with each member taking turns at the tee, requires little coordination; nonetheless, the team may be collaborating through sharing a variety of information between each stroke or putt. In other words, team members may give each other feedback on their putting form, or they may share information about how the particular golf course relates to each member's golf game.

In her historical research of teams in the workplace, Wesner (1995) used Dyer's (1977) definitions of teams to view the evolution of teambuilding throughout the twentieth century. Wesner defined team building as "An educational process which aims to allow group members to work together to identify problems, design and implement solutions to these problems, and to learn from the experience" (p. 17). Wesner organized the emphasis on team building into three time periods. According to Wesner, up until the 1950's, researchers and management were in the process of discovering the value of teams in the work place. This period was predominately a top down approach, without the worker needing to make decisions. Both Frederick Taylor's scientific management and later the human relations movement, which was a revolt against scientific management, were important influences in this era. The influence of Kurt Lewin's group dynamics and training continued into the next era of team building. During the 1950's and 1960's, the social interaction between workers and levels of management increased. However, most problems in companies were viewed as a lack of relationship skills within management (Wesner, 1995). Therefore, separate human relations training, which focused on learning from laboratory experience rather than lecture, was emphasized for managers. Wesner states, "The participants in this early team building intervention were, unlike today's participants, all managers" (p. 92). Later in this period, the emphasis started to shift from the development of the individual to the development of the group. Wesner states that this was the beginning of team building.

With the transition to the information age in the 1970's and 1980's, there was an emphasis on information, service, problem solving, and new technology. Now, the worker had to make many decisions. According to Wesner (1995), it was during this period that front line workers were required to work in teams to solve common problems facing companies and organizations. Also, she asserted that team building is different from structured teamwork exercises. Wesner writes that for team building to occur the team process must result in work-related outcomes; however, structured teamwork exercises "may be utilized as methods for helping teams learn about group processes during team building" (p. 135).

With the problem solving of the 1970's and 1980's, there was a proliferation of different team definitions (Wesner, 1995). In addition to Dyer's (1977) definition found above, Morgan et al. (1986) had more of an emphasis on team evolution and development. During this time period J. Dyer (1984), commented on the confusion of investigators between groups and teams, which made it difficult to determine important team research variables. In addition to this, Freeberg and Rock (1987) are critical that some researchers tried to apply small group research findings to team training technology. However, many fields do apply research findings from other behavioral sciences, such as education using findings from sociology and psychology. For this reason, researchers may conclude their journal articles with statements speculating how well and under what conditions their findings may generalize to other populations.

Meta Analysis of Team Research

Under a contract from the Office of Naval Research, Freeberg and Rock (1987) conducted a review of all team performance related research studies. Of the 547 papers Freeberg and Rock reviewed, only 21% met both their statistical requirements and "team" entity as a task interacting group. Due to the difficulty of obtaining unpublished studies from industry and unclassified studies from the military, Freeberg and Rock used a majority of studies that had been conducted using college samples (NRC, 1994). Even though many of the studies used college samples, the purpose of those studies was usually not to apply their findings to public or college education. The average team size was 3.2 (NRC, 1994). Using the effect sizes reported in the studies, Freeberg and Rock developed a model (see Figure 2) based on inputs (independent variable), throughputs or processes (mediating variable), and outputs (dependent variables).

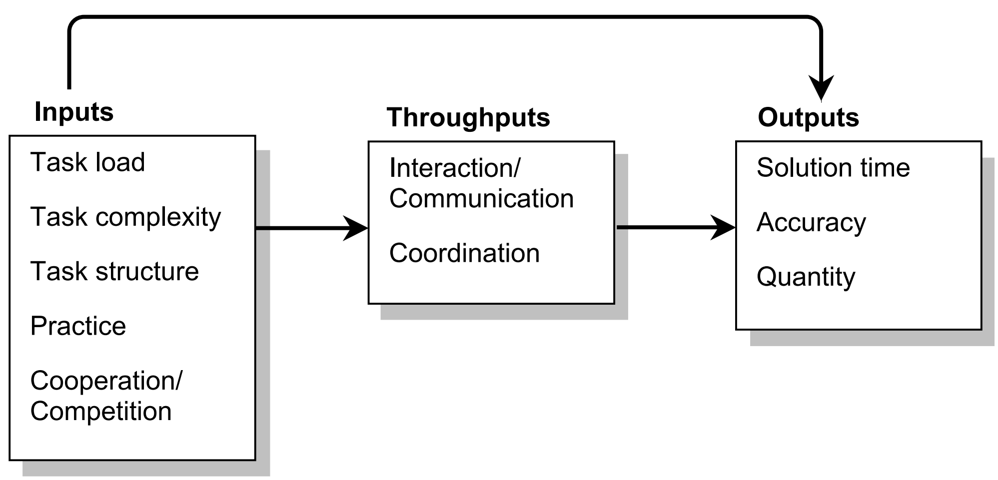

Figure 2. *Input, throughputs, and output variables in team performance.*
National Research Council (1994). *Learning, remembering, believing: Enhancing human performance*, Figure 6-1, p. 116. Washington, D. C: National Academy Press. Reprinted by permission of the National Academy Press.

Freeberg and Rock (1987) identified nine dependent measures, twenty-five independent variables, and three mediating or process variables. Some of the dependent measures included team accuracy, quantity, perceived satisfaction, task transfer, and performance proficiency.

Technological problem solving as a variable or construct does not align well with any of these measures. The twenty-five independent variables were classified under the categories of team member characteristics, team task characteristics, and team organization.

Experiential Learning and Teams

One cannot *not* experience. If one is reading this, then one is experiencing. However, most educators would not embrace the possibility that all experience leads to learning and development. David Kolb's (1984) theory of experiential learning distinguishes between developmental learning and rote learning. To develop his theory of experiential learning, Kolb integrated theories and research findings, principally from Kurt Lewin's training groups and reflection, John Dewey's experience as an organizer for learning, and Jean Piaget's cognitive development. Kolb also included other theorists, such as Erik Erikson's socioemotional tasks throughout life. Kolb proposed that integrating the different socioemotional and cognitive developmental schemes provided a more accurate theory of the learning processes. In addition, according to Kolb, Carl Jung's psychological types, which are different adaptation modes, are important in understanding how the individual learns from experience. Kolb's experiential learning theory proposes that individuals will have preferences for how they structure knowledge, based on experience. Kolb described the process of experiential learning as a four-stage cycle, having four adaptive learning modes: concrete experience, reflective observation, abstract conceptualization, and active experimentation. Kolb stated that it is the integration of these four adaptive modes that leads to the learning process, which creates knowledge through "grasping experience and transforming it" (p. 42). Kolb thought of learning as an iterative process that involves taking action, reflection upon that action (Edmondson, 2003), and then modifying knowledge to take action again (Kolb, 1984).

Edmondson, Bohmer, and Pisano (2001) proposed that teams do not automatically engage in Kolb's iterative process of learning. Edmondson (2003) states that team learning requires coordination and structure, so that the team can take advantage of the insights of different members, which will guide future actions. Edmondson et al. (2001) found that successful work teams engaged in more active process than did unsuccessful teams. The active process is characterized by iterative trial and reflection. According to Edmondson et al., reflective teams, "asked themselves, through … shared review of the data. 'What are we learning? What can we do better? [and] What should we change?'" (p. 705).

Psychological Safety in Teams

Edmondson (2003) suggests that psychological safety is an important factor for learning in a team context. Trust and psychological safety are related, but they are distinct constructs. According to Mayer, Davis, and Schoorman (1995), trust is, "the willingness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other party" (p. 712). Contrasted with trust, Edmondson (2003) states that psychological safety is a more immediate concern than trust: it involves one's interpersonal actions, considers whether interpersonal risks will be supported, and is more affected by the current work environment than one's life history. Psychological safety creates a climate in which people do not fear asking questions that may make them appear less knowledgeable. From the interpersonal perception of a team member it is, "I don't have to wear a mask in this team … it's easy to be myself" (Edmondson, 2003, p. 259). In 1999, Edmondson defined team psychological safety as, "a shared belief that the team is safe for interpersonal risk taking" (p. 354). According to

Edmondson, these beliefs are not usually given direct attention by team members or the team as a whole.

Edmondson (1999) investigated work teams on the basis of psychological safety and learning behaviors, using mixed methods of qualitative and quantitative analysis. She found that team learning behavior was significantly and positively related to team performance. In addition, team psychological safety significantly predicted team-learning behavior; however, team psychological safety, as predicted, became insignificant when entered into the regression model. Therefore, she found that team learning behavior mediates the effects of team psychological safety on team performance. Edmondson (2003) concluded that team psychological safety is a useful construct for understanding collective learning processes in saying that, “Psychological safety can increase the chances of effortful, interpersonally risky, learning behavior, such as help seeking, experimentation, and discussion of error” (p. 260).

Trust in Teams

Mendoza (2001) defined trust in a way similar to Mayer et al. (1995). Mendoza investigated the impact of experiential teamwork exercises on individual ratings of team trust with intact manufacturing teams. The teamwork exercises in Mendoza’s study were low-rope initiatives, many of which would not be appropriate in a classroom setting (e.g., low rope courses sometimes have participants lifted off the ground by other team members). Nonetheless, the low rope initiatives have some similarities to the student teamwork exercises utilized in the current study. Mendoza found that teams which received, “experiential team building methods maintained a statistically significantly higher trust level than the control group over time (30-day post and pre-test) when traditional team building methods (classroom discussion) did not.”

Human Problem Solving

Newell, Simon, and Shaw (1958) were pioneers in developing theories of human problem solving. They used current research on human problem solving, as well as theories, such as Gestalt and directed thinking, to help them develop a theory of human problem solving. In addition, Newell et al. (1958) made analogies between the way computers and humans solve problems to develop their theory. That is, one way to describe human problem solving was to investigate the sequence in which humans process information. To help them with their analogies, Newell et al. developed the "think aloud" method, which asked participants to tell what they were thinking as they attempted to solve problems. Newell et al. were well aware that problem solving occurs in an interactive process between the problem solver and his or her environment:

> It [The theory] should show how changes in the attendant conditions—both changes "inside" the problem solver and changes in the task confronting him—alter problem-solving behavior (p. 151).

Although Newell et al. may have been arguing that different task complexity affects how humans attempt to solve a problem, individuals also structure the task to reduce complexity. In addition, one might think of an algorithm when a computer solves a problem; however, Newell et al. described the heuristics humans use in problem solving, as well as the strategies used to have more than a "trial and error" approach.

One major contribution of Simon and Newell's (1971) theory of human problem solving is that it incorporates theories of information processing that have all been well researched in cognition, such as short-term memory, working memory, and long-term memory. It is generally accepted that short-term memory has limited capacity, working memory has limited processing capability, and long-term memory has greater capacity, but it takes longer to access. All of these constructs influence how and to what extent humans are capable of solving problems. Because of the limits on information processing, the environment and an individual's interaction with that environment, as well as the problem-solving task, may greatly influence problem-solving ability. For example, if a person is interrupted while trying to access long-term memory, that person can forget the relationship of elements they previously had in their working memory or problem space.

Small Group Research on Ideation

Some small group research illustrates how group processes can impact individual information processing. As mentioned in Chapter One, with the *Standards for Technological Literacy*, and earlier in Chapter Two with the company IDEO, many educators and people in industry advocate the technique of group ideation, which is also known as brainstorming. However, it has been well researched that small groups not only produce less ideas, but they also generate less relevant ideas than individuals brainstorming separately as a group. Diehl and Stroebe (1987) reviewed 22 studies that investigated brainstorming in real groups compared with nominal groups. Nominal groups are made up of participants that know of each other, but they are placed separately to brainstorm. In their review, Diehl and Stroebe found that in only 4 out of 22 studies did the real group outperform the nominal group, and the four studies that did find a difference only used a group size of two. Similarly, Bouchard and Hare (1970) found that process dysfunctions increase as numerical size increases. Several reasons are generally given for this production or process loss. They are: participants forget their own ideas while waiting their turn, mental rehearsal does not allow for generation of new ideas, and participants become distracted by the ideas of others (Diehl & Stroebe, 1991). On the other hand, "process gain occurs when new ideas, solutions, or efforts are generated through group interaction that are not generated when persons work individually" (Johnson & Johnson, 1990, p. 26).

Diehl and Stroebe (1991) further elucidated the causes for a lack of group productivity in brainstorming. In addition to a nominal group, which produced 99 nonredundant ideas, they included three groups that were also not face-to-face but connected by microphones that activated lights, creating unorganized, predictable, and controllable treatment conditions. All four-member groups had the task of generating ideas on how persons with disabilities could be further integrated into society. In the unorganized condition, group members could jump in whenever they wanted, as long as no lights were on. This was to simulate a real group brainstorming situation, and the groups produced 68 nonredundant ideas. With the predictable groups, they had to go in the same order each time, which was indicated by the lights. The predictable groups only averaged 49 nonredundant ideas. Finally, the control groups had to enter their names on a list displayed to all members, and they had to then contribute in that sequence. The control groups produced only 29 nonredundant ideas. Diehl and Stroebe (1991) suggest that short-term memory limitations may be the reason for this production loss.

With an additional experiment, Diehl and Stroebe (1991) found a trend to reduce the above-mentioned production loss when the participants were allowed to take notes; there were 39 nonredundant ideas, instead of only 30. Group brainstorming is often suggested as one of the initial steps in team technological problem solving. The previous findings suggest that group brainstorming may actually hinder idea generation and relevancy. However, it is also possible that team members that brainstorm separately may not realize the emotional enthusiasm behind the idea. Furthermore, team members may not remember other members' ideas later on if they are generated separately and then shared. Moreover, a greater frequency of ideas may not equate to better designs or greater technological problem solving.

While idea generation has been found to decrease in a face-to-face context, Valacich, Wheeler, Mennecke, and Wachter (1995) found the opposite relationship in a computer context. In this research study, each participant was allowed to concurrently generate ideas with a system similar to "computer chatting." The group size ranged from five to ten members. The task was a university problem that had five unique administration roles. In this Valacich et al. (1995) study, each role had unique information about the problem (e.g., declining quality of instruction, flat budget increases, or faculties' unwillingness to increase class enrollments). The other independent variable in this study was that in the heterogeneous information groups, each member had different task relevant information, and in the homogeneous groups, each member had all the information. Idea generation, feasibility, and quality were the three dependent measures used by Valacich et al.

Valacich et al. (1995) found that the larger group sizes computer-generated statistically more solutions, more unique solutions, and more feasible solutions. As hypothesized, as numerical group size increased, heterogeneity interacted with group size. That is, groups that had diverse information increased at a faster rate than homogeneous information groups for all three dependent measures. Small heterogeneous groups shared more information than any other groups, but Valacich et al. concluded that these groups did not have enough human information processors to educate the other members on unique role information. When the average member contribution on each of the three dependent measures was accounted for, the homogeneous group member contributions diminished as numerical group size increased. Therefore, the findings suggest that the homogeneous groups were at their optimal size (i.e., five members) while the optimal heterogeneous groups were either ten or larger in number of members. Since numerical group size was opposite to that found in face-to-face groups, Valacich et al. suggest that further research is needed on how heterogeneity interacts with production blocking in face-to-face groups.

In another study, Grawitch, Munz, Elliott and Mathis (2003) looked at promoting creativity in temporary problem-solving groups. The independent variables manipulated by the researchers were mood and autonomy. Groups, each consisting of three undergraduate members, were randomly assigned to either a neutral mood or a positive mood. The treatment included having the neutral mood groups visualize stuffing envelopes, while the positive mood groups visualized a recent pleasant experience. These groups were further assigned based on the level of autonomy being either high or low. Autonomy, as operationalized for this study by Grawitch et al., was how much autonomy the groups had in defining the problem. The high autonomy groups had a list of problems from which they were to choose to elaborate a solution. The low autonomy group did not receive a list of problems, but rather, through a yoked design, these groups received the selection of the previous high autonomy group.

Grawitch et al. (2003) measured the four different treatment groups based on efficiency, fluency, rated originality, importance of ideas, and satisfaction with decisions. Although not significant, the low autonomy groups were, opposite to what had been hypothesized, more fluent in the production of ideas. The autonomy effect on originality of ideas was also not significant. However, the mood effect on rated originality was significant. That is, the findings supported that the positive mood effect increased the originality of ideas. In the neutral mood condition, the high autonomy groups reported higher levels of satisfaction, while in the positive mood condition, the positive mood groups reported significantly lower levels of satisfaction. Finally, Grawitch et al. found that the positive mood condition identified significantly more relevant areas in the problem solution. It is important to note that the group problem-solving study by Grawitch et al. was focused on areas of university life, which, for purposes of this study, would not be classified as a technological problem.

Most of the research on individual and group brainstorming does not investigate the subsequent impact on problem solving. To address this, Jonassen and Kwon (2001) investigated engineering student problem solving in computer-mediated groups compared with face-to-face problem-solving groups having both well-structured and ill-structured problems. According to Jonassen (1997), well-structured problems, with clear end state and limited logical operators, are what students typically encounter in educational settings. In contrast, professionals many times will encounter ill-defined problems, which have undefined goals, multiple solutions and unclear solutions, and require learners to voice opinions. Unlike with the Valacich et al. (1995) study above, Jonassen and Kwon (2001) used an asynchronous computer-mediated environment.

In their study, Jonassen and Kwon (2001) found that students rated the quality of the problem-solving process higher in the computer-mediated environment. These students perceived that the face-to-face environment required more effort and lower clarity of information, while the computer-mediated environment gave them more flexibility to reflect on their ideas and those of their teammates. In addition, the computer-mediated environment resulted in phasic communication patterns that were more robust and representative of problem-solving processes, while the face-to-face situation resulted in more linear and less active problem-solving communication. Jonassen and Kwon concluded that constraining communication might foster reflection and direction in the team problem-solving process.

Moreover, Jonassen and Kwon's findings support prior research findings that group interactions may increase the information processing demands of individuals.

Small Group Research on Information Processing

Stasser and Titus (1985) discovered that small groups tend to discuss information held by all members, rather than information known by only one member. In addition, once a group member mentions information, groups tend to return to this information several times instead of discussing other information that might lead to different decisions. One proposed explanation for this is that previously discussed information may be more easily accessible from memory. Not realizing this, groups may make a decision that is not congruent with their collective information, because information remains unshared. Several other studies have confirmed the original findings of Stasser and Titus, under a variety of conditions (Cruz, Boster, & Rodriguez, 1997; Gignone & Hastie, 1997; Stasser, Taylor, & Hanna, 1989).

Stasser et al. (1989) investigated group size and information sampling with shared and unshared information. The researchers had the following independent variables: group size (3 or 6 members); amount of shared information (33% or 66%); and structured vs. unstructured groups. For example, in a group of three with 33% shared information, each group member read six of a candidate's eighteen statements. The task was to choose a student body president from three candidates. All participants in the initial briefing were made aware that no contradictory information would be presented, but each group participant may have different information. Group discussions were rated based on discussion of the candidates' statements. Stasser et al. manipulated the structured situation by reading instructions that had members suspend stating preferences for candidates during an initial period of sharing information.

Overall and as hypothesized, the groups in the Stasser et al. (1989) study discussed more shared than unique information (46% vs. 18%). In addition, the six-member groups discussed more information than the three-member groups (38% vs. 27%); however, this group size effect was due to discussing more shared information. That is, the six and three-member groups did not differ significantly on the discussion of unshared information. This is consistent with Stasser's model that as group size increases, there is a greater likelihood of shared information being mentioned than unshared information. In addition, groups having only 33% shared information discussed more shared and unshared information than did the 66% shared information condition. The explanations for this are that processing demands were less for the 33% shared information groups in that they had less to read and remember and that distributing the processing demands resulted in better recall during the measurement period. The six-member groups returned to already discussed information more than the three member groups (37% vs. 25%). Furthermore, once discussed, shared information was more likely to be returned to than unshared information (.34 vs. .26). The researchers concluded that groups might tend to avoid unique information, because no one else in the group could verify it.

Using Bray, Kerr, and Atkin's (1978) work on functional and actual group size, which is based on that active participation may be less with larger groups, Stasser et al. (1989) calculated the functional group size to be 2.46 for three-member groups, while it was 4.44 for six-member groups. Stasser et al. used the formula $\ln(n) = \ln[-\ln \{1 - p(\mathrm{Ds})\}] - \ln[-\ln\text{-}\{1 - p(\mathrm{Du})\}]$, where n is group size, and Ds (discussion shared) and Du (discussion unshared) are estimates of shared and unshared information. Functional size has been hypothesized to be due to motivation loss and coordination loss as the group size increases.

Using further analysis, Stasser et al. (1989) concluded that the functional size was due mostly to coordination loss. The formula $n = \ln[1 - p(\text{Ds})] / \ln[1 - p(\text{Du})]$, in which Ds and Du are proportional estimates of shared and unshared information discussed. Also, the researchers collected written recall data from individuals that read the candidate information, but they did not participate in the group discussions. Using the above formula and the individual data, Stasser et al. estimated that that the functional sizes for groups of three were 2.26 in structured discussion and 1.5 in unstructured discussions. However, the functional sizes for the six-member groups were 3.53 for structured discussions and 2.12 in unstructured discussions, which suggests two possibilities for the coordination loss. First, as suggested by Diehl and Stroebe (1987) and described above, production loss occurs when members in larger groups force members to hold thoughts longer while other members are sharing ideas or two other people are in a discussion. Second, Sanders, Baron, and Moore (1978) suggest that social apprehension can interfere with cognitive tasks in the presence of others. The Stasser et al. findings, as well as other research results on unshared information, are important because the unshared information was important to the final decision made by groups. Overall, Stasser et al. (1989) found that groups discussed 45% of shared information, returning to previously discussed items 34% of the time, while only 18% of unshared information was discussed, returning to it only 26% of the time.

In a similar study to Stasser et al. (1989), Cruz, Boster, and Rodriquez (1997) investigated group sizes of four and eight, and they also measured acts of discounting and bolstering and their relationship to shared and unshared information. Discounting occurs when a group member negates information that is not consistent with his or her information, whereas bolstering is promoting a position that is consistent with one's own position. Examples, from Cruz et al. (1997) respectively, are: "but usually when students like a professor it's … [because]

… they are the easy ones" and "… [that's] important to us communication majors because we want to be able to take lots of different classes" (pp. 302-303). Analysis of variance in the Cruz et al. study did not reveal that larger groups with greater portions of shared information bolstered or discounted more frequently than smaller groups. However, there was a significant main effect on the bolstering measure for groups with greater amounts of shared information, which both bolstered and discounted with greater frequency than groups with a low amount of shared information. As a result, there is less chance to integrate all the informational resources in the group. Furthermore, unique information was more likely to be discussed when groups were diverse in knowledge rather than homogeneous. The diverse knowledge group was more likely to be cognizant of the fact that there was unshared information. As hypothesized, groups of four, when manipulated to have a low proportion of shared information, were more likely to discuss or discover unique information than other experimental conditions. Moreover, groups of four with a low proportion of shared information were more likely to make a correct decision, congruent with all of the information. Within groups of eight, it was necessary to include some partially shared information to keep the experimental task equivalent. With groups of eight, fully shared information was discussed with greater frequency than partially shared information, which was discussed with greater frequency than unshared information. From a qualitative analysis, Cruz et al. noted that some groups seemed to quickly evaluate ideas, moving from one to the next, while others quickly realized the importance of discovering all unique information. Cruz et al. have advocated the latter as a more productive way of evaluating information to make a final decision.

Teamwork Schemas, Social Relations Model, and Relationship Conflict

Rentsch, Heffner, and Duffy (1994) suggested that member teamwork schema and similarity of these schemas among team members might affect team functioning. Many authors (e.g., Rentsch et al., 1994; Zechmeister & Nyberg, 1982) credit Bartlett (1932; 1967), using a method of repeated reproduction, with the discovery that individuals both construct and reconstruct knowledge in long-term memory (schemas). "Bartlett concluded from this [stories and their creative regeneration over time] that human memory consisted of cognitive structures [schemas] that were built over time as the result of our interaction with the world and that these structures colored our encoding and recall of subsequently encountered ideas" (Winn, 2004).

Different authors seem to have different conceptualizations of schema. It seems many of them are describing the same theoretical construct, but they are calling it different names, or they are expanding on different components or characteristics. According to Winn (2004), there is agreement that a schema has the following characteristics:

1. It is an organized structure that exists in memory and, in aggregate with all other schemata, contains the sum or our knowledge of the world (Paivio, 1974, cited in Winn, 2004).
2. It exists at a higher level of generality, or abstraction, than our immediate experience with the world.
3. It is dynamic, amenable to change by general experience or through instruction (p. 86).

Schemata are important in knowledge organization. There have been many studies that compare how experts and novices organize knowledge into meaningful patterns. For example, de Groot (cited in NRC, 2000) noted how experts and novices noticed chess patterns differently. de Groot (1965) demonstrated a most profound example of memory and prior knowledge with expert and novice chess players (NRC, 2000). The expert chess players were able to recall chessboards set with meaningful patterns with greater accuracy and fewer trials than novices. It has been theorized that experts can "chunk" items, so that a chunk becomes one of the approximately seven pieces of information possible in short term memory (Miller, 1956). That is, instead of seven chess pieces, the chess player is able to store approximately seven chunks, with approximately seven chess pieces each (Reed, 1996). In addition, “expert knowledge that underlies the ability to recognize problem types has been characterized as involving the development of … schemas that guide how problems are represented and understood” (NRC, 2000).

Rentsch et al. (1994) suggest that people develop teamwork schemas. However, teamwork schemas are not domain specific, like those that have been studied with physics experts. Drawing on the work of Leinhardt and Greeno (1986) with experienced teachers, Rentsch et al. (1994) suggest that teamwork schemas are more like the general schemas that an experienced classroom teacher develops when he or she must make rapid decisions about the state of his or her learners. Similarly, team members often need to make decisions about the state of other team members. Rentsch et al. go on to suggest that individuals with greater teamwork experience will develop more articulated teamwork knowledge, with items such as enhancing the quality of team member interactions and communication.

Rentsch et al. (1994) investigated the teamwork knowledge structures for individuals with high and low experience participating in teams. The 23 participants came from the U.S. Department of Defense, or they were upper level undergraduate psychology majors. The high or low level of team experience was determined through a Likert instrument. The participants, working as individuals, were given 100 note cards, printed with teamwork adjectives, that had been generated through a pilot study. Each participant was asked to group the note cards into categories and to generate a label for each category, such as “believe in goals.” After completing the categories, the individual participants placed these items on an item comparison matrix, which was later analyzed with multi-dimensional scaling. In addition, participants in the Rentsch et al. study were asked to draw concept maps using their self-generated labels.

The Rentsch et al. (1994) multi-dimensional scaling analysis revealed that the low team experience individuals had similar teamwork knowledge structures, as did the high team experience individuals. However, the high and low team experience individuals had different knowledge structures. In addition, the high team experience individuals sorted teamwork items into significantly fewer categories than did the low team experience individuals ($M = 6.00$ vs. $M = 10.22$). A qualitative analysis revealed that research assistants, who were blind to the purpose of the study, more reliably sorted self-generated labels written by high team experience individuals. In addition, the high experience team items could be sorted into fewer categories, which tended to be less specific. In contrast, the low team experience individuals had more specific labels or repeated concepts. For example, one low experience individual in the Rentsch et al. study had three labels dealing with the same concept: "goal strategy, agreeing on goals, [and] belief in goals" (p. 463). Finally, the research assistants, with high interrater reliability ($\alpha = .90$), rated the similarity between the multi-dimensional scaling spatial solutions and the drawn conceptual maps of the high and low team experience individuals. The teamwork knowledge structures were found to be more consistent between the two methods of spatially representing the knowledge structures. These findings on teamwork schema by Rentsch et al. are consistent with research on expert-novice differences in other areas, such as teaching and physics.

Teamwork schemas are what team members use to interpret each other's behavior in a team context (Rentsch & Zelno, 2003). Rentsch and Hall (1994) proposed that team member schema similarity (TMSS) has two components: schema congruence and schema accuracy. Schema congruence is the extent to which team members have comparable teamwork schemas in content and structure. For example, two team members may think that trust is a prerequisite to task performance. Teamwork schema accuracy is the extent to which team members are accurate about the contents or structure of other team members' schemas. The following quote illustrates Rentsch and Zelno's (2003) team schema inaccuracy:

> Donna's schema of Mitch is deficient because she does not realize that speaking "speaking one's mind" and "integrating ideas" are parts of Mitch's schema … Because Donna's schema of Mitch is inaccurate, when she observes Mitch adapting his ideas to accommodate other teammates' ideas, she interprets this behavior as compliant … Mitch, on the other hand, believes he is speaking his mind to integrate ideas …" (p. 135).

Rentsch and Zelno further suggest that empirical evidence is revealing a correlation between TMSS and team effectiveness (see the Team Mental Models section above).

Rentsch and Woehr (2004) adapted Kenny and LaVoie's (1984) nine aspects of interpersonal person perception to TMSS. Kenny and LaVoie's social relations model (SRM) is a model for interpersonal dyads or dyads within a larger social group. The model is used in the study of self-perceptions, metaperceptions, and meta-accuracy during social interactions (Rentsch & Woehr, 2004). Rentsch and Woehr state, "Metaperception is an individual's perception of another individual's perception of someone" (p. 20). The SRM by Kenny and LaVoie (1984) separates interpersonal perception into three effects: perceiver, target, and unique relationship. According to Kenny and Lavoie, each of these effects can be calculated using a round robin approach in which every member of an interpersonal group rates himself or herself and every other member on a given behavior, such as trust. Kenny and LaVoie's perceiver effects are based on how an individual thinks other people see him or her, whereas target effects are how individuals think a target generally sees others, and the relationship effect is how a perceiver thinks a specific target views him or her uniquely.

Rentsch and Woehr (2004) organized Kenny and Lavoie's (1984) nine component SRM into three general categories: primary interpersonal perception, perceptual congruence, and perceptual accuracy. The primary interpersonal perception category contains Kenny's three primary effects described above. One other primary interpersonal perception component is consensus. Consensus is the extent to which team members view a specific target (in this case, one teammate) in the same way. That is, “Is Donna seen the same way by others?” (p. 21). Consensus is similar to schema congruence, which was described previously. From Rentsch and Woehr’s organization, the second general category focuses on congruence in perceptions. An example of a perceptual congruence component is assumed reciprocity. Assumed reciprocity is the extent to which the perceiver thinks the target sees the perceiver in a similar way to the way in which the perceiver sees the target. For example, “Does Mitch think others perceive him as he perceives them?” (p. 22). The third general category is perceptual accuracy, which is team schema accuracy in TMSS. One component of perceptual accuracy is target accuracy. Target accuracy includes perceiver, generalized, and dyadic accuracy. According to Rentsch and Woehr, “Dyadic accuracy is the correspondence between how the perceiver uniquely sees others and how others uniquely behave with the perceiver” (p. 23).

Rentsch and Woehr (2004) state that application of SRM with TMSS illustrates the complexity of team cognition in understanding team process and performance. The following quote from Rentsch and Woehr reveals the complexity in accuracy of TMSS:

> Donna perceives that Mitch believes he is an engineering expert and Mitch does believe this … Donna also perceives that Mitch is not the engineering expert he thinks he is but is a creative designer … [when] Mitch presents the engineering requirements for his [bridge] design … [Donna] tolerates his inept assessment of the engineering problems … However, she addresses the engineering problems with the other team members in a way to avoid offending Mitch (p. 26).

Rentsch and Woehr suggest that Donna helped the team avoid conflict, because she had an accurate perception of Mitch’s perceptions and abilities. Without this accuracy, Donna may have taken offense at Mitch for treating her as an incompetent engineer. Rentsch and Woehr expanded the preceding example to include congruence in TMSS. For example, in assumed reciprocity, if each team member in this case views the other as cooperative, he or she will act in a way that leads to a self-fulfilling prophecy.

Relationship Conflict and Team Performance

de Dreu and Weingart (2003) conducted a meta-analysis of research that had been conducted on the relationship between task or relationship conflict and team performance or team satisfaction. Task conflicts are disagreements on issues such as distribution of resources, procedures and policies, and responsibilities. Relationship conflicts involve disagreements on issues such as personal taste, political preferences, and interpersonal style. de Dreu and Weingart state that many management books present relationship conflict as counterproductive, while task conflict is advocated as mostly functional, leading to better consideration of alternative solutions. de Dreu and Weingart found that twenty-eight studies included a measure of team performance, such as decision quality, product quality, production quality, and team effectiveness. Overall, relationship conflict and task conflict were both found to be equally and negatively correlated with team performance (r_{obs} = -.19). In addition, both types of conflict were negatively correlated with team satisfaction (r_{obs} = -.48 and r_{obs} = -.19, respectively). Furthermore, both types of conflict had the smallest correlations in production teams with routine tasks, suggesting that conflict interferes the most with new learning tasks. de Dreu and Weingart concluded that strategies to eliminate relationship conflict are needed, and when task conflict emerges, teams need high levels of openness, psychological safety, and within-team trust.

Carnevale and Probst (1998) investigated the impact of social conflict on creative problem solving and categorization. The creative problem-solving task was Duncker’s (1945) functional fixedness task. In this task, participants are asked to write a solution to placing three candles at eye level on a door. On a table near the door are three candles, matches, tacks, and three boxes the size of a matchbox. When the matches were not in the box, more participants were able to develop the solution of tacking the boxes to the door. Duncker found that when the matches were in the box, participants had a functional fixedness that the boxes were to hold the matches. The perceived customary function interferes with seeing the box as a support for the candles. In the Carnevale and Probst study, categorization was measured on Rosch's (1975) weak exemplars, which are viewed as a measure of cognitive rigidity.

Carnevale and Probst (1998) had three independent conditions in which participants expected either: a conflictive negotiation, individually competing for twenty dollars; or a cooperative situation, with the highest negotiating team winning; or a control group. Significantly fewer participants in the conflictive situation solved the creative problem than did those in the cooperative or control group. Similarly, participants in the conflictive situation averaged significantly less on the categorization score than those in the cooperative or control conditions. In another experiment by Carnevale and Probst, this relationship stayed the same even when the participants started to experience a real cooperative situation, after expecting to encounter a negative one. Carnevale and Probst concluded with the possibility that conflict may raise cognitive demands to a level that interferes with problem solving. In addition, they found that once cognitive inflexibility is experienced, it remains for short periods, decreasing problem solving. In a similar study, Mohammed and Angell (2004) found a marginally significant relationship conflict on gender diversity by team orientation interaction. They found that when team orientation was high, increased gender diversity resulted in lower relationship conflict than when team orientation was low.

Teamwork Exercises

A teamwork exercise, also known as initiatives, can elucidate certain aspects of team functioning. Many of these teamwork exercises involve a high level of coordination and cooperation, while other exercises may involve trust issues. For example, an exercise involving coordination and cooperation is called “hole tarp.” In this activity, teams are provided with a large tarp with five large diameter holes cut in the top. Each team member holds onto the tarp, orienting it parallel with the ground. The team is then provided with a tennis ball, which they must let encircle each of the holes, without letting the ball fall through. After initial success, the teamwork consultant may add the additional challenges of having the ball encircle the holes in a particular sequence or add two tennis balls to the tarp at the same time. With two tennis balls, the majority of teams are not successful with the task challenge (personal communication, T. Heck, Summer, 2004).

After such an exercise, the teamwork consultant helps the participants “debrief” their experience, which is similar to Kurt’s Lewin’s (1951) reflection. For example, when teams are unsuccessful, the participants may debrief and or express their feelings of frustration. Some may discuss “giving up” at some point, while others may express “if the team would only have listened” to their plan. The teamwork consultant may have the team reframe their idea of success as not giving up or another team ideology. The teamwork consultant, much like a classroom teacher, is acting as a facilitator, and he or she is not defining the students’ experiences, but helping the students to further them. Though similar, these exercises are not to be confused with “high and low ropes.”

Personality Types

In psychology, personality is thought of as an individual's consistent ways of thinking, feeling, and behaving. During the first part of the twentieth century, one of Freud's disciples, Carl Jung, took issue with Freud and his other disciples' ideas of singular motivation (Keirsey & Bates, 1984). According to Keirsey and Bates, Jung disagreed with Freud's Eros, Adler's power, and Fromm's seeking self, because each theory only had one source of motivation. Jung, however, theorized that even though an individual has all instincts, which are stored in the collective unconscious, it is his or her preference for those instincts that is important (Keirsey and Bates, 1984). For example, Jung states in relation to the introversion and extraversion attitude, "Every human being possesses both [opposed] mechanisms as an expression of his natural life rhythm" (Jung, 1923, p. 13, cited in Kolb, 1984). Myers (1980) theorized that the preferences of four dialectical instincts or "archetypes" are what create personality differences among individuals. Based on the Carl Jung's personality theory, presented in his *Psychological Types*, a mother and her daughter, Isabel Myers, developed the Myers-Briggs Type Indicator (MBTI), which has become the most widely used personality inventory (Myers, 1980). The MBTI instrument they developed was based on preferences rather than traits (Myers & McCaulley, 1985). Therefore, all personality types are presented in a positive way, focusing on strengths rather than weaknesses or pathology.

Briggs and Myers operationalized Jung's theory of types into four dimensions or preferences (Myers, 1980). The first preference describes how a person focuses his or her attention and interest, either toward the outer environment or the inner world (Extraversion and Introversion). This preference is important for how a person energizes himself or herself. That is, individuals who prefer extraversion receive energy from people and the environment, and they seek understanding through experience, whereas individuals with the introversion preference receive energy from their inner world or concepts and ideas, and they prefer to understand something before experiencing it. A common misunderstanding with this preference is that people who prefer introversion do not like working with people. This is an oversimplification, because individuals with this preference enjoy other people, but they may regain their energy when they have had time to reflect. Conversely, according to Myers, individuals with the extraversion preference can deal effectively with ideas, but they tend to prefer an action orientation.

The second MBTI preference, Sensing-Intuitive, describes opposite ways of acquiring information, or investigating. A sensing type uses his or her senses to gather information, focuses on the concrete, and may be good at working with a great number of facts. A person of this type may view him- or herself as practical. The intuitive type, on the other hand, values imagination and inspiration, and this person may be good at noticing relationships between ideas and concepts (Myers, 1980). According to Keirsey and Bates (1984), failure to appreciate the different ways of acquiring information is a great source of miscommunication between people with one preference or the other.

Once an individual has acquired information, the person will prefer to make decisions or reach conclusions on that information based on the third MBTI preference, Thinking or Feeling. An individual who prefers thinking makes decisions based on objectivity or cause and effect, and may be good at analysis. On the other hand, an individual with the feeling preference makes decisions based on values. This type of individual considers what is important to self and others. The decision does not necessarily need to be logical. This preference does not refer to feelings and emotions (Myers, 1980). According to Keirsey and Bates (1984), the feeling person may express his or her feelings more outwardly, but the thinking person feels just as intensely. In addition, Keirsey and Bates learned that since formal schooling encourages thinking over feeling decisions, an individual with a feeling preference may develop the thinking preference more than the thinking individual has an opportunity to develop a feeling preference.

The final MBTI preference (Judging-Perceiving) is how an individual orients toward the outer world (Myers, 1980). A common misconception of this preference is to relate the preference with tendencies to be judgmental (Myers, 1980), or more perceptive (Keirsey & Bates, 1984), which is not the definition of this preference. Individuals with a judging attitude tend to live life in a planned and orderly fashion, desiring closure, while perceiving individuals tend to live life in a spontaneous, flexible way, leaving their options open (Myers, 1980). The judging-perceiving attitude relates to the second and third preferences. That is, if an individual's attitude is judging, then the individual will take a judging attitude, using the thinking-feeling preference. If an individual has a perceiving attitude, then the person will have a perceptive attitude, either sensing or intuitive. The theory proposes that everyone has a dominant process, which is determined by one of the two middle preferences (Sensing-Intuition or Thinking-Feeling). In addition, whichever dominant preference an individual has, the auxiliary to that preference will be found in the other preference. For effective functioning, an individual's dominant function needs the auxiliary function, though to a lesser degree, to be developed. For example, if a person's dominant function is on the thinking-feeling preference, then the auxiliary will be from the sensing-intuitive preference. According to Myers, the four dimensions, based on Jung's theory, create sixteen different types.

As the industrial arts field transitioned to technology education, Wicklein and Rojewski (1995) administered the MBTI to 246 technology educators. Approximately half of the respondents were high school teachers; the remaining half had approximately equal numbers represented by middle school teachers and college instructors. Wicklein and Rojewski also determined whether each educator had a technology education or industrial arts orientation by asking questions regarding the emphasis of his or her current program. There was a significant proportion difference on the Keirsey and Bates (1984) temperament sorter between professionals sampled in the field having an industrial arts orientation and a technology education orientation [$\chi^2(3, N = 224) = 117, p < .001$.] That is, of the professionals with an industrial arts orientation there were 63.6% SJs, 13.6% NTs, 7.3% NFs, and 4.6% SPs, while the technology educators were 41.9% SJs, 24.3% NTs, 25% NFs, and 1.5% SPs. For comparisons, Keirsey and Bates (1984) found the SJ and SP temperament comprised 38% of the general population each, while NT and NF comprised 12% each. In addition, Myers and McCaulley (1987) found that of the teachers taking the MBTI between the years 1978 and 1982, 42.2% were SJs, 34.2% NFs, 16.2% NTs, and 7.4% SPs. Keirsey and Bates also found as few as six percent of the teachers were NTs. From the results of their survey study, Wicklein and Rojewski (1995) concluded that technology education would attract professionals who prefer conceptual approaches to problem solving (NF and NT). For example, Keirsey and Bates (1984) state, “NTs are better at teaching technical subjects …” (p. 162). With the new emphasis on problem solving, instead of the individual projects that were used in the industrial arts era, it seems likely that students were being placed in groups in order to solve problems. Although Wicklein and Rojewski (1995) state that technology educators should be aware of the influence of their temperament upon their students, it seems also plausible that it is important to be aware of the impact of team problem solving upon students with different temperaments.

Temperament

Keirsey and Bates (1984) agreed with Jung's theory, and the validation work of the Jung's theory, which was developed through the MBTI (Myers & McCaulley, 1985). However, Keirsey and Bates (1984), acknowledging the importance of psychological type, theorized that temperament was more important in explaining behavior. That is, Jung's theory proposed that combining preferences creates an individual's unique type; however, Keirsey and Bates argued that an individual develops a type *because* of his or her temperament. In other words, type has a subordinate role to temperament in determining and explaining behavior. Temperament determines behavior because of what an individual values. As a result of their theoretical work, Keirsey and Bates grouped the sixteen MBTI types into four temperaments. The four temperaments and their principal values are: NF (INFJ, ENFJ, INFP, ENFP) values ethics or religiousness; NT (INTP, ENTP, INTJ, ENTJ) values theoretical or scientific; SP (ISTP, ESTEP, ISFP, ESFP) values aesthetics, artistry, and action; and SJ (ISFJ, ESFJ, ISTJ, ESTJ) values economics, commerce, and responsibility.

Volkema and Gorman (1998) suggest that there is a relationship between temperament and problem-solving strengths. SJs are practical and tend to solve problems through established algorithms. They are often quick to develop a solution, and many times they have a supervisory role in projects. According to Volkema and Gorman, SPs are "hands on" problem solvers and like short-term solutions to problems. Keirsey and Bates (1984) add that SPs enjoy using tools and may be good at troubleshooting problems. Due to enjoying troubleshooting action, SPs like teamwork, especially if they can help with a crisis. NTs are good at conceptualizing the problem, and they are often able to explain the underlying principles of systems (Volkema & Gorman, 1998). It is important for NTs "To be able to understand, control, predict, and explain realities"

(Keirsey & Bates, 1984). Like the NT, the NF sees possibilities, but this person is more focused on human potential (Volkema and Gorman, 1998). “The NFs are generally articulate and persuasive, quick to draw out the best in others” (p. 107).

Keirsey and Bates (1984) suggest that each temperament brings different strengths and liabilities to a team. The SJ is product oriented, and this individual is good at keeping the team on task. However, the SJ becomes irritated when the team is not making progress and may communicate impending failure scenarios. The SP is good to get the team moving but may not pay much attention to theories. In addition, other teammates may find the SP unpredictable. An NT is good at developing alternative solutions for the team but may want to delay the team from taking action until everything is understood. An NF is good at taking in the different ideas of his or her teammates; however, the NF may become frustrated if the team has too many standard operating procedures (Keirsey and Bates, 1984).

Team Temperament

Volkema and Gorman (1998) investigated cognitive-based team composition, the decision-making process, ideation, and outcome. Volkema and Gorman state that the Keirsey and Bates Temperament Sorter provides a construct for evaluating group composition. The different temperaments include abstract and concrete thinking orientations, as well as different ways of acquiring information (sensing or intuitive). Based on this, Volkema and Gorman hypothesized that having the two orientations in a team is important during the problem formulation and ideation stages of the decision-making process. Nutt (1984) found that teams tend to focus on problem solutions, without fully understanding the parameters of the problem. Volkema and Gorman (1998) state that the problem formulation is often rushed, and that both sensing and intuitive types create a balance between looking at current states and future conditions. Volkema and Gorman add that intuitive types allow the team to get the bigger picture, while the sensing types make sure the group is staying on task.

In this study, Volkema and Gorman (1998) randomly assigned college business students, based on temperament, to create groups comprised of either four SJs (homogeneous temperament) or all four temperaments (heterogeneous temperaments). Team temperament was the independent dichotomous variable. Temperament was measured several weeks before the dependent measure to help make sure knowledge of type did not influence role expectations. The group task was the Winter Survival Exercise in which participants are placed in a hypothetical life-threatening situation, forcing them to rank order fifteen items that they think will aid in survival. The participants' lists are then compared with the rank-ordered list of an expert survivalist. First, the participants are scored for their individual ranking, which is followed by a ranking score for the group. Two team performance scores were calculated: *team score minus individual average score* (GAI) and *team score minus best individual score* (GBI). Both of these scores are consistent with the ideas of process gain or loss for a team. Trained observers rated the teams on two possible mediating variables: problem formulation and ideation. Volkema and Gorman measured problem formulation by occurrences of discussions that involved: "(1) no discussion or decision regarding objectives, (2) discussion without a decision on objectives, (3) a decision without a discussion of competing objectives, or (4) discussion with a decision" (p. 113). Ideations were operationalized as the amount of times groups mentioned possible uses for the fifteen items, or ways of combining some of the items, to aid in survival.

Volkema and Gorman (1998) found that GAI scores ranged from 32 to -8.5, and GBI scores ranged from 26 to -28, with the negative scores indicating that some groups had process loss. Volkema and Gorman state that "For multi-temperament groups, the mean improvement scores were 10.8 (GAI) and -0.8 (GBI), while the mean scores for uni-temperament groups were 4.4 (GAI) and -7.8 (GBI)" (p. 114). Fifty percent of the groups showed no problem formulation activity. Both GAI and GBI scores were higher for the heterogeneous teams (M = 10.8 vs. M = 4.4: M = 10.8 vs. M = 4.4). Unfortunately, there were only twenty-six teams in the study and a large amount of variance in the dependent measures, indicating the possibility of a Type II error in this study. Teams that had discussion and decisions had significantly higher GAI and GBI scores than teams that did not. In addition, there was a significant interaction between multi-temperament teams that used a discussion and decision-making process. Volkema and Gorman found that multi-temperament teams, which used a discussion and decision-making progress, outperformed all other team temperament with problem formulation combinations.

In a similar study, Mohammed and Angell (2003) investigated the effect of personality heterogeneity and attitude toward teamwork on two related team tasks. The personality dimensions measured were conscientiousness, extraversion, agreeableness, and neuroticism. Team orientation is a construct that is not team or task specific, but a general tendency to seek out opportunities to work with others. The participants in Mohammed and Angell's study were 259 college level students from both master and undergraduate business courses. The team size ranged from three to six, resulting in fifty-nine teams. The team tasks were a written report and an oral presentation on process improvement projects, which were sponsored by business organizations and counted as thirty percent of the final course grade. In addition, this study investigated whether certain independent variables are better predictors when considered as an aggregate team score (average), or within team variance (diversity). According to Mohammed and Angell, this latter methodology is consistent with a configuration perspective, which allows for the examination into internal team dynamics.

Mohammed and Angell (2003) hypothesized that variability in the conscientiousness team score would be negatively related to written report scores, because of the inconsistent quality of work produced. Inconsistent with the hypothesis, the team variance in conscientiousness was not significantly related with lower written team scores; however, the team average conscientiousness was positively related to the written team score in the full model. As hypothesized by Mohammed and Angell, team variance in the personality dimensions of agreeableness and neuroticism were negatively related to oral presentation score, while the extraversion variance was positively related. However, variability in conscientiousness was not related to oral presentation score. In addition, Mohammed and Angell found that higher team orientation variability was *not* negatively related to team presentation score; there was merely a weak negative relationship. Team research has typically included only one task. With this study, the oral presentation task was thought to create a higher level of team interdependence than the written task. Mohammed and Angell concluded that a description of team composition must consider individual team dispersion scores around the mean with some variables. Also, the study findings of Mohammed and Angell suggest that the personality team-performance relationship may be different depending on the team task.

Simulation and Bridge Building as a Technological Design Activity

Michael (2001) cites several research studies that are relevant to technology education, especially as the field moves more and more towards modular instruction and computer simulation. Michael reviewed research studies which have revealed that simulation software may:

(1) Be equally as effective as real life, hands-on laboratory experiences in
(2) teaching students scientific concepts (Choi and Gennaro, 1987).
(3) Enhance the learning achievement levels of students (Betz, 1996).

(4) Enhance the problem solving skills of students (Gokhale, 1996).
(5) Foster peer interaction (Bilan, 1992); (all cited in Michael, 2001, p. 31).

However, in his research study, comparing real versus virtual Lego bricks instruction, Michael found no significant differences in the participating seventh graders' designs on creativity, originality, or usefulness. Furthermore, Ressler (2002) fears that students will see the computer simulation as a game. Unlike a computer game, an educational simulation does not operate under fixed rules, and the system may operate dynamically (Denton, 1994). Denton writes, "The objective of a simulation is one of assisting participants to learn from the experience and to be able to transfer that learning to a real world context" (p. 17). Denton was referring to both computer simulations and other simulations, such as a student company that tries to develop and market a product.

Parkinson (2001) suggests that bridge building as a problem-solving activity has great benefit, because there is no "right" answer. Lavonen et al. (2001) state that this is evidence of creative problem solving: "A common feature of these approaches is to place pupils in the midst of a realistic, ill-defined, complex, and meaningful problem, with no obvious or 'correct' solution" (p. 22). Rather, teams attempt to make bridges to meet the design constraints as well as possible. With his paper bridge problem, Parkinson (2001) observed that students in the first year of a teacher preparation program exhibited "serial development of solutions" behavior patterns identified by Welch (1997). Welch (1999) found that students developed a series of solutions, tested them, then rearranged them, through, " … complex interactions of technological activity in terms of interactive strands of building, modeling, idea-generation, and understanding (Welch, 1997, cited in Parkinson, 2001). With some concepts, Parkinson found that the students seemed to make intuitive, appropriate modifications to their design, while with others they did not. In addition, Parkinson found that students attempted to make sense of perceived events, without always being aware of all the salient factors. For example, Parkinson proposed that students misconceived that paper may be strong based on its shape. In addition, Parkinson found students could perceive buckling, but their awareness of tensile strength was less obvious. Through discussions, Parkinson determined that the students still held some misconceptions from childhood regarding forces; nonetheless, the students yielded a variety of solutions even when they were unsure of the nature and location of forces. Furthermore, in an extensive study on the elementary school child's awareness of fair testing, Gustafson, Rowell, and Guilbert (2000) found that students had a range of ideas about how to test for structural strength. Moreover, Gustafson et al. (2000) speculate that student ideas for testing structures are based on prior experiences, even before formal classroom instruction.

West Point Bridge Designer

Bridge building projects, in which students build and test a model bridge for load failure, have a long tradition of being included in the technology education classroom. In a 1992 survey of technology education teachers by DeLuca (1992), bridge building was found to be the most commonly used problem-solving activity. The *West Point Bridge Designer* (WPBD) Project (Ressler, 2002), which was developed by a group of Civil Engineers at West Point Military Academy for use with technology education, engineering, and construction students, may prove to be a great innovation in this traditional project. The curriculum and computer modeling software developed at West Point are copyright free for persons involved in education. The computer software allows a student to design a bridge on the computer and increase the strength or type of bridge member if the bridge fails. The computer animation, consisting of a truck driving across a bridge, allows students to view different colors and brightness of color depending on whether an individual bridge member is in tension or compression (blue or red color, respectively), and the corresponding level of that compression or tension (brightness). For example, dark red is a high level of compression, whereas light pink is a low level of compression (see Appendix B: *WPBD V4 Graphic User Interface*, p. 228; and *List of Media* in the Preface).

Seeing that a bridge member is either in compression or tension, the student may then change the type of bridge member to either a tube (hollow, rectangular) or a bar (solid, like a cable) and choose the size of that member based on the level of compression or tension. For greater efficiency (load failure divided by bridge mass), bridge members that are in tension should be designed as bars. While tubes will work for members that are in tension, tubes add mass, decreasing the efficiency of the bridge. On the other hand, choosing a bar or cable for a member in compression may cause a premature failure (buckling), due to a bar having little or no compressive strength. The concepts of tension and compression may not have been included in traditional bridge building projects because they were difficult to model or understand; however, this new curriculum accomplishes teaching these concepts on the computer and with the real model (see Appendix C: *Tension and Compression Concepts*, p. 231).

The curriculum book, which goes along with the computer software, is entitled *Designing and Building File Folder Bridges.* Traditionally, technology education classrooms have used either balsa wood or strip spaghetti as the construction material; however, neither of these materials allow for students to be exposed to the concept of constructing members in compression with tubes and members in tension with bars. File folders can be cut into strips to simulate a solid bar, or they can be folded four times and glued with a flap overlap in order to simulate a hollow steel tube on an actual truss bridge. According to Ressler (2002), a steel truss bridge typically fails in the member itself, while a balsawood bridge will fail at the joint, because the member is stronger than the joint itself. Ressler proposed this may lead to engineering misconceptions. A card stock or file folder bridge may be made with gusset plate connections, so that the joints are stronger than the member, which increases the likelihood of the member failing through yielding or buckling. Yielding is failure due to tensile forces, while buckling is failure due to compressive forces. One advantage of using balsawood over file folders is that it does not require as many fine motor skills in constructing the bridge, nor is it as tedious or time-consuming. Balsa wood may be more appropriate as a building material for a middle school student. However, when under load, it is difficult or impossible to view that members are in tension or compression with a balsawood bridge.

While the secondary technology education student may be able to develop a qualitative understanding of significant factors in bridge design, such as tensile and compressive strength, the university student has had courses such as physics and upper level mathematics, which should allow them to apply a quantitative analysis to a bridge design. After determining the required amount of compressive strength for a member, the student may use a testing procedure to see to what size he or she must design the member to meet the requirements. For example, a university student may be able through vector analysis to determine the compressive load factors on an individual bridge member. However, even though university students have completed courses such as these, those students may not be able to apply their knowledge and skills to this task.

Research Hypotheses

Based on team literature, small group research, information processing theory (process gain or loss), social relations model, and experiential learning, the following alternative and null hypotheses were developed:

$H1_a$: Due to developing overlapping, shared teamwork mental models, teams receiving teamwork exercises will increase bridge scores at a faster *rate* than the control group for teamwork exercises. Within the context of this study, rate is *change* in computer bridge scores *over* a fixed amount of *time*. Rate differences in computer bridge scores and iterations were tested through time by factor interactions. *Note.* Although lower raw bridge scores (dollar amount) indicate greater technological problem solving, the computer bridge scores were transformed so that a higher score indicates greater technological problem solving. Although the inner time terms cancel below, they are shown to indicate that all time x teamwork interactions were compared.

$H1_0$: $(\mu_{T2\ teamwork} - \mu_{T1\ teamwork}) + (\mu_{T3\ teamwork} - \mu_{T2\ teamwork}) + (\mu_{T4\ teamwork} - \mu_{T3\ teamwork}) \leq (\mu_{T2\ control} - \mu_{T1\ control}) + (\mu_{T3\ control} - \mu_{T2\ control}) + (\mu_{T4\ control} - \mu_{T3\ control})$

$H1_a$: $(\mu_{T2\ teamwork} - \mu_{T1\ teamwork}) + (\mu_{T3\ teamwork} - \mu_{T2\ teamwork}) + (\mu_{T4\ teamwork} - \mu_{T3\ teamwork}) > (\mu_{T2\ control} - \mu_{T1\ control}) + (\mu_{T3\ control} - \mu_{T2\ control}) + (\mu_{T4\ control} - \mu_{T3\ control})$

$H2_a$: Due to developing overlapping task work mental models, bridge scores will increase at a faster rate for teams receiving problem structure than the control group for problem structure.

$H2_0$: $(\mu_{T2\ structure} - \mu_{T1\ structure}) + (\mu_{T3\ structure} - \mu_{T2\ structure}) + (\mu_{T4\ structure} - \mu_{T3\ structure}) \leq (\mu_{T2\ control} - \mu_{T1\ control}) + (\mu_{T3\ control} - \mu_{T2\ control}) + (\mu_{T4\ control} - \mu_{T3\ control})$

$H2_a$: $(\mu_{T2\ structure} - \mu_{T1\ structure}) + (\mu_{T3\ structure} - \mu_{T2\ structure}) + (\mu_{T4\ structure} - \mu_{T3\ structure}) > (\mu_{T2\ control} - \mu_{T1\ control}) + (\mu_{T3\ control} - \mu_{T2\ control}) + (\mu_{T4\ control} - \mu_{T3\ control})$

$H3_a$: Due to process gain, as team size increases, bridge scores will increase at a faster rate.

$H3_0$: $(\mu_{T2\ team\ size\ 2} - \mu_{T1\ team\ size\ 2}) + (\mu_{T3\ team\ size\ 2} - \mu_{T2\ team\ size\ 2}) + (\mu_{T4\ team\ size\ 2} - \mu_{T3\ team\ size\ 2}) \geq (\mu_{T2\ team\ size\ 3} - \mu_{T1\ team\ size\ 3}) + (\mu_{T3\ team\ size\ 3} - \mu_{T2\ team\ size\ 3}) + (\mu_{T4\ team\ size\ 3} - \mu_{T3\ team\ size\ 3})$, and

$(\mu_{T2\ team\ size\ 3} - \mu_{T1\ team\ size\ 3}) + (\mu_{T3\ team\ size\ 3} - \mu_{T2\ team\ size\ 3}) + (\mu_{T4\ team\ size\ 3} - \mu_{T3\ team\ size\ 3}) \geq (\mu_{T2\ team\ size\ 4} - \mu_{T1\ team\ size\ 4}) + (\mu_{T3\ team\ size\ 4} - \mu_{T2\ team\ size\ 4}) + (\mu_{T4\ team\ size\ 4} - \mu_{T3\ team\ size\ 4})$

$H3_a$: $(\mu_{T2\ team\ size\ 2} - \mu_{T1\ team\ size\ 2}) + (\mu_{T3\ team\ size\ 2} - \mu_{T2\ team\ size\ 2}) + (\mu_{T4\ team\ size\ 2} - \mu_{T3\ team\ size\ 2}) < (\mu_{T2\ team\ size\ 3} - \mu_{T1\ team\ size\ 3}) + (\mu_{T3\ team\ size\ 3} - \mu_{T2\ team\ size\ 3}) + (\mu_{T4\ team\ size\ 3} - \mu_{T3\ team\ size\ 3})$, and

$(\mu_{T2\ team\ size\ 3} - \mu_{T1\ team\ size\ 3}) + (\mu_{T3\ team\ size\ 3} - \mu_{T2\ team\ size\ 3}) + (\mu_{T4\ team\ size\ 3} - \mu_{T3\ team\ size\ 3}) < (\mu_{T2\ team\ size\ 4} - \mu_{T1\ team\ size\ 4}) + (\mu_{T3\ team\ size\ 4} - \mu_{T2\ team\ size\ 4}) + (\mu_{T4\ team\ size\ 4} - \mu_{T3\ team\ size\ 4})$

$H4_a$: There will be a relationship between the change in iteration scores and the change in computer bridge scores over time.

$H4_0$: $r_{\Delta T1\text{-}T2} = 0$; $r_{\Delta T2\text{-}T3} = 0$; $r_{\Delta T3\text{-}T4} = 0$

$H4_a$: $r_{\Delta T1\text{-}T2} \neq 0$; $r_{\Delta T2\text{-}T3} \neq 0$; $r_{\Delta T3\text{-}T4} \neq 0$

$H5_a$: Teams receiving teamwork exercises will have greater physical truss model scores than the control group for teamwork exercises. *Note.* Greater physical truss scores indicate greater technological problem solving.

$H5_0$: $\mu_{\text{teamwork}} \leq \mu_{\text{control}}$

$H5_a$: $\mu_{\text{teamwork}} > \mu_{\text{control}}$

$H6_a$: Teams receiving problem structure will have greater physical truss model scores than the control group for problem structure. *Note.* Greater physical truss scores indicate greater technological problem solving.

$H6_0$: $\mu_{\text{structure}} \leq \mu_{\text{control}}$

$H6_a$: $\mu_{\text{structure}} > \mu_{\text{control}}$

$H7_a$: Teams receiving both teamwork exercises and problem structure will have a multiplicative effect on total technological problem-solving score (final computer bridge scores and truss efficiency scores combined). That is, teams receiving both teamwork exercises and problem structure will have higher scores than teams that only received teamwork exercises or problem structure.

$H7_0$: $\mu_{\text{control}} \geq \mu_{\text{structure only}}$; $\mu_{\text{control}} \geq \mu_{\text{teamwork only}}$; $\mu_{\text{structure only}} \geq \mu_{\text{both teamwork and structure}}$; $\mu_{\text{teamwork only}} \geq \mu_{\text{both teamwork and structure}}$

$H7_a$: $\mu_{\text{control}} < \mu_{\text{structure only}}$; $\mu_{\text{control}} < \mu_{\text{teamwork only}}$; $\mu_{\text{structure only}} < \mu_{\text{both teamwork and structure}}$; $\mu_{\text{teamwork only}} < \mu_{\text{both teamwork and structure}}$

$H8_a$: Final team bridge scores will be more positively correlated with physical truss model scores for teams receiving teamwork exercises than for the control group. That is, treatment teams will have better task transfer.

$H8_0$: $r_{\text{teamwork}} \leq r_{\text{control}}$

$H8_a$: $r_{\text{teamwork}} > r_{\text{control}}$

$H9_a$: With teams receiving teamwork exercises, heterogeneous temperament teams will have greater technological problem-solving scores than homogeneous temperament teams, while the opposite will occur in the control group. Teams not receiving teamwork exercises will not capitalize on the potential diverse contributions in their team, and the different temperaments will increase processing demands in control group teams. Although the hypothesis is testing interaction, the hypothesis is written to show the pattern of the means.

$H9_0$: $\mu_{\text{teamwork hetero temp}} \leq \mu_{\text{teamwork homo temp}}; \mu_{\text{control hetero temp}} \geq \mu_{\text{control homo temp}}$

$H9_a$: $\mu_{\text{teamwork hetero temp}} > \mu_{\text{teamwork homo temp}}; \mu_{\text{control hetero temp}} < \mu_{\text{control homo temp}}$

$H10_a$: With teams receiving teamwork exercises, heterogeneous gender teams will have greater scores than homogeneous temperament teams on total technological problem solving, while the opposite will occur in the control group.

$H10_0$: $\mu_{\text{teamwork hetero gender}} \leq \mu_{\text{teamwork homo gender}}; \mu_{\text{control hetero gender}} \geq \mu_{\text{control homo gender}}$

$H10_a$: $\mu_{\text{teamwork hetero gender}} > \mu_{\text{teamwork homo gender}}; \mu_{\text{control hetero gender}} < \mu_{\text{control homo gender}}$

$H11_a$: There will be no relationship between average teamwork orientation scores and technological problem solving for teams that receive teamwork exercises. This is predicted, because the teamwork exercises have had an effect, regardless of teamwork orientation. If supported, the null hypothesis will be retained.

$H11_0$: $r_{\text{teamwork}} = 0$

$r_{\text{teamwork}} \neq 0$

$H12_a$: For teams not receiving teamwork exercises, there will be a positive relationship between technological problem-solving scores and average teamwork orientation scores for teams. In other words, as team teamwork orientation scores increase, technological problem-solving scores will increase for teams not receiving teamwork exercises.

$H12_0$: $r_{\text{control}} = 0$

$H12_a$: $r_{\text{control}} > 0$

Chapter 3. Methods and Procedures

Overview

The purpose of this study was to investigate the impact of teamwork exercises, team size, and problem structure on technological problem solving using engineering design activities. Three independent, manipulated variables were included in the research study: *teamwork exercises*, *problem structure*, and *team size*. In addition, three non-manipulated, independent variables were also included: *team temperament* (homo/heterogeneous), *teamwork orientation* (team average), and *team gender* (homo/heterogeneous). Team technological problem solving was measured in this study as a dependent, output variable. Two related technological tasks, each having similar scientific, mathematical, and technological concepts, were used to measure team technological problem solving. The first task was a *computer bridge* simulation, which was measured over four 30-minute intervals. The teams had an initial experience of two intervals with the computer bridge. For the second task, teams started to design and construct a truss model, which was later tested for efficiency (*truss efficiency*). For approximately one-third of the problem-solving duration, each team worked simultaneously on the two technological tasks. While the teams worked on both problems at the same time, they were under high-task load conditions. After the fourth interval with the computer bridge, the teams worked only on their truss models.

Participant Pool

The participant pool for this study was first-semester engineering students at a mid-size to large university located on the east coast. All non-transfer students at the university are required to reside on campus during their first year, unless they live locally with a relative. In addition, all first-year students are required to purchase a laptop. The college of engineering enrolled 1,218 new students in the Fall of 2004. First-year engineering students are admitted to general engineering. If a student obtains a grade point average (GPA) of 3.4 or greater during the first semester, the student is eligible for transfer to the engineering department of choice. Otherwise, those students with at least a *C*- (1.7 GPA) in all coursework transfer to a degree-granting engineering department, such as civil or aerospace engineering, at the end of their second semester. Those with lower than a *C*- retake courses until satisfactory grade marks are received.

During the first semester, the coursework for a first-year engineering student has a strong emphasis on mathematics and science. *General Chemistry* and *Chemistry Laboratory for Engineers* account for four hours of the total course load, while five hours of the course load are devoted to *Calculus I* and *Linear Algebra*. In addition, students take first-year *English* and a core curriculum along with other first-year courses, as well as the *Engineering Exploration* course (see Appendix D: *First-Year Engineering Curriculum*, p. 233).

General engineering enrollments during the fall of 2004 were recorded at 1,725 students, with 15.1% females (n = 260) and 84.9 % males (n = 1,465). Not all general engineering students were enrolled in *Engineering Exploration* in the fall of 2004. The Engineering Education Department provided the researcher with a list of 1,292 unique PIDs, which are also the students' e-mail addresses at this university. Each of the 1,292 PIDs was entered into an electronic list, so only those students were eligible to participate in the study. During the fall of 2004, the 1,218 incoming first-year general engineering students consisted of 13.96% (n = 170) females and 86.04% males (n = 1048). Because of the large number of incoming engineering students required to take *Engineering Exploration*, 94% of the population pool for the study was incoming first-year engineering students. As with past years, the incoming general engineering students had rather homogeneous SAT scores: (*M* = 664, *SD* = 58.33) for math, (*M* = 609, *SD* = 72.22) for verbal, and total SAT scores (*M* = 1273, *SD* = 108.83). The SAT scores for the incoming freshmen were higher than the mean scores from other colleges within the university. For example, the next highest mean SAT scores were for incoming architecture students (*M* = 1,227). No SAT data was available for 23 of the 1,218 incoming engineering students. Similarly, high school GPA was high and had little variance (*M* = 3.69, *SD* = .23). A high school GPA was not available for 367 students. The ethnicity of the incoming engineering students was 70.4% Caucasian, 2.8% African American, 1.8% Hispanic, 7.9% Asian, 0.2% Native American, 3.9% Foreign Alien, and 13% unknown, because they chose to leave the race question blank.

Participants

On October 23rd, 2004, 294 students currently enrolled in *Engineering Exploration* completed the research study. On the day of this study, the majority of participants reported that they were between 18 to 19 years of age (*M* = 18.65, *SD* = 0.41). More males participated in the study than females (84.4% males, $n = 248$; 15.6% females, $n = 46$). Although a greater proportion of females (15.6% vs. 13.96%) participated in the research study than with the entering first-year engineering students, a binomial test revealed that the proportion was not statistically different from first-year female entering engineering non-participants ($p = .215$). SAT scores were not collected due to the restricted range of scores in the general engineering students as a whole (see above). Ethnicity data were not collected, because this was not one of the research purposes.

Participant Pool and Participant Major

As mentioned above, the Engineering Education department provided the researcher with a list of 1,292 potential participants enrolled in the *Engineering Exploration* course. From the list of potential participants, frequencies and percentages for their current majors were calculated as follows: general engineering 83.67% (*n* = 1,081); computer science 15.40% (*n* = 199); and other majors 0.93% (*n* = 12). The other majors listed were university studies (*n* = 10), chemistry (*n* =1), and biology (*n* =1).

With this study, the distribution by major differed between the students enrolled in the *Engineering Exploration* course (*N* = 1,292, see above) as a whole and the study participants. More general engineering students participated in the study (91.8%: *n* = 270) than expected, while less computer science majors (7.1%: *n* = 21) participated than expected, based on the percentage of majors in the *Engineering Exploration* course as a whole (see Table 4). There was one participant from university studies, one from chemistry, and one from biology. A one-sample, chi-square goodness-of-fit test, revealed significant proportional differences based on major ($\chi^2 = 15.39$, $df = 2$, $p < .001$). It is not clear why fewer computer science students participated in the research study than would be expected based on the percentages enrolled in the *Engineering Exploration* course. Some possible reasons may include 1) that computer science majors had greater homework demands during the week following the research study, or 2) since the research study was titled the *Engineering Challenge Workshop*, computer science majors may have felt that the workshop was less pertinent to their major.

Table 4
Major Frequency for Engineering Exploration Course and Study Participants

	Engineering Exploration		**Study Participants**		
Major	**N**	**%**	**Observed *N***	**%**	**Expected *N***
General Engineering	1081	83.7	270	91.8	246.0
Computer Science	199	15.4	21	7.1	45.3
Other Majors	12	.9	3	1.0	2.7
Total	1292	100.0	294	100.0	294

Participant Academic Level

Directly following the experimental study, the participants reported their academic level on an exit survey. The majority of participants were freshmen (95.6%: n = 281), followed by sophomores (4.1%: n = 12), and one participant reported junior academic level. From the data collected it was impossible to determine the proportion of freshmen participants who were actually first-year students; however, it is thought to be high due to the high number of entering engineering students (N = 1,218). Stated differently, it is possible that there were some participants that reported freshmen academic level, but they were second-year university students.

Table 5
Number of Teams (Total N = 99) Randomly Assigned to Each Condition

Team Size	**2**		**3**		**4**	
Problem Structure	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
Teamwork Exercises	8	8	8	8	8	8
No Teamwork Exercises	7_b	11_a	9_c	9_e	8	7_d

After randomization, there were [a]4 extra teams of 2, but one member decided not participate within the first few minutes. Therefore, the participant's teammate was reassigned to a team of [b]2, which made this a team of [c]3.

After the first few minutes, one member on a team of [d]4 decided not to participate, so this made an extra team of [e]3.

Participant Teams

After the morning orientation, the participants were randomized into teams (N = 99) based on the independent variables of team size, teamwork exercises, and problem structure. Because in the first few minutes of the study two participants decided not to continue, five cells or conditions did not have the desired count of eight teams (see Table 5). According to Howell (2002), uneven cell size leads to some power loss. In other words, even though the average cell count is 8.25 teams, the effective sample size or *N* harmonic is slightly less (8.15 teams per condition).

Team Gender Composition

As mentioned earlier, more males participated in the study than females (84.4% males, *n* = 248: 15.6% females, *n* = 46). After randomization into teams, this gender difference resulted in more homogeneous male teams (59.6%, *n* = 59), less heterogeneous gender teams (39.4%, *n* = 39), and few homogeneous female teams (1.0%, *n* = 1). With team sizes of 2, 3, and 4, there is a possibility of 12 different team gender compositions; however, only nine of the gender possibilities occurred in the study (see Table 6). For purposes of this study, teams with members of all the same gender were categorized as homogenous, while teams with both male and female members were coded as heterogeneous.

Table 6
Team Gender Composition

Gender Composition	*n*	%
MM	26	26.3
MMM	17	17.2
MMMM	16	16.2
MF	7	7.1
MMF	15	15.2
MFF	2	2.0
MMMF	12	12.1
MMFF	3	3.0
FF	1	1.0
Total	99	100.0

M = male participant
F = female participant

Participant Temperament

From the results of the Keirsey Temperament Sorter II, an overwhelming number of the participants had a Sensing-Judging (SJ) temperament (65.6%, $n = 193$). Based on temperament and career choice, one might have expected there to be more of the SJ temperaments among the participants; however, the actual proportion of SJs still seems higher than might be expected. The frequency of participants with iNtuitive-Feeling (NF) and Sensing-Perceiving (SP) was very similar (13.9%, $n = 41$ and 13.3%, $n = 39$, respectively), while iNtuitive-Thinking (NT) occurred with the least frequency (7.1%, $n = 21$).

Team Temperament

After randomly assigning students to team sizes of 2, 3, and 4, this resulted in 28 unique team temperament compositions (see Appendix E: *Team Temperament Compositions*, p. 234). With team sizes of 2, 3, and 4, and four possible temperaments, there is a possibility of 65 different team sizes by team temperament compositions. Due to the greater proportion of participants with the SJ temperament, 30 of the teams had a homogeneous SJ temperament, while only one team had a homogeneous NF temperament. The rest of the teams ($n = 68$) had different temperaments on the same team. For purposes of this study, teams with members of the same temperament were categorized as homogenous, while members on the same team with different temperaments were coded as heterogeneous.

Promotion and Participant Incentives

During the second week of the semester, the engineering instructors distributed an informational flyer to all students (see Appendices F, G, and H, pp. 235-237, for study announcement documents). In order to keep the communication consistent between instructors, all the instructors read an identical announcement as the flyer was distributed. The flyer listed a

URL to a Web site for learning more about the study. At the Web site, interested participants could watch a 30-second animated commercial promoting the research study. They could, in addition, learn more about the study by reading the FAQ page with 18 question and answer pairs. The researcher composed the question and answer pairs in anticipation of what students might wonder about the study. It was thought students would more likely register for the study if the students could know as much about what they would be doing without giving information that might bias the study. Potential participants could also submit a new question through a link at the site. Six new questions were submitted. No one who was at least 18 years of age was excluded from the study, but registration was on a first-come, first-serve basis. Initially, 550 students registered to indicate that they would like to participate in the study. Ten days before the study date, the top 312 students on the list were notified via e-mail in order to confirm that they would actually attend. If students failed to confirm their attendance after a certain period, the researcher contacted other students on the list. Registration was not opened until the above-mentioned announcement had been read in all the sections of *Engineering Exploration.* No data were available on the proportion of first-year engineering students who were under the age of 18 years on the day of the research study.

In order to recruit participants for the study, a variety of tangible incentives were offered, which included:

- Pocket PCs to the top two design groups
- Plaques for the top 6 design groups
- A free movie ticket and key lanyard for all participants
- Pizza lunch and snacks for all participants

In addition to the above incentives, intangible incentives were displayed on the Web site, such as "place the experience on your resume for summer positions or co-op opportunities." For additional electronic communication with participants, see Appendix I: *Electronic Communication with Participants*, p. 238; Appendix J: *Information for Participants Prior to the Study*, p. 245; and *List of Media* in the Preface.

The incentives were offered for two reasons. First, incentives were offered to reduce social loafing. Social loafing occurs when people working together exert less effort than individuals working alone, because individual efforts or accomplishments may remain unnoticed in a group context (Latane, Williams, & Harkins, 1979). Group productivity loss, due to social loafing, has been researched with a variety of tasks, including productivity (Zaccaro, 1984) and cognitive tasks (Weldon & Garango, 1988). For example, Zaccaro (1984) found that groups of four (high task attraction) out-produced groups of two (high task attraction), while groups of four (low task attraction) produced less than any other task to group size in the 2 x 2 ANOVA. All groups in Zaccaro's study produced the same paper products; however, the high task attraction groups were told the study was investigating decline in the American workforce productivity and that the most productive group would receive more extra credit.

In addition, the current research study was modeled in part after a Technology Student Association competitive event, in which incentives are offered in the form of trophies, and even consumer products at the national level. Usually these items are something that would be useful to a student academically, such as an inkjet printer or educational software. With the current study, it was thought that pocket PCs (personal computers) would be interesting to students and have educational value as a tool that could be used in the classroom.

Engineering Exploration Course

Participants in the current study were enrolled in a two-hour credit course entitled *Engineering Exploration*. Although this research study was experimental, it was conducted within the cultural setting of the *Engineering Exploration* course. Therefore, what follows in this section is a discussion of the educational environment for the course and curriculum in which participants were enrolled. While many engineering programs have moved away from having a general engineering program for first-year engineering students, the college of engineering at this university has a long tradition of providing engineering coursework to parallel the science and mathematics required for engineering preparation programs. For many years, the first-year engineering course was entitled *Introduction to Engineering*, with the primary delivery of instruction being lecture based, without active "hands-on" exercises. In 2004, the course title was changed to *Engineering Exploration* to reflect a move away from lecture-based instruction. According to the undergraduate course catalog, the general engineering program objectives include: providing hands-on experience in basic problem solving and design exercises; reinforcing application of concepts covered in other coursework; engineering ethics and social responsibility; computer programming and algorithm development to promote logical thinking; special visualization skills and engineering graphics; and communication skills needed in the engineering professions. Before proceeding to any other general engineering courses, students must obtain at least a grade of *C-* in *Engineering Exploration.*

According to one engineering education faculty member, it was during the 1998-1999 school year that *Engineering Exploration*, formerly the *Introduction to Engineering* course, started to include collaborative design activities as part of the course (R. M. Goff, personal communication, Summer 2004). Before this time, the course had been primarily a lecture-based format, with note taking activities and covering homework solutions. Design, problem-solving, and collaborative activities were introduced gradually into the curriculum. Students were paired with three other classmates into a four-member team, and they were provided with what was called a MacGyver Box, which is a toolbox that includes a variety of consumable items and construction tools, such as flex straws, batteries, and a five-piece tool set (see Appendix K: *MacGyver Box Tools and Materials*, p. 247). The engineering faculty selected the name MacGyver based on the fictional TV character who always made do with the "tools at hand." Like MacGyver, the teams were only allowed to use the materials in the box for the assigned open-ended design briefs, which teams completed for homework. A design brief is a report that gives the students a design context and serves as a starting place as they define the parameters of a problem. Prior to the research study during the fall of 2004, the *Engineering Exploration* students had completed two teamwork exercises as part of their classroom instruction. A typical teamwork exercise or scenario was, "You are trapped on an island and must rank order the following items in importance for survival." The teamwork exercises students completed during class *do not* involve the level of psychomotor activity and synchronized coordination, as the ones used in the teamwork exercises treatment for this research study.

During the fall semester of 2004, the *Engineering Exploration* course syllabus had the following course objectives listed:

- demonstrate a basic understanding of the design process;
- demonstrate a basic facility with hands-on design and design evaluation, accomplished working in teams;
- demonstrate a knowledge of the disciplines of the college of engineering;
- demonstrate an understanding of professional ethics and application to real life situations;
- apply the scientific method to problem solving, including use of software where applicable;
- graph numeric data and derive simple empirical functions;
- develop and implement algorithms that focus on object oriented approaches; and
- describe basic concepts associated with working in teams.

To meet the computer programming and problem-solving goals, the course piloted an object-oriented programming environment entitled *Alice* during the fall semester of 2004. The textbook for the software is called *Learning to Program with Alice*, about which the authors state, “Our [software] approach [to programming] allows students to author on-screen movies and games, in which the concept of an “object” is made tangible and visible” (Dann, Cooper, & Pausch, 2005, p. ix).

The general textbook for the *Engineering Exploration* course was *Concepts in Engineering*, which included the following goals: excite students about engineering; cultivate problem-solving skills; cultivate professionalism; provide information that students are unlikely to find elsewhere; introduce the design process; and emphasize the importance of communication skills. The authors of the textbook write, “Engineers are problem solvers …. we can expand this to say that engineers are *ingenious* problem solvers …. In a sense, all humans are engineers” (Holtzapple & Reece, 2005, p. 3). Holtzapple and Reece continue that problem-solving challenges are seldom accomplished by an engineer acting alone, rather than as part of a team. The first trait of a successful engineer is listed as interpersonal skills, because industry requires a group effort. Holtzapple and Reece state that there is “magic” in teamwork; however, for team efforts to surpass individual efforts, the following conditions are necessary:

- mutual respect for the ideas of fellow team members;
- the ability of team members to transmit and receive ideas of the team;
- the ability to lay aside criticism of an idea during early formulation of solutions to a problem;
- the ability to build on initial or weakly formed ideas;
- the skill to accurately criticize a proposed solution and analyze for both strengths and weaknesses; and
- the patience to try again when an idea fails or a solution is incomplete (p. 7).

Many of these ideas are employed by IDEO, the company described in Chapter Two.

The *Concepts in Engineering* textbook employs a problem-solving model called the engineering design method. In the textbook, Holtzapple and Reece (2005) list a possible engineering design method approach as:

1. Identify and define the problem.
2. Assemble a design team.
3. Identify constraints and criteria for success.
4. Search for solutions.
5. Analyze each potential solution.
6. Choose the best solution.
7. Document the solution.
8. Communicate the solution to management.
9. Construct the solution.
10. Verify and evaluate the performance of the solution (p. 22).

The steps listed in a high school technology education textbook *Technology Systems* are very similar to the ones above: "identify the problem; develop possible solutions; detail the best solution; model the solution; and finalize the solution" (Wright, 1996, p. 28).

Holtzapple and Reece (2005) state that engineers use analytical skills, and to aid in the analysis of physical systems, engineers use models. The models used by engineers are qualitative, mathematical, digital, analog, and physical. However, they do not use the term mental models. The authors group engineers with other creative professions, such as a composer or artist. Holtzapple and Reece list the goals of an engineer as: "simplicity, increases reliability, improved efficiency, reduced cost, better performance, smaller size, lighter weight, etc." (p. 27). Holtzapple and Reece state that creative professions all have constraints, with engineers being bounded by physical laws and economics. In their textbook presentation of the creative thinker, Holtzapple and Reece utilize ideas from several theories.

Holtzapple and Reece (2005) state that people can be classified into the categories of organized thinkers, disorganized thinkers, and creative thinkers. In relation to knowledge organization, Holtzapple and Reece seem to be drawing from cognitive theories of knowledge structures and memory organization, such as Bartlett's (1932) schema theory. For example, Holtzapple and Reece (2005) write about knowledge organization:

> The organized thinker has a well-compartmentalized mind. Facts are stored in unique places, so they are easily retrieved when needed ... The disorganized thinker has no structure ... his mind is so disorganized that the information is hard to retrieve when needed ... The creative thinker is a combination of the organized and disorganized thinker (p. 27).

In addition, the authors suggest a Freudian process, which is an interplay between conscious and subconscious, with the subconscious out of a person's awareness during problem solving. Holtzapple and Reece go on to say: "When an engineer tries to solve a problem, she works at both the conscious and subconscious level ... The subconscious seeks information that solves a qualitative model of the problem" (p. 27). Finally, Holtzapple and Reece refer to a gestalt phenomenon in that problem solutions occur with bursts of insight. Metcalfe (1986) provided some evidence for gestalt rapid insight by having participants rate how close they were to a problem solution with anagrams. Metcalfe found that participants rated their closeness, which she termed "warmth," as very low until they actually had a solution.

The textbook *Engineering Exploration* has content that is relevant to the technological tasks presented to teams in this research study (Holtzapple & Reece, 2005). For example, Holtzapple and Reece state, "The weight of a product can be reduced by putting materials where the stresses are …" (p. 34). Holtzapple and Reece give an illustration of how a rectangular beam, when loaded, has compression forces concentrated at the top of the beam, while tension forces concentrate at the bottom of the beam. Therefore, this is the design principle of an I-beam, which is illustrated by showing a full sectional view (p. 35). In addition, Holtzapple and Reece indicate Newton's law of equal and opposite reactions with their rectangular beam illustration by having opposing force vectors at the applied load and the end supports.

Experimental Design

The double blind experimental design for this study consisted of two treatments: teamwork exercises and problem structure. Both of these treatments had control groups. In addition, three levels of team size were used: teams consisting of two, three, and four members. This resulted in twelve unique conditions, which are detailed in Table 7. For the conceptual design of Table 7, see Appendix L: *Conceptual Design of the Research Study*, p. 249.

Table 7
Experimental design of the study

Random Assignment	R		R		R		R		R		R	
Team Size	2		3		4		2		3		4	
Random Assignment	R		R		R		R		R		R	
X_1 (teamwork exercises)	X_1		X_1		X_1							
Random Assignment	R	R	R	R	R	R	R	R	R	R	R	R
X_2 (problem structure)	X_2		X_2		X_2		X_2		X_2		X_2	
O_1 (computer bridge)	O_1	O_1	O_1	O_1	O_1	O_1	O_1	O_1	O_1	O_1	O_1	O_1
O_2 (computer bridge)	O_2	O_2	O_2	O_2	O_2	O_2	O_2	O_2	O_2	O_2	O_2	O_2
O_3 (computer bridge)	O_3	O_3	O_3	O_3	O_3	O_3	O_3	O_3	O_3	O_3	O_3	O_3
O_4 (computer bridge)	O_4	O_4	O_4	O_4	O_4	O_4	O_4	O_4	O_4	O_4	O_4	O_4
O_1 (model truss)	O_1	O_1	O_1	O_1	O_1	O_1	O_1	O_1	O_1	O_1	O_1	O_1
O_1 (teamwork orientation)	O_1	O_1	O_1	O_1	O_1	O_1	O_1	O_1	O_1	O_1	O_1	O_1
O_1 (temperament)	O_1	O_1	O_1	O_1	O_1	O_1	O_1	O_1	O_1	O_1	O_1	O_1

Random Assignment Method

Random assignment, which gives each participant an equal chance of being in an experimental condition, is important in experimental research designs, and it is considered the best method for creating equivalent treatment and control groups (Gall, Gall, & Borg, 2003). In order to randomly assign the participants to the six treatment and six control conditions, a spreadsheet was generated with 11 columns and 312 rows. From a power analysis, the goal was to have eight teams in each of the treatment conditions for a total of 96 teams ($N = 288$). Due to the possibility of "no shows" or students withdrawing during the morning orientation, twenty-four extra participants were told to arrive the morning of the study (maximum $N = 312$ or 102 teams). These twenty-four extra students would be placed in a separate room equipped for six teams of four. If less than 312 participants were in the study, there would be teams of lesser size than 4 members in this room. The extra teams, regardless of team size, would be additional control teams for the independent variables of teamwork exercises and problem structure. These extra six teams were reduced in a round robin fashion. For example, if sixteen extra participants were in the study, this would mean that this room would consist of four teams of 3 members and two teams of 2 members. On the day of the study, there were six extra participants over the desired 288; therefore, there were three extra teams with two members each.

Each row of the spreadsheet represented one participant. The first two spreadsheet columns were serial numbers through 312, representing stack order and participant number respectively. Both of these numbers, one in each top corner, were included on the back of each participant's ID card. The next three spreadsheet columns were building name, room number, and team number, and these were printed on the front of each participant's ID card. A team member letter was printed on the back bottom corner of the ID card, such as the letters, I, J, K, and L, for a team of four. Spreadsheet column seven was for the organizational group, and column eight was the team size. The next two columns of the spreadsheet were for treatment level, with "one" standing for control and "two" for treatment. For example, if both numbers were two, then that participant received both teamwork exercises and problem structure.

The next column in the spreadsheet was random numbers from one to a million, which were generated with a spreadsheet function [=RAND()*(1,000,000-1)+1]. All the columns were sorted in ascending order based on the random column, except for the serial, stack order. Once the participant ID cards were printed, those cards were ordered in ascending order based on the serial stack order. Therefore, the participants were placed in random order within the stack order. This method would allow a researcher to retain nearly equal cell sizes if more or less than the number of participants needed arrive for the study. For example, if the researcher expected 312 participants, but only 300 participants arrived the day of the study, then the research assistant could flip through the cards, maintaining the stack order but taking out any card with a *N* number greater than 300. With this example, the cards 301 to 312 would be removed.

As the participants sat in a theater-style classroom, the cards were distributed to the participants working from left to right, then front to back. Therefore, even if participants were sitting near friends or acquaintances at the beginning of the study, the participants would not be on the same team with their friends. That is, since the cards were in random order, they would most likely not be paired with someone sitting in adjacent seats. As a visual check, none of the participants with the same team numbers randomized into adjacent rows of the spreadsheet chart (see Appendix M: *Random Assignment List*, p. 250, for the top 36 participants before and after randomization).

Each participant's research study ID card had a duplicate stapled to it. Once participants received their study ID cards, they were instructed to write their university ID number on both cards, which at this particular university was not the student's social security number. They were also instructed to write their university e-mail, as a double check, in case they transposed two digits within their university ID. On the front of the ID card was a space for the students to write their first name. After completing this information, the students were instructed to return one card to the research assistants. At the end of the day, the students' university ID numbers were checked as they turned in the other card to make sure these matched the number they had written during the morning. This step was to prevent students from possibly changing teams to be paired with people they preferred or knew. Because the population pool consisted of 42 sections of the *Engineering Exploration* course, it is unlikely that students were paired with classmates from their same section. This possible pairing was checked after the study, and ten occurrences of two participants within the same team who had the same instructor were found. The number of participants having the same section and being on the same team is probably actually less than ten for two reasons. First, the students may have the same instructor but different sections, because each of the 19 engineering instructors had anywhere from one to four sections of the course. Second, since only the instructors' last names were collected from participants and there were two instructors with the same last name, five of the ten occurrences are indeterminable for the same participant instructor on the same team. Moreover, because there were approximately eight MacGyver teams per section, there is even less of a chance that participants were on the same team with MacGyver teammates.

Timeline for the Experiment

To control for confounding variables, the entire experiment was completed in one day (see Figure 3). The only data collected after the experiment was the temperament type with the Keirsey Temperament Sorter. Registered participants reported for the morning orientation at 9:00 a.m., and the experiment ended between 5:00 and 6:00 p.m. The teamwork exercises took place during the morning (AM), while the problem structure treatment and technological problem-solving activities occurred in the afternoon (PM).

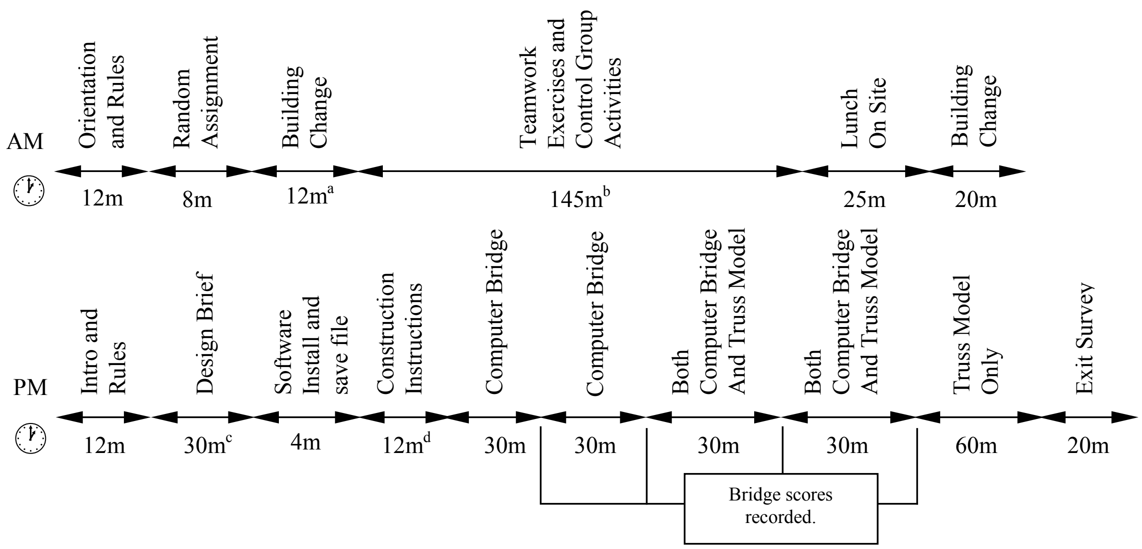

Figure 3. *Time line for the experiment in minutes.*

[a]Only the teamwork teams made this building change. [b]This is the time the teamwork treatment took place. Both teamwork exercise teams and control group teams were with their teammates during this period. [c]This is the time the problem structure treatment and control group activity occurred. [d]Before starting the technological problem-solving activities, time was devoted to the construction instructions to help ensure each team read the instructions.

Software Install

Each team was provided with a CD that included the *West Point Bridge Designer* V4 (WPBD) software and a file template. The file template was a 24-meter, single-span truss bridge, without any members drawn. Providing the template helped insure that all teams were making the correct bridge length, because the software allows for a variety of sizes and types of bridges (e.g., an arch truss bridge or a two-span bridge with anchorages). All teams, regardless of team size, were only allowed to load the computer bridge software onto one computer. On a second computer, each team was allowed to use Microsoft Excel and the calculator on the Windows operating system. In addition, on this second computer, teams could view a construction PDF, which was also provided in hard copy. The software installation instructions are provided in Appendix N: *Computer Bridge Installation and Set Up*, p. 254.

Room Proctor Training and Script

Room proctors, as well as research assistants for the teamwork exercises and control group activities, were required to attend a 90-minute training and orientation session. There were two different times for each of the four different training sessions, based on the treatments of teamwork exercises and problem structure and the control group for each of these treatments. Different training sessions were used to help insure that the investigation remained a double-blind experiment for the room proctors and participants. Because the room proctors were not aware of the teamwork exercises, they were randomly assigned to either teams which had the teamwork exercises or control group activities. During the training sessions, room proctors were trained on how to record information from the WPBD, as well as how to refrain from interacting with the study participants. All room proctors and AM research assistants were graduate students, except for one room proctor and one assistant, who were both professionally employed. Since two buildings were used for the problem solving, each building had one head research assistant with the responsibility of overseeing that the methodology was being conducted correctly. The head research assistants were able to call the principal investigator if any questions happened to arise. In addition, the principal investigator visited each building every 20 minutes to make sure the methodology was consistent among the teams for all twelve conditions.

To make sure that the directions were consistent for each treatment condition, room proctors read from a script. During the training sessions, the importance of working from the provided script was emphasized to the room proctors. The introduction and rules were provided to each team member to make sure that each participant had the opportunity to read along with the room proctor. The introductions and rules for the participants were the same for all treatment conditions, while the room proctor script varied slightly based on whether the teams received the problem structure treatment or were in the control group for problem structure (see Appendix O: *Room Proctor Script*, p. 259; and Appendix P: *Participation Rules for the Design Activity*, p. 265).

Data Collection Sheet

A data collection sheet was designed for the room proctors to record the computer bridge scores, iterations, successful/unsuccessful designs, and truss completion times. The data collection sheets, which were placed on a clipboard, were pre-printed with the team numbers of the teams located in each particular room. To make sure the computer bridge scores were recorded every 30 minutes, two timers were included with the data collection sheet and clipboard. One timer was pre-set to 25 minutes, while the other timer was set to five minutes, for the "five minutes until test" announcement. Because of the twelve treatment conditions, the team numbers on each data collection sheet increased by twelve, except the data collection sheet in the extra participant team room, which increased by one. The rooms were organized so that a room proctor could go around in ascending order, just like the team numbers on the data collection sheet (e.g., 12, 24, 36, …). The room proctors were instructed not to deviate from this sequence. In addition, the laptops for the teams included the team number, printed on card stock, projecting above the monitor from which they were to record data from the simulation software. This was to insure that room proctors recorded the correct data corresponding to each team number (see Appendix Q: *Room Proctor Data Collection Sheet and Timers*, p. 267).

Teamwork Exercises

Immediately following orientation and randomization (see Appendix R: *Morning Orientation Script*, p. 270), the participants in the teamwork condition went to a different building with a large room, while the control group stayed in the theater-style classroom. A professional teamwork consultant, who had conducted large teamwork workshops with different populations, such as K-12 educators and MCI new hires, led the teamwork exercises. In addition, the teamwork consultant had many years experience working with a YMCA and a school system, running teamwork exercises for youth. Also, he had a bachelor's degree in technology education. Before becoming a teamwork consultant, he taught high school for one year. The teamwork exercise workshop for the participants was designed through a full-day meeting between the researcher and teamwork consultant.

The teamwork consultant, who led the workshop in this research study, does not come to an event with "X" amount of exercises that he must lead the participants through in a certain amount of time. Rather, he has more than double the number of exercises typically needed for the planned time of the workshop from which he selects, based on the dynamics he is sensing with the team participants. It is important to note that, depending on the past experience of the group members with each other, the teamwork consultant must provide different exercises. For example, if the participants are strangers to one another, then initial exercises must be a "warm-up" for later ones. Similarly, a classroom teacher would have different activities planned for first-day students, than for students who have been together for part of a school year. None of the teamwork exercises in this study involved designing or producing an artifact, which may commonly occur in the classroom. This was to make sure that the teamwork teams did not get design experience together. For more information on the teamwork exercises, see Appendix S: *Example Teamwork Exercises*, p. 283; Appendix T: *Information for Research Assistants to the Teamwork Exercises*, p. 294; and *List of Media* in the Preface.

Control Group for Teamwork Exercises

Since some of the teamwork activities may involve cognitive processes or problem solving, each of the teams in the control group was provided with some paper and pencil problems to solve (see Appendix U: *Control Group Activities*, p. 297). The problems were in the form of puzzles, similar to the Monty Hall problem (see Krauss & Wang, 2003). The rationale for this was to make sure that it was teamwork activities the participants engaged in, rather than simply solving problems together. To explain further, both the control and treatment groups received cognitive problems; however, only the teamwork treatment teams were required to cooperate and coordinate their actions. Because the team problems for the control group were considered more cognitively challenging, they only worked on problems for the first hour of the control period. For the remainder of the time, the participants watched a Modern Marvels video on jet engines and an IMAX Cosmic Voyage DVD. These videos, both having engineering and science content, were chosen because it would not be obvious to the participants that they were in the control group condition. At the same time, the videos did not actively promote teamwork. Participants in the control group were permitted to talk during the video if they desired.

The teams in the control group were addressed as a “small group,” instead of a team. In addition, they were allowed to work independently or in cooperation, whichever they desired. However, each participant in a group was required to turn in one set of solutions to the problems. Therefore, a group could either work on the problems cooperatively, independently, or even possibly in coordination: “You work on problems four through six, while I work on problems one through three.” This situation was to simulate an unstructured situation in which student groups are allowed to work on the written problems in any way they wished. For more information on the control group, see Appendix V: *Script for Control Group Activities*, p. 302.

Organizations for Teamwork Exercises and Control Group Activities

Organizations were used for the teamwork exercises and the control activities. There were eight organizations for the teamwork exercises and the control group activities. An organization consisted of two teams of 2, two teams of 3, and two teams of size 4. The team members were with their team and within their organization, for the teamwork exercises and control activities. This allowed smaller groups (n = 18 x 8 groups) for the teamwork consultant to conduct teamwork exercises. With the control group organizations, one room proctor was assigned to an organization in which he or she was responsible for distributing water, snacks, and lunch, as well as distributing and collecting the worksheet problems. For the technological problem-solving phase, teams were no longer with their organization; rather, the teams were with their specific treatment condition.

Problem Structure and Control Group

Before beginning the technological tasks, half of the teams received specially designed procedures during the design brief, problem formulation period. This variable is called problem structure. The rest of the teams served as the control group for this variable. Based on social psychology findings, as discussed in Chapter Two, that groups produce fewer ideas and less relevant ones than individuals working separately, the teams receiving the problem structure treatment were not allowed to talk to teammates during the first twenty minutes. The room proctor monitored, without making the atmosphere unpleasant, to ensure there was no talking in the entire room. These teams were instructed to read over the design brief and to write out answers to the questions that were developed by the researcher. Two examples of structuring questions were, “How is the computer bridge tested? What are the factors that impact this score?” This component of the treatment was developed based on the finding that students tend not to explore alternative ideas, and that domain knowledge structure helps discovery learning. The following two "team structure" related questions were also included in the problem structure treatment design brief:

1. What are suggestions you have for your group to insure ALL ideas and their relationships to other ideas are explored fully?
2. How can you make sure that everyone's unique knowledge of the situation is shared?

However, none of the questions added any content knowledge for the teams receiving this treatment. That is, the control and treatment groups received the same design brief, except the control group received no questions and was allowed to talk as much as desired.

After twenty minutes had lapsed, the treatment group teams were permitted to share their ideas within each team. This sharing continued for ten minutes, which resulted in thirty minutes total time for the design brief, problem formulation period. During this entire period, the teams in the control group were allowed to formulate problem solutions in the manner of their choosing [see Appendix W: *Design Brief (Problem Structure),* p. 307; and Appendix X: *Design Brief (Control Group),* p. 315].

Keirsey Temperament Sorter II

Two weeks after the day of the experiment, the participants completed the electronic version of the Keirsey Temperament Sorter II (KTS II) that is based on the work of Keirsey and Bates (1984), which is described in Chapter Two. In reality, this is the same test as the Myers-Briggs Type Indicator (MBTI), but the KTS II sorts the sixteen Myers-Briggs types into four temperaments. The KTS II was not administered on the day of the study for three reasons. First, the participants' responses could be influenced by the group situation or something experienced during the workshop. Second, temperament is thought to be relatively stable over time. Third and finally, the online version of the KTS II is a more sensitive instrument than the pencil and paper based version. If, after answering the 70 items on the instrument, a student's preference is not clear on any of the four dimensions (e.g., T/F dimension), then three additional questions will be generated to determine that preference. Therefore, the maximum number of questions for a participant is 82. However, people are rarely borderline on all four dimensions of this scale.

The KTS II has high reliability. The alpha reliabilities of the four scales, E/I, S/N, T/F, and J/P are 83%, 82%, 83%, and 82%, respectively. In addition, the test-retest reliabilities of the four scales, E/I, S/N, T/F, and J/P are 88%, 82%, 82%, and 80%, respectively. Test-retest reliabilities are higher for individuals that have a clear preference (+7) for a scale: 91%, 91%, 89%, and 98%, respectively (The Temperament Sorter II: Statistical Analysis, 2003).

To complete the KTS II, participants in the study were e-mailed a unique password and a link to the instrument. Each participant had a unique password, so the researcher was able to determine who had completed the instrument. In the e-mail note, students were instructed on how to take the survey instrument and interpret their results. For this study, heterogeneous and homogeneous teams were decided upon after the experiment in a way to reduce the number of categorical variables.

The MBTI is the most extensively used personality instrument for psychologically healthy populations (DeVito, 1985; Lynch, 1985). In 1985, Myers and McCaully compiled over 1,500 studies into a user manual. The MBTI has been used extensively in educational and career testing. In addition, the instrument has been found to have test-retest reliability with college students and other populations (Murray, 1990). Murray states that the instrument has proved its construct validity with other related measures, and it describes the pattern that individuals display as they gather information. “[The MBTI] has been extensively investigated and has met successfully most challenges to its rationale, test procedures and results” (Murray, 1990, p. 1201).

Teamwork Orientation Scale

The *Teamwork Orientation Scale* (see Appendix Y: *Exit Survey*, p. 321) measures a general propensity to seek out and look forward to opportunities to complete tasks in a team context (Mathieu & Marks, 1998). It was piloted with 99 to 111 college students, depending on the time interval. The instrument has three subscales: comfort in team settings (comfort: 6 items); interest in learning from and sharing with others (interest: 8 items); and confidence that working with teams is productive (confidence: 7 items). In the pilot study by Mathieu and Marks, each of the subscales has shown moderate to high test-retest reliability coefficients. With the comfort subscale, the test-retest reliability coefficients were .80, .84, and .72, for times one-two, two-three, and one-three, respectively. The productivity subscale had test-retest reliability coefficients greater than or equal to .70 for each of the possible time comparisons (.74, .71, and .70). The learning scale had test-retest coefficients of .62 between times one-two and two-three; however, it was low between times two and three (α = .49). All items combined for test-retest reliability coefficients of .82, .86, and .73. At each of the three times, the interitem reliabilities were high (Cronbach’s α = .91).

In a study with 267 business college students, Mohammed and Angell (2003) combined all items into one scale with high interitem reliability (Cronbach’s α = .90). In the present study with 294 first-year engineering students, the Teamwork Orientation Scale interitem reliability was high (Cronbach’s α = .91). Unlike with the Keirsey Temperament Sorter, students completed the Team Orientation scale directly after the technological problem-solving period. While completing the *Teamwork Orientation Scale*, which is part of the exit survey, the participants were separated from their former teammates.

Team Teamwork Orientation Score

A team's teamwork orientation score was calculated in the following manner. First, each team member's average on the 21-item scale was calculated. Each item was on a seven-point Likert scale from "strongly disagree" to "strongly agree." Therefore, the maximum possible score for 21-item scale is 147. Second, each team member average was averaged for a team. For example, for a team of two, the average is the mid-point between each team member's average score. Third, the team average was multiplied by a factor of 21, so the score reflected the original scale with a maximum score of 147. The team teamwork orientation scores ranged from a low of 66.57 to a high of 133.56 (M = 98.21, SD = 12.25).

Technological Problem Solving Tasks

Two separate *but* conceptually related tasks were presented to each team: 1) design the lowest-cost bridge possible that spans twenty-four meters and supports the dynamic load of a twenty kiloton truck, using a bridge simulation software, and 2) design and construct the most efficient truss model possible that spans sixty centimeters. The bridge simulation software used was version 4.1 of the *West Point Bridge Designer* (WPBD) software, which was released in the fall of 2001. Although there were newer versions of the software, this version was selected for two reasons. First, it was thought that if participants had used any version of the software recently, they would have used a more recent release, such as 2004, which had been available before the study. Each new release of the software is a substantially different engineering design problem, not just an improvement of the previous release (personal communication, S. Ressler, Spring, 2004). For example, the 2003 version included site costs, deck elevation, and support configuration, while earlier versions did not. Prior experience with the specific problem by one team member would diminish the possible treatment effects. The second reason for selecting this version is that the truss model is based on a scale model that is sixty centimeters, compared with twenty-four meters in the simulation software. That is, the truss model is one-fortieth the size of the computer simulation and has the same amount of equally spaced joints at roadbed elevation. Therefore, a student team could potentially scale its truss model, based on the computer model they had designed with the simulation software.

Computer Bridge Task and Score

The *West Point Bridge Designer* simulation includes information about material properties and generates a cost for materials selected when designing the simulated bridge (see Figure 4). The type of material, the number of connections, and the product costs affect the total

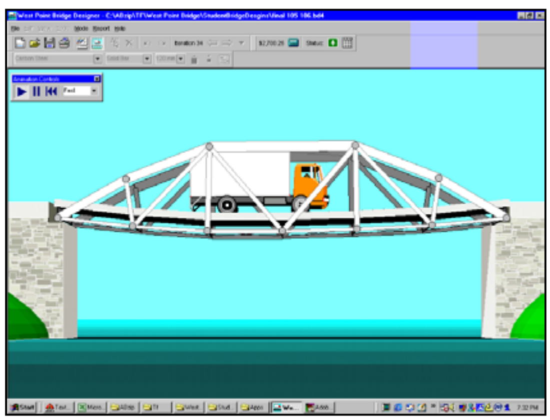

Figure 4. *WPBD V4 (computer bridge) during simulation mode.*

cost of a bridge with the simulation software. A member of the bridge may be designed with either carbon steel, high strength low alloy steel, or quenched & tempered steel. Each of these materials has different member properties, such as tensile and compressive strengths, for varying lengths. The costs from the least to most expensive are: carbon steel, high strength low alloy steel, and quenched & tempered steel. In addition, a bridge member may be designed as either hollow or solid. Designing a member that is primarily in compression as a tube results in a significant cost savings. For example, two members, a 210 mm x 210 mm x 5 m tube (hollow member) and a 130 mm x 130 mm x 5 m bar (solid member), both made of carbon steel, have equal compressive strength (approximately 1500 kN); however, the bar costs $55.72 per meter, while the tube costs only $39.56 per meter. Students may choose a square cross section of members (solid or hollow) from 10 to 75 mm, increasing in 5 mm increments, and from 80 to 500 mm, increasing in 10 mm increments. For more information on the software, see Appendix B: *WPBD V4 Graphic User Interface*, p. 228.

The connections for the bridge cost $25.00 each. Therefore, the more connections a bridge design has, the greater the cost. A bridge design starts with seven joints at the roadbed, which cannot be moved or changed, so the cost of a bridge design starts at $175. In addition, the more different types of members a bridge design uses, the greater the cost. Each different product raises the cost of the bridge by $100.00. Even if two cross sections are made of the same material, this adds $100.00 to the cost of the product. Increasing length increases material cost but not unique product cost. If a designer does not study the cost calculations report, this may not make sense. For example, the designer may wonder, "I just made a cross section of a member smaller, without changing the type of material; therefore, I used less material ... " However, this would increase the cost if this were the first time this size, material, and cross-sectional type of a member has been used in the design. This selection process simulates the cost of custom manufacturing, with each different item raising the total cost.

To add to the cost complexity of the bridge discussed thus far, the student design team may also choose different angles and layouts for its bridge members. This changes how much tensile and compressive strength that an individual member of the bridge requires. Therefore, the amount of increase or decrease results in requiring either more or less material, which results in added costs or savings to the total bridge cost. For purposes of this study, a lower raw bridge score ($) indicates greater technological problem-solving ability (see Figure 5).

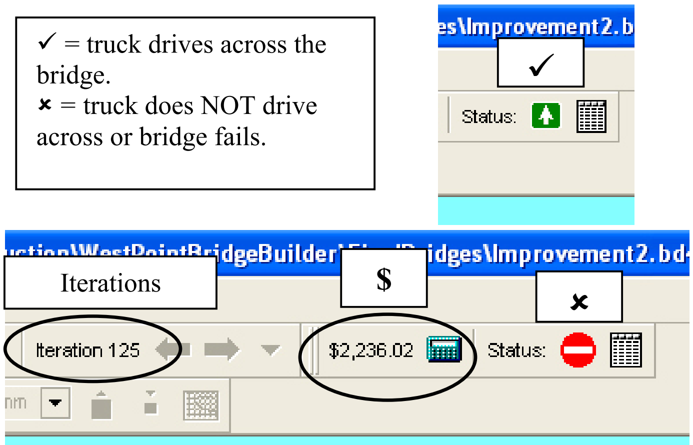

Figure 5. *Computer bridge score information recorded by room proctors.*

Note. This figure illustrates the score section of the graphical user interface of the *West Point Bridge Designer*. Raw computer scores were recorded in a dollar amount ($), with a lower score equating to a better score. Iterations is the number of times the students have made changes and tested whether the bridge will successfully support the dynamic load (✓) or not (×).

Iteration Score

The computer bridge software (WPBD V4) continuously keeps track of the number of iterations made by a team. The iteration score starts at one. There are two ways in which the software will increase by one iteration. First, if the user presses the simulation button followed by a change to any member, that is one iteration. Second, if the user clicks the arrow back to view a previous iteration, followed by a change to any member, that is one iteration, and it will cause the software to add one iteration to the highest number of iterations thus far. For example, once a team has made ten iterations, if they arrow back to iteration number five and make a change, the total number of iterations will increase to eleven. Between iterations, if a user makes one or many changes to the design, the software still only records one iteration. For example, a change to one member or many members followed by simulation will result in counting one iteration at the next change of any member.

Prior Experience with West Point Bridge Designer

With the exit survey, participants (*N* = 294) were asked to check the versions of the *West Point Bridge Designer* software in which they had experience. The majority of participants (76.5%) had never used any version, 1.4% had used V3, 10.9% had used V4, 3.4% had used V2002, 2.7% had used V2003, 2.0% had used V2004, and 2.7 % had used two or more versions. One participant had used the software but could not remember which version. In addition, the participants were asked to estimate how much total experience they had using different versions of the software. The intervals for participants to check were 0-2 hours, 2-4 hours, and so on. The survey did not include a midway interval (6-8 hours). These intervals were recoded as 1 hour for 0-2 hours, 3 hours for 2-4 hours, and so on, up to 15, for a high of 16+ hours. Of the participants reporting having some experience (*N* = 69), the mean hours of usage was 6.22 with a standard deviation of 5.33. After randomization, this resulted in the majority of teams having no experience with the computer bridge (*N* = 53), with the remaining teams who had some experience, having an average of 2.40 hours of experience per team member (*SD* = 1.90, range = .25 – 7.5). Average prior team experience with the software was used as a covariate in the computer bridge score analysis described in Chapter Four.

Truss Model Task and Score

Although the truss model (see Figure 6) is similar to the computer bridge model, there are several differences. First, all the members of the truss are made of one type of material: 80 lb., uncoated cover stock paper, which is .012 inches thick (.305 mm). There were six different member sizes: 7.25 mm x 7.25 mm tubes; 9.25 mm x 9.25 mm tubes; 3 mm bars; 4 mm bars; 5 mm bars; and 6 mm bars. Each of the tubes had a 6.75 mm overlap on one side, with double-sided adhesive tape in between the overlap and that respective side. The truss model had fewer options for selecting size than the computer simulated bridge. However, with two different tubes and four different bar sizes, a team had six different options for the cross-sectional design of any member. Furthermore, there were many possibilities for the length, angle, and number of members in any truss configuration. The maximum length of raw tube stock was limited to 8.75 inches (22.23 cm), unless a team employed a butt joint utilizing gusset plates.

Once a truss configuration is designed, a team must decide if members are in tension or compression, just like with the computer bridge simulation. However, it is not assumed that a team will make the correct decision. Although a tube will function for a member that is in tension, there is no added efficiency. A better decision is to use a doubled bar, which will be significantly lighter for the same amount of tensile strength. However, choosing a

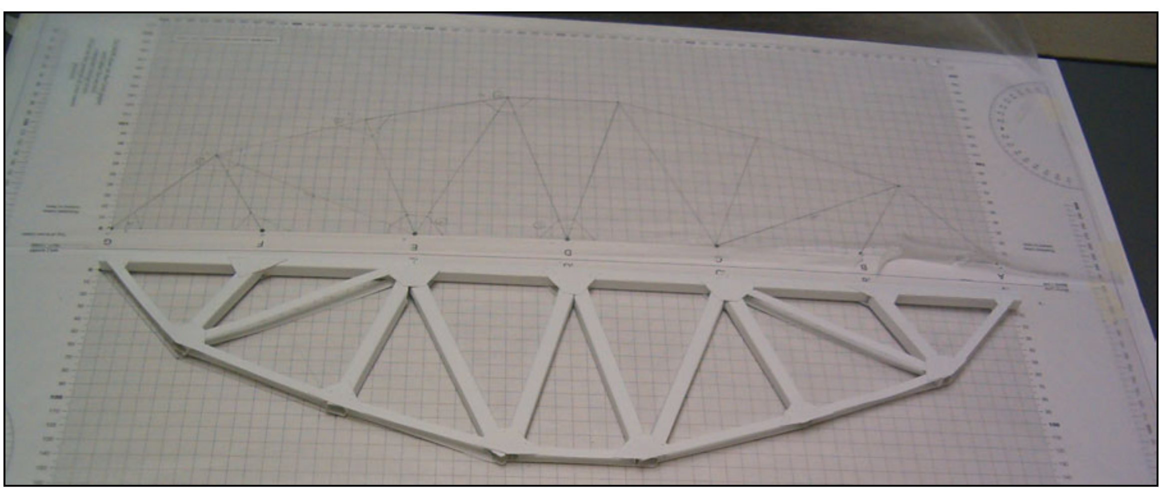

Figure 6. *Truss model example: constructed and designed by a participant team.*
Note. Models were tested for efficiency at the three middle joints. Teams were required to construct a deck truss, so every team had the same location of joints at the roadbed for testing purposes.

doubled-bar for a member that is in compression would lead to premature failure of the truss structure. Once a team decided if a member would be in tension or compression, they could predict how strong the member needed to be within their particular design. It is not assumed that student teams would calculate exact quantitative amounts for forces. Rather, teams would use their senses to evaluate the materials, and they would then make qualitative predictions (e.g., high or low compression for a member).

The paper members of the truss model are different than the metal ones simulated with the computer bridge. A metal bar member simulated with the computer bridge has some compressive strength, while the paper bars have almost none; nonetheless, conceptually the paper members act the same as metal members. On the other hand, the computer simulation does not mimic the fact that materials in the real world always have tolerances: materials have inconsistencies (Petroski, 1992). When tested, the card stock paper members will have a range of values. Each team was provided with some sample test data of differently-sized card stock members tested until failure. Furthermore, card stock paper mimics the concepts of tension and compression quite well (Ressler, 2002). The relationship is that larger tubular cross sections increase compressive strength, and compressive strength decreases with increasing length of a tubular member. Paper bars, just like steel members, do not loose tensile strength for increasing lengths, if the weight of the member itself is not factored into the equation. The tensile strength of paper bars increases linearly for increases in member width. Teams were not allowed to glue any bridge members face-to-face, because increasing width serves the same purpose. Furthermore, altering material properties was not a part of this technological task. Glue between the members might change the properties of the materials themselves.

As discussed in Chapter Two, a real bridge will typically fail in the member itself, as will the truss model (Ressler, 2002). However, Ressler writes that unlike a paper bridge, a balsawood bridge typically fails at a joint, because the member itself is stronger than the joint. This makes paper a more authentic modeling material for model bridges and trusses. With balsa wood, students cannot see whether members are in tension or compression, nor are students required to consider these dynamics in their designs. Furthermore, balsawood, having a 1/8-inch square cross section, is typically provided to technology education students for the construction of structures. For example, the researcher observed balsawood as the modeling material used in the structural engineering contest for four years in a row at a state level TSA competition.

The computer bridge was tested with a dynamic load of a twenty-kiloton truck driving across it, while the model truss was tested with a static load. A dynamic load changes over time, but at any given time, a member is either in tension or compression. That is, as the truck drives across the computer bridge, the values for tension and compression change for members of the bridge as the location of load changes with the position of the truck. A bridge member must be designed for the maximum amount of tension and compression imparted by the truck while it crosses the bridge. This is different than the static load applied to the truss bridge model during testing in that the location of the forces does not change: only the amount of load varies. The load was applied symmetrically two-thirds of the way from the middle joint on the truss model. However, since metal bars were taped at the three middle joints (C, D, and E), the load was concentrated more toward the middle members of the bridge. In theory, the load is applied equally at these three joints. For example, if the total load is 30 kN, then the load is 10 kN at each of these joints. The equal and opposite reactions are applied to the supports at the two ends of the truss.

The teams had to design their truss model as a deck truss. A deck truss has the connected triangles all below roadbed elevation. With the computer bridge simulation, teams could design their bridge as a deck, pony, through, or combination type (truss design below and above roadbed elevation). There are several reasons that a deck truss was chosen instead of a through truss for the truss model. First, any truss requires approximately one-third less time to construct than the entire bridge with a truss on both sides. Second, students are probably less familiar with deck trusses, so it was expected that this would be a novel technological problem for them. Third, due to the testing requirements, the deck truss allowed for any deck configuration below the roadbed elevation.

Because the top chord of the truss had to be constructed entirely of either small or large tubes, this allowed the same location of joints for testing each truss. With a truss bridge, the load should be applied at the joints. Therefore, the load was applied equally to the three middle joints of the truss. For testing purposes, a steel bar was inserted 2 cm into each end of the card stock, top chord tube. The participants were instructed to design the outer gusset plates, located at each end of the top chord, to be larger than the other gusset plates. The truss models were tested until failure for efficiency, maximum load ÷ bridge mass, which yielded the *truss efficiency* score. For purposes of this study, more efficiency of the truss model is a measure of greater technological problem-solving ability.

Truss Tester and Truss Material Reliability

The same procedure was used to test each truss. First, the mass of each truss was measured twice, using two digital scales that had a resolution of 0.1 grams. The two scales were used, in case one scale might not be consistent. In addition, two researchers independently recorded the mass of every truss with the two scales. Two researchers were used to insure that the scores were recorded correctly. In addition, there is a possibility that the trusses might be placed in a slightly different location on each scale. The two scores recorded for each truss by each researcher were recorded. As a check of interrater reliability, a Pearson correlation coefficient was calculated between the recorded mass average scores for the two researchers. There was almost perfect agreement on the mass of the trusses across the two researchers ($r = 1.00$). Due to the high level of agreement, the four mass measurements for each truss were averaged.

Second, after the mass of all trusses was measured, each truss was tested until failure. The mass of the bucket and the water in the bucket used to test each truss was then measured using an electronic “live” animal scale. The scale has a resolution of 0.01 kg. Before taking the first mass of the partially filled bucket, the scale was calibrated with five 2 kg weights, which are used in physics classes. Once the bucket was placed on the scale, the score for each truss was recorded and a photo taken of the reading on the digital scale display. Each photo included the number of the truss. After all truss loads (kg) at failure were recorded, the two researchers independently went through the photos to verify that all scores had been recorded correctly. There was 100% agreement that the truss scores were recorded accurately (see Appendix Z: *Truss Testing System*, p. 324, for more information on how the trusses were tested).

In order to estimate the reliability of the materials and the truss tester, the researcher, using a template, constructed 12 identical trusses. This was a laborious task, making variability in construction quality a possibility. Nonetheless, trying to construct the trusses, just as the student teams had, gives a more authentic estimate of reliability, because it includes many sources of possible variance. Even though the researcher tried to build identical trusses, the construction quality and material strength can and did still vary. The mass of each of these 12 trusses was measured with the same methods described above. The mass of these trusses ranged from a low of 17.8 g to a high of 18.5 g (*M* = 18.17, *SD* = 0.17, *SE* = 0.05). The load at failure ranged from a low of 8.27 kg to a high of 8.98 kg (*M* = 8.60, *SD* = 0.23, *SE* = 0.07). *Truss efficiency* with the 12 sample trusses, which was one of the task measurements for the teams in this study, ranged from a low of 455.19 to a high of 493.41 (*M* = 473.20, *SD* = 12.10, *SE* = 3.49, 95% *CI* = 465.51 - 480.89).

Prior Experience Constructing a Model Truss or Bridge

With the exit survey, participants (*N* = 294) reported on their prior experience constructing a model truss or bridge. Half (50%) of the participants responded that they had no prior experience constructing a model bridge, while the other half had some experience. The majority (78.6%, *n* = 114) of participants who had prior experience reported using balsa or some other type of wood, while 17.0% (*n* = 25) reported using some other type of material, and 5.4% (*n* = 8) reported having prior experience with both balsa and another material. Other types of material listed included “paper, but not file folders” (*n* = 10), plastic straws (*n* = 6), pasta (spaghetti/fettuccini; *n* = 4), and manila folders (*n* = 4). Other unique materials reported were K’nex ® toys, steel, and marshmallows with toothpicks. For purposes of this study, teams were coded as either having a member with experience or not having a member with experience.

Problem Sequence

After the teams had thirty minutes to consider their design brief and formulate solutions and strategies, they were allowed to start working with the bridge simulation software. After twenty-five minutes of working with the computer bridge, the room proctors announced, “five minutes to test.” Five minutes after this, the room proctors instructed all teams to place their computer bridges in the test mode and to stop all computer work. By having the animated truck drive across the bridge, the room proctor could both record the team's current bridge score, plus the proctor could know whether a team had a successful bridge. That is, if the truck caused the bridge to fail, then an unsuccessful solution was indicated. The proctors also recorded the number of iterations at each of four thirty-minute intervals.

After the first hour of working with the computer bridge software, the students were allowed to start construction of the model truss. They were also allowed to sketch ideas during the first hour of working with the computer bridge software. However, until one hour had elapsed, the student teams could not sketch on the metric grid paper, cut any bridge members to length, or even inspect any of the materials. The teams had to refer to the information presented in the design brief. During the first hour of working on the truss model, the teams continued to work on the computer bridge score for two additional intervals. While the teams were working on both the computer bridge and the truss model, they were under high task load conditions because they had to determine how to balance and focus their efforts. After the 4^{th} computer bridge score was recorded, the teams were told to complete their trusses.

Work Environments

All participants in this study met in the theater-style classroom (3,800 square feet) for the orientation phase (see Appendix AA: *Rooms for the Research Study*, p. 330; and Appendix BB: *Request for Academic Space*, p. 332). The padded seats in this room were comfortable and had fold-up desks for writing purposes. During the orientation phase, participants were not paired with their teammates. After orientation, which included the distribution of participant ID cards, the teams receiving the teamwork exercises treatment walked twelve minutes to a room (5,000 square feet) in a different building. Because the teamwork exercises required some movement, this room needed to be larger than the one for the control group. After the morning period, both groups ate lunch in their respective buildings.

During the technological problem-solving phase the teams went to academic classrooms in two different buildings, based on whether they had received the teamwork treatment or not. All teams met in rooms with movable student desks for the problem-solving activities. The teams in the control group, on average, met in smaller academic classrooms ($M = 601$, $SD = 33$) than did those in the teamwork exercises treatment group ($M = 862$, $SD = 169$). Due to the room size differences, efforts were made to ensure that teams had the same amount of space between themselves. The rationale for this was to make the psychological space seem the same to the participants by not utilizing all the floor space in the larger rooms. With the problem structure treatment, half of the teams received the treatment and half did not. Therefore, these treatment conditions were separated into different rooms. The desks for the teams that had received the teamwork treatment had larger desktops. Two of these desktops when combined measured 26 x 39 inches (1,014 in.^{2}), which was sufficient space for construction of the truss model. Since the teamwork control group teams had smaller desks, a 2 x 4 feet (1,152 in.^{2}) sheet of ½ inch sanded plywood was straddled across two desktops as a construction space for each team.

Engineering Workspace

An engineer modeling workspace was designed specifically for the research study. The workspace consisted of a 3/16 x 20 x 32 inch piece of foam core board. The foam core board allowed stickpins to hold gusset plates and truss members in place during construction. A local printer, with a direct computer to plate offset lithography printing system, printed the workspace drawing onto eighty-pound paper. The workspace drawing, which was designed specifically for this study using CAD software, included: two 600 mm x 210 mm grids, with bolder grid lines every centimeter; a top chord elevation bar; serial letters A through G and A′ through G′ for location of the joints; a mirror line between the top and bottom grids; two 180° protractors; and two 30 cm rules. The serial letters A-G were used to communicate to the participants about the different construction requirements, which were illustrated in the truss construction instructions (see Appendix CC: *Partial Plot of Engineering Workspace for Truss Construction*, p. 334; and *List of Media* in the Preface).

Construction Sequence and Room Proctor Role

Because variability in construction ability was not an emphasis in this study, the students were given written instructions on construction techniques and on the major steps needed to complete the construction of the model truss. In other words, the researcher wanted to measure variation in design decisions that effected truss efficiency, *not* construction ability. The researcher also wanted to reduce the amount of construction time. This was accomplished by having all necessary tube members prefabricated and bars precut into strips. In addition to designing the truss layout, the teams only had to select truss member type and length. From a task analysis of the construction requirements, the following major steps were provided to all teams to further reduce construction time:

1. **Choose top chord size:** The top chord must be made entirely of 7.25 square mm tubes or 9.25 square mm tubes.
2. **Truss Design:** Mark all joint locations and connect them with lines. Make a mirror image of this on the other half of the graph paper. Label all joints with letters. Since A through G and A′ through G′ are already marked, start with H through H′ serially progressing.
3. **Gusset Plate Design:** Measure along each member (lines drawn in step 1 above) from the joint location at least 20 cm, marking a point. Then, connect each point with a line for all gusset plates. Do this only on one side of the mirror line. The other side will be identical.
4. **Gusset Plate Template:** Lay the transparency paper (clear plastic) on top of each gusset plate, marking over the gusset plate shape with a marker. Label each gusset

plate template with the letter of the joint. Note: You only need templates for one side of the truss. In addition, if your truss design is symmetrical, this reduces the number needed by half.

5. **Cut Out All Gusset Plates:** Calculate how many gusset plates are necessary. For example, joint A will need 2 gusset plates, and (if your truss bridge is vertically symmetrical) joint F will be identical. Therefore, stack four tabs on top of each other and cut them out. It is not suggested to gang cut more than 4 sheets at once. You must hold them securely when cutting, or each plate will not be identical.
6. **Pin All Gusset Plates:** Each gusset plate must have two holding pins. Make sure the holding pins will not interfere with where your strips (bars) or tubes need to be glued.
7. **Cut All Bars:** Stack bars on top of each other like you did with the gusset plates in step 4 above. Make sure you cut angles so there is no overlap.
8. **Cut All Tubes:** Tubes must be carefully flattened to cut. Carefully make the tube square again.
9. **Glue All Bars:** Glue the bars to the gusset plates on both sides of the mirror line. Make sure that you pull this snug before the glue sets.
10. **Glue All tubes:** Glue all tubes on one side. Remove all holding pins.
11. **Assemble Sides:** Carefully glue the side without tubes on top of the one with tubes.
12. **Double check glue joints:** Make sure all your gusset plates have been glued. It is easy to overlook one.

In addition, each of these steps was illustrated to help ensure that the teams understood the sequence of steps described above (see Appendix DD: *Truss Construction Instructions*, p. 336). However, the illustrations were designed so that they did not give the teams any design hints. In addition, it was important that a team's truss model measured 60 cm in length, and it was important that the top chord was made entirely from one tube or the other (i.e., 7.25 or 9.25 square millimeters). Otherwise, the truss models would not be testable. In a pilot study with middle school students, Childress (1994) recognized the necessity of training teachers to monitor students, so that students would have testable technological artifacts. Based on Childress' findings, this study employed three example models that illustrated design constraints, a portion of a truss with double bars and tubes, and a portion of a truss under construction (see Appendix EE: *Truss Model Construction Examples*, p. 353). These models, labeled, A, B, and C, were passed around by the room proctor for teams to inspect. The room proctors were not allowed to answer any questions regarding truss design, member type selection (i.e., tube or bar), and member size (cross section or length). Both the model examples and the truss construction instructions were written so as not to give teams any truss design suggestions.

Tools and Materials for Truss Construction

In addition to the computer and the card stock members described above, each team was provided with the following tools and materials for constructing the truss (see Appendix FF, p. 356, for the tools and materials provided to each team for construction of their truss):

1. Cover stock paper tubes and bars (strips) of varying sizes;
2. A transparent 30 cm (12in.) rule, with 1/16 of an inch graduations on one edge, and mm graduations on the other;
3. A transparent 17 cm (6.5 in.) 45° triangle, with 1/16 of an inch graduations on one leg, and mm graduations on the other leg;
4. A transparent 24 cm (9.5 in.) 30° - 60° - 90° triangle, with 1/16 of an inch graduations on one leg, and mm graduations on the other leg;
5. A transparent 11 cm, 180° protractor;
6. Two pairs of scissors (in order to cut bridge members);
7. Approximately 100 # 17 straight sewing pins (to pin gusset plates during construction). Taking the mass, instead of counting them out one by one, approximated the number of pins. One hundred pins were more than needed;
8. Two thimbles to drive the sewing pins through the gusset plates and into the foam core board;
9. One 4 oz. bottle of safe, non-toxic Elmer's Glue All (to glue bridge members to gusset plates);
10. Two sheets of wax paper the length of the engineering work space to cover the engineering space during truss construction;
11. One roll of masking tape to tape down the wax paper;
12. One inkjet color transparency (to design gusset templates);
13. One permanent felt-tip ultra fine marker (to draw on overhead transparency, when creating gusset plate templates);
14. One mechanical pencil (7mm lead) per team member.

Once teams designed their gusset plates on the mm grid paper, then they could lay the transparency paper on top, transferring the gusset plate to the transparency with the marker. Inkjet transparency paper was selected over laser transparency paper, because inkjet transparency has one rough side, making it easer to draw on and work with in general. The first four items in the list that comprised the geometry set were selected because they were transparent, have mm and 1/16 in. graduations, and could be used both for measurement and as straight edges. In addition, the four-piece geometry set provided every team member with at least one measurement instrument. If a team wanted to lay out any angle, the protractor and triangles would allow them to do so. The multi-purpose glue all was chosen because it is school safe, strong once dry, and is slightly adjustable before setting. Cover stock paper was selected because it is sufficiently absorbent, making the connections more or less permanent once pressure is applied.

Pilot Study

In order to identify possible problems during measurement, team design, and construction, two teams of two members each, from a local community college, participated in a pilot study during October of 2004. Participants from a community college were chosen because they were the same age as the study participants and to make sure that the potential participants in the study did not learn of the design problems. The pilot study required four hours to complete, with fifteen minutes of verbal proctor instructions, thirty minutes of design brief/problem formulation, three hours for bridge design/truss construction, and fifteen minutes for the exit survey. After each session, participants were interviewed to determine if they understood the verbal and written instructions, as well as the information presented in the design brief. In addition, computer bridge scores were recorded every ten minutes to determine a meaningful interval of measurement for the main study. Furthermore, the number of iterations to the bridge design was recorded. From the information gathered, some revisions were made to: the verbal instructions to be read by the room proctor, the design brief, the problem structure instructions, and the team orientation survey. Therefore, the pilot study resembled more a formative evaluation process for the instruction than a pilot study to conduct a power analysis for needed sample size. A pilot study of this nature was beyond the resources available for this research study.

Statistical Analysis

To address the first three research hypotheses (H_1, H_2, and H_3), the researcher used a mixed factorial design that includes three between subject factors and one within subject factor (computer bridge scores repeated four times); that is, a mixed ANOVA, 2 (teamwork exercises and control group) x 2 (problem structure and control group) x 3 (team sizes of 2, 3, and 4 members) factorial design. In other words, the between subjects factors are experimental treatment assignments (teamwork exercises, problem structure, and team size). The within subject factor permits an analysis of interactions between the experimental factors and the computer bridge scores. An interaction indicates that experimental conditions (treatment and control), or levels of team size, are not learning to improve their scores at equal rates. “An experimental design in which every level of every factor is paired with every level of every other factor is called a factorial design” (Howell, 2002, p. 422). If cells are sufficient in size, factorial designs allow for greater generalizability of results, without requiring more participants. According to Howell, because the effects are averaged across the levels of the other factor, a two-variable factorial requires fewer participants than two one-way ANOVAs. Therefore, this study included three levels of team size, instead of one or two. Another advantage of a factorial

ANOVA is that it allows a researcher to examine interaction effects among independent variables. The within subject factor is technological problem solving (via computer bridge design score) measured at four time intervals. Repeated measures allow for the researcher to reduce the amount of variance due to error (Howell, 2002). Moreover, a repeated measures design allows the researcher to analyze the effects of treatments over time.

Depending on the research questions, a repeated measures or within subject factors design may produce invalid findings. For example, if the same version of a form is given to students over time, the students may become sensitized to the form, influenced by experimenter effect, and/or the Hawthorne effect. Another result that may invalidate findings is known as a practice effect, which is when participants score higher because of what they have already experienced in the study (Kantowitz, Roediger, & Elmes, 2001). For example, a researcher may want to compare whether it easier for English speaking students to learn basic Spanish, French, or Italian. However, if all participants were taught each language for 15 weeks and the order of the languages were not varied, then there most likely would be unwanted practice effects. For example, if students score highest on Italian and were given instruction in Italian last, then the higher scores may be as a result of already learning some basics in the other foreign languages of Spanish and French. With the research focus in this example, counterbalancing is needed.

According to Howell (2002), practice or carry-over effects are usually unwanted as in the previous example. However, there are exceptions to this rule:

> In certain studies, carry-over effects are desirable. In learning studies, for example, the basic data represent what is carried over from one trial to another (p. 515).

For example, if the previous example were comparing two methods of instruction (between subjects factor) in the three languages, each participant serves as his or her own control, reducing the amount of within subject error variance (Howell, 2002). With the new example, the researcher was not interested in whether language proficiency scores improve after the corresponding instruction in that language. Rather, the researcher was investigating method x language interactions. That example is still not identical to *this* research study. Because *this* study did not change versions of the computer bridge software, like research study on foreign languages changed languages, and the research questions with computer bridge scores were investigating time x independent variable interaction, the practice effects were desirable. In other words, with the present study, it was expected for bridge scores to improve, but the hypotheses investigated whether or not scores improve differently over time based on the independent variables.

For H_4, three Pearson correlation coefficients were computed between the change in iterations and the change in computer bridge scores for the corresponding interval. Hypotheses five and six (H_5 and H_6) were answered with a between subjects factorial ANOVA, with the same between subject factors as the repeated measures ANOVA mentioned above. If there were main effects in the omnibus F test, post hoc tests were conducted to contrast treatment and control conditions within each team size. The Bonferroni technique was applied to all post hoc analyses.

Correlation coefficients for final computer bridge scores with truss model scores were calculated for the teams receiving teamwork exercises and control, as well as the problem structure and the control teams. Team size was not included due to treatment cell sizes. For H_8, to test the independence of the correlation coefficients, a Fisher z test is necessary (Howell, 2002). The Fisher transformation is needed, because the sampling distribution for r is not normally distributed; therefore, standard error differences cannot be calculated. Pearson correlation coefficients were also conducted for H_{11} and H_{12}.

The final bridge score and truss efficiency score was standardized, which then allowed them to be added for each team. This score is the total technological problem-solving score for each team. For H_7, Dunnett's *t* test (> control) was conducted to compare the control group with each of the three experimental conditions on total technological problem solving (i.e., control compared with: structure, teamwork, and both structure and teamwork conditions). Because this analysis does not take team size into account, the data was recoded into these four conditions. If there was a main effect and scores were in the hypothesized direction, post hoc analyses were conducted to determine if the "both treatments" condition had a multiplicative effect on total technological problem solving. For H_9 and H_{10}, 2 x 2 ANOVAs were analyzed for interactions between teamwork exercises and the team composition factors (i.e., team temperament and team gender).

Chapter 4. Findings

Overview

The principal purpose of this study was to investigate the effects of teamwork, problem structure, and team size on two related technological tasks: a computer bridge and a truss model. The computer bridge score was measured over four time periods, while the truss efficiency score was recorded only once. The two scores were combined for a team's total technological problem-solving score. At the same four time periods as the computer bridge, each team's iterations with the software were measured. Correlations were conducted to see whether a change in the number of iterations was related to a change in computer bridge scores. The sections in this chapter that are located before specific hypotheses describe how the dependent measures were calculated and provide other information related to the dependent variable (e.g., team prior experience with the computer bridge). The alternative and null hypotheses are repeated at the beginning of sections that include corresponding test statistics.

Relationship Between Prior Experience and Computer Bridge Scores

The participants reported their prior experience with the computer bridge software on the exit survey. Pearson correlations were calculated between *team prior experience* with *West Point Bridge Designer* and computer bridge scores ($N = 99$) at each of four 30-minute intervals. Raw bridge scores were transformed, so higher scores were better than lower scores. There was a significant positive correlation between bridge scores and *team prior experience* with the software at each time interval: $r_{T1} = .37$, $p < .001$; $r_{T2} = .41$, $p < .001$; $r_{T3} = .38$, $p < .001$; and $r_{T4} = .32$, $p = .001$. At each time interval, the greater average prior experience of a team, the higher the bridge scores tended to be. Because *team prior experience* at each time was associated with bridge scores, the ANCOVA assumption of a linear relationship between the covariate "team average prior experience with the software" and the dependent measure was assumed.

To determine if the homogeneity of regression slopes assumption was tenable (H_0: $b_{\text{condition 1}} = b_{\text{condition 2}} = \ldots b_{\text{condition 12}}$), an F test was performed on the interaction: time x team size x teamwork x structure x team prior experience on computer bridge scores. There was not a significant interaction ($F = 0.83$, $p = .715$). Therefore, it was assumed that the covariate related similarly to the dependent measure for each condition. Due to the modest cell size for each condition, the equity of regression slopes assumption for each factor was also tested separately. There was not a significant interaction between the factors of teamwork, structure, and team size on computer bridge scores over the four times ($F = 1.08$, $p = .368$; $F = 0.75$, $p = .563$; $F = 0.85$, $p = .535$, respectively). In addition, none of the three adjacent, individual time comparisons had significant interactions between "time by factor by prior experience" on computer bridge scores ($p_{\text{9 comparisons}} > .05$). Furthermore, due to random assignment, it is reasonable to assume that the independent variables or factors did not affect the covariate variable. Therefore, for H_1, H_2 and H_3, team prior experience with the computer bridge software was entered with other fixed factors to determine the amount of explained variance in the dependent measure: team computer bridge scores.

Computer Bridge Scores

Room proctors recorded the computer bridge scores over four 30-minute intervals. The simulation software indicates a dollar amount for the current design, and it also indicates whether or not the bridge will successfully support a dynamic twenty-kiloton load (in this case, a moving truck). A lower dollar amount indicates a better computer bridge score. Therefore, a team, with little understanding or a poor design, could build an inexpensive bridge, but the bridge would not successfully support the load. The room proctors recorded the dollar amount, as well as whether the bridge would successfully support the load or not (*unsuccessful status*). Of the 396 total scores recorded, seventeen (4.3%) had an *unsuccessful status*. After the first 30-minute interval, there were eleven teams ($n = 11$) with unsuccessful bridge designs. At the second time interval or after sixty minutes with the software, there were three ($n = 3$) unsuccessful teams from the first time that still had unsuccessful bridge designs. In addition, there was one team with only an unsuccessful bridge at time two, while there was another team with only a successful bridge at time two.

Because an unsuccessful computer bridge design tends to underestimate the true dollar amount for a team, successful bridge scores, from adjacent time periods, were used to replace these scores in the following manner. First, for the team that only had an unsuccessful bridge at time two, the time two bridge score was replaced through interpolation of their time one and time three scores. Second, in the one case with unsuccessful time three and four scores, these scores were replaced with the time two score, which was the only successful score that team achieved. Third, a simple regression analysis, with the eleven unsuccessful time one scores filtered and one case with a residual greater than 3 standard deviations, was conducted with the bridge score time two onto bridge score time one. The prediction equation, Bridge Score T_1 = 1.138 (Bridge Score T_2) + $948.38, explained 81.7% of the variance in time one bridge scores [$F(1, 85) = 378.54$, $p < .001$]. The eight unsuccessful T_1 bridge scores were replaced using this prediction equation. This method is more accurate than simply replacing the scores with the mean, because the mean tends to underestimate the true dollar amount. Similarly, with the three unsuccessful time two bridge scores and three residuals greater than 3 filtered, the teams with unsuccessful bridge scores at time two were replaced with the regression equation, Bridge Score T_2 = 1.076 (Bridge Score T_3)

+ \$532.55; [$R^2 = .709$, $F(1, 90) = 219.36$, $p < .001$]. With the three remaining teams unsuccessful at time two, time one bridge scores were replaced with: Bridge Score $T_1 = 1.138$ (Bridge Score T_2) + \$948.38. All of the above replacements resulted in an increase to fifteen scores and a decrease in two scores. The total increase to the original scores was 1.91%, while the decrease was less than one percent (0.16%).

Table 8
Descriptive Statistics for Computer Bridge Scores Over Time

	Raw Scores[a]			Transformed Scores[b]		
Time	***M***	***Mdn***	***SD***	***M***	***Mdn***	***SD***
1	7,199.66	6,231.89	3,817.70	208.58	205.74	85.18
2	5,423.12	4,538.71	2,982.67	266.56	271.72	86.20
3	4,257.26	3,857.58	1,698.97	316.84	318.81	80.93
4	3,515.47	3,332.24	918.89	367.76	318.81	75.28

[a]Raw scores, based on cost in dollars, were not normally distributed at any time.
[b]Scores were transformed by the following: Raw Score$^{-0.983}$ x 1,068,768.83. Ten outliers (2.55%) were winsorized to the first non-extreme value. The transformed scores did not differ significantly from a normal distribution at all four time intervals (p >. 05).

The computer bridge score distributions at each time interval were positively skewed and leptokurtic. A lower raw computer bridge score indicates greater technological problem solving. This means that the data were scattered in the upper tail at each of the four time interval distributions, and a large number of scores formed a high peak below the mean. The shape of the distribution indicates the nature of the score, which is characterized by the increasing difficulty required to lower scores (cost) as scores approach the lower bound. For example, it is probably more difficult for a team to lower its score from \$3,000 to \$2,500 than from \$6,500 to \$6,000. The outliers in the upper tail of the distribution may indicate teams that had a poor understanding of the cost calculations for a design (e.g., mixing too many types of materials or using a variety of cross sections). From the values of the Kolmogorov-Smirnov statistic, the distribution of scores for each time period differed significantly from normal ($p < .05$).

Two transformations were made to the bridge scores. In order to make the four distributions more normal, the bridge scores for each time interval were raised to a power of -.983, which was suggested by the explore feature in a statistical program. This transformed score has the advantage of reversing the distribution, so that a higher score indicates greater technological problem solving. However, this transformed score has the disadvantage of making the scores less than a value of one, so the scores were multiplied by a factor of 1,068,768.83, which was derived by dividing the mean truss efficiency score by the power-transformed, time four computer bridge score. Therefore, the means for both the final bridge scores and truss efficiency scores are equal. The above-mentioned second transformation is completely linear and does not have an effect on the shape of the distribution. From the box and whisker plot of the transformed scores, ten outliers (2.55%) were identified: three positives at times one and two, and one positive and negative at times three and four. All ten of these outliers were winsorized to the first non-extreme score inside the corresponding whisker. From the values of the Kolmogorov-Smirnov statistic, the distribution of scores for each time period did not differ significantly from normal ($p > .05$). Descriptive statistics for the raw and transformed sample computer bridge scores are displayed in Table 8.

The majority of the 48 subsample means did not deviate significantly from a normal distribution ($\text{Shapiro-Wilk}_{12 \text{ conditions x } 4 \text{ times}} > .05$), while four of the subsample means did deviate ($p < .05$). Since no post hoc analysis was conducted between individual cells or conditions, this finding does not violate the normal subsamples distribution assumption. At each time interval, Levene's Homogeneity of Variance on between subject factors test failed to reject the null hypothesis of equal variance [H_0: $\sigma^2_{\text{condition 1}} = \sigma^2_{\text{condition 2}} \ldots = \sigma^2_{\text{condition 12}}$; $\text{Levene}_{\text{T1 to T4}}(11, 86)$ $p > .05$]. In addition, Levene's Homogeneity of Variance on the within subjects factor failed to be significant [$\text{Levene}(47, 348)_{\text{12 conditions x 4 times}} = 0.74$, $p = .895$). Therefore, the necessary ANOVA assumptions of normal sample distributions and homogeneity of variance were met for the computer bridge scores.

Repeated Measures ANOVA and Computer Bridge Scores

$H1_a$: Due to developing overlapping, shared teamwork mental models, teams receiving teamwork exercises will increase bridge scores at a faster *rate* than the control group for teamwork exercises. Within the context of this study, rate is *change* in computer bridge scores *over* a fixed amount of *time*. Rate differences in computer bridge scores and iterations were tested through time by factor interactions. Although the inner time terms cancel below, they are shown to indicate that all time x teamwork interactions were compared.

$H1_0$: $(\mu_{\text{T2 teamwork}} - \mu_{\text{T1 teamwork}}) + (\mu_{\text{T3 teamwork}} - \mu_{\text{T2 teamwork}}) + (\mu_{\text{T4 teamwork}} - \mu_{\text{T3 teamwork}}) \leq (\mu_{\text{T2 control}} - \mu_{\text{T1 control}}) + (\mu_{\text{T3 control}} - \mu_{\text{T2 control}}) + (\mu_{\text{T4 control}} - \mu_{\text{T3 control}})$

$H1_a$: $(\mu_{\text{T2 teamwork}} - \mu_{\text{T1 teamwork}}) + (\mu_{\text{T3 teamwork}} - \mu_{\text{T2 teamwork}}) + (\mu_{\text{T4 teamwork}} - \mu_{\text{T3 teamwork}}) > (\mu_{\text{T2 control}} - \mu_{\text{T1 control}}) + (\mu_{\text{T3 control}} - \mu_{\text{T2 control}}) + (\mu_{\text{T4 control}} - \mu_{\text{T3 control}})$

$H2_a$: Due to developing overlapping task work mental models, bridge scores will increase at a faster rate for teams receiving problem structure than the control group for problem structure.

$H2_0$: $(\mu_{\text{T2 structure}} - \mu_{\text{T1 structure}}) + (\mu_{\text{T3 structure}} - \mu_{\text{T2 structure}}) + (\mu_{\text{T4 structure}} - \mu_{\text{T3 structure}}) \leq (\mu_{\text{T2 control}} - \mu_{\text{T1 control}}) + (\mu_{\text{T3 control}} - \mu_{\text{T2 control}}) + (\mu_{\text{T4 control}} - \mu_{\text{T3 control}})$

$H2_a$: $(\mu_{\text{T2 structure}} - \mu_{\text{T1 structure}}) + (\mu_{\text{T3 structure}} - \mu_{\text{T2 structure}}) + (\mu_{\text{T4 structure}} - \mu_{\text{T3 structure}}) > (\mu_{\text{T2 control}} - \mu_{\text{T1 control}}) + (\mu_{\text{T3 control}} - \mu_{\text{T2 control}}) + (\mu_{\text{T4 control}} - \mu_{\text{T3 control}})$

$H3_a$: Due to process gain, as team size increases, bridge scores will increase at a faster rate.

$H3_0$: $(\mu_{\text{T2 team size 2}} - \mu_{\text{T1 team size 2}}) + (\mu_{\text{T3 team size 2}} - \mu_{\text{T2 team size 2}}) + (\mu_{\text{T4 team size 2}} - \mu_{\text{T3 team size 2}}) \geq (\mu_{\text{T2 team size 3}} - \mu_{\text{T1 team size 3}}) + (\mu_{\text{T3 team size 3}} - \mu_{\text{T2 team size 3}}) + (\mu_{\text{T4 team size 3}} - \mu_{\text{T3 team size 3}})$, and
$(\mu_{\text{T2 team size 3}} - \mu_{\text{T1 team size 3}}) + (\mu_{\text{T3 team size 3}} - \mu_{\text{T2 team size 3}}) + (\mu_{\text{T4 team size 3}} - \mu_{\text{T3 team size 3}}) \geq (\mu_{\text{T2 team size 4}} - \mu_{\text{T1 team size 4}}) + (\mu_{\text{T3 team size 4}} - \mu_{\text{T2 team size 4}}) + (\mu_{\text{T4 team size 4}} - \mu_{\text{T3 team size 4}})$

$H3_a$: $(\mu_{T2\text{ team size }2} - \mu_{T1\text{ team size }2}) + (\mu_{T3\text{ team size }2} - \mu_{T2\text{ team size }2}) + (\mu_{T4\text{ team size }2} - \mu_{T3\text{ team size }2}) < (\mu_{T2\text{ team size }3} - \mu_{T1\text{ team size }3}) + (\mu_{T3\text{ team size }3} - \mu_{T2\text{ team size }3}) + (\mu_{T4\text{ team size }3} - \mu_{T3\text{ team size }3})$, and
$(\mu_{T2\text{ team size }3} - \mu_{T1\text{ team size }3}) + (\mu_{T3\text{ team size }3} - \mu_{T2\text{ team size }3}) + (\mu_{T4\text{ team size }3} - \mu_{T3\text{ team size }3}) < (\mu_{T2\text{ team size }4} - \mu_{T1\text{ team size }4}) + (\mu_{T3\text{ team size }4} - \mu_{T2\text{ team size }4}) + (\mu_{T4\text{ team size }4} - \mu_{T3\text{ team size }4})$

For H_1, H_2, and H_3, the computer bridge scores over the four time intervals were analyzed with a repeated-measures ANOVA. Each hypothesis is investigating interaction between time and a different fixed factor. Teamwork, structure, and team size were entered as between subject factors, while time was entered as the within subjects factor. Team average prior experience with the software was entered as a covariate. Whenever there are more than two levels of a within subjects factor, it is important that the group variance-covariance matrix exhibits sphericity. A repeated measures ANOVA is not robust to the violations of sphericity, so the Huynh-Feldt degrees of freedom correction was employed. According to Howell (2002), the Greenhouse Geiser estimate of ε is overly conservative, if ε is close to or greater than 0.75. The closer the value of ε is to one, the less severely the sphericity assumption has been violated. The Huynh-Feldt ε was calculated at 0.769 and applied to all within variable tests. With the sample data, three juxtaposed times exhibited more sphericity than all four times. For example, Huynh-Feldt ε was calculated at 0.974 for times one, two, and three.

The repeated measures ANOVA is displayed in Table 9. The repeated measures ANOVA revealed a significant main effect for time, which determines whether any of the four computer bridge scores are different from one another [$F(2.31, 198.46) = 148.45$, $p < .001$]. Time explained 63.3% of the variance in bridge scores ($\eta^2 = .63$). Also, the bridge score at each successive time interval was significantly greater (i.e., $T_2 > T_1$, $T_3 > T_2$, and $T_4 > T_3$) than the previous one ($p_{\text{all comparisons}} < .001$). There was not a significant interaction between the factors of time and

Table 9
Analysis of Variance for Bridge Scores Over Time

Source	*df* [b]	*MS*	*F*	*p*
Time	2.31	425,273.36	148.45	*<.001
Time x Prior Experience [a]	2.31	3,191.11	1.11	.336
Time x Team Size	4.62	7,863.95	2.75	*.023
Time x Teamwork	2.31	285.59	0.10	.928
Time x Structure	2.31	75.91	0.03	.984
Time x Team Size x Teamwork	4.62	1,487.77	0.52	.747
Time x Team Size x Structure	4.62	1,581.33	0.55	.723
Time x Teamwork x Structure	2.31	6,074.51	2.12	.115
Time x Team Size x Teamwork x Structure	4.62	858.45	0.30	.901
Error	198.46	2,864.71		
Total	228.46			

[a]Prior experience was entered as a covariate.
[b]Huynh-Feldt ε was calculated at 0.769 and applied to *df*.
* $p < .05$, two-tailed

teamwork, [$F(2.31, 198.46) = 0.10$, $p = .928$]. The rate of change across time between the teamwork group teams and control group teams remained almost identical. The estimated mean change across all four time intervals ($T4_{mean}$ - $T1_{mean}$) for the teamwork teams was very similar to that of the control group teams ($M = 161.51$, $SEM = 12.79$; $M = 158.56$, $SEM = 12.57$, respectively). Therefore, H_1 is not supported; teams receiving teamwork exercises did not improve bridge scores at a faster rate. Similarly, there was not a significant interaction between the factors of time and structure, [$F(2.31, 198.46) = 0.03$, $p = .984$]. The estimated mean change across all four time intervals ($T_{4\ mean}$ - $T_{1\ mean}$) for problem structure teams was very similar to that of control group teams ($M = 159.62$, $SEM = 13.05$; $M = 160.45$, $SEM = 12.80$, respectively). H_2 is not supported; teams receiving problem structure did not improve bridge scores at a faster rate. However, there was a significant interaction for the factors of time and team size [F(4.62, 198.46)

= 2.75, p = .023]. The team size interaction over time is graphed in Figure 7. Overall, the time x team size interaction is in the hypothesized direction (see Table 10).

Specific Time Contrasts for Computer Bridge Scores

Between time intervals one and two, the teams were under low load conditions, working with only the computer bridge. After the second time interval, between times two and three, as well as times three and four, the teams were under high task load, working with both the computer bridge and design/construction of the truss model. There was not a significant time x team size interaction between times one and two [$F(2, 86) = 0.83$, $p = .443$]. Under the low task

Table 10
Marginal Mean Differences for Computer Bridge Scores by Team Size

Interval (Δ)		**(Δ1) T_1 - T_2**[a]		**(Δ2) T_2 - T_3**[b]		**(Δ3) T_3 - T_4**[b]		**ΔT_1 - T_4**[c]	
Team Size	***n***	***M***	***SEM***	***M***	***SEM***	***M***	***SEM***	***M***	***SEM***
2	34	67.68	9.62	${}_{\mathbf{e}}32.99_{\mathrm{d}}$	8.36	${}_{\mathbf{e}}35.32$	9.31	${}_{\mathbf{d}}135.99$	15.59
3	34	54.71	9.41	${}_{\mathbf{e}}59.34$	8.18	46.83_{d}	9.10	160.88	15.24
4	31	50.69	9.91	58.63_{d}	8.61	${}_{\mathbf{e}}73.91_{\mathrm{d}}$	9.59	${}_{\mathbf{d}}183.23$	16.06
Total (*N*)	99	57.69	5.53	50.32	4.81	52.02	5.35	160.04	8.96

Note. Bonferroni technique was applied to the alpha level of the three post hoc interaction tests (time x team size) within each column ($\alpha = .05/3 = .0167$). Significance tests are one-tailed for the hypothesized direction.
[a]Change in bridge scores under low task load (working on computer bridge task only).
[b]Change in bridge scores under high task load (simultaneously working on the computer bridge and truss model tasks).
[c]Change in bridge scores from first to last recording.
Means in the same column that share the same letter subscript (d) approached significance ($.0167 < p < .05$).
Means in the same column that share the same bold letter (e) represent a difference that contributed to a significant time x team size interaction ($p < .0167$).

load conditions, teams of two had the greatest rate change, followed by teams of three, and then teams of four (see Table 10). This is opposite to the hypothesized direction. However, between times two and three, as well as times three and four, there were significant interactions between the factors of time and team size [$F(2, 86) = 3.16$, $p = .047$; $F(2, 86) = 4.32$, $p = .016$]. Generally, under high task load conditions, as team size increased, bridge scores tended to increase at a faster rate.

Post Hoc Analysis of Team Size and Computer Bridge Scores

Making pair-wise comparisons for team size, three post hoc repeated measure ANOVAs were analyzed for time x team size interactions. The other factors and the covariate were left in the model during the post hoc analysis, except for one level of team size for each comparison. All tests are one-tailed, since a hypothesized direction was indicated. A negative effect (-) indicates that a smaller team size had a greater computer bridge score change for that interval. Effect sizes were calculated with one team size excluded from the analysis. To guard against Type I errors, the Bonferroni technique was applied to the alpha level of the three post hoc *F* tests (α = .05/3 = .0167). Overall, between initial and ending score ($T_1 – T_4$), the mean change in scores displayed the hypothesized direction. However, the only post hoc interaction test that approached significance was between team size of two and of four [$F(1, 56) = 4.00$, $p = .050$, Cohen's $d = 0.50$], while the interaction between team size of two and of three, or team size of three and of four, over time did not approach significance [$F(1, 59) = 2.40$, $p = .119$, Cohen's d =.30; $F(1, 56) = 2.40$, $p = .163$, Cohen's $d = 0.25$].

Since there was no significant time by team size interaction for the first interval ($T_1 – T_2$), no post hoc analysis was conducted. However, during this interval team size of two had greater changes than team size of three and of four (Cohen's d = -0.24, *ns* and -0.29, *ns*, respectively). For the second interval ($T_2 – T_3$), the only significant difference was between team size of two and of three [$F(1, 59) = 5.34$, $p = .012$, Cohen's $d = 0.56$], while the difference between team size of two and of four approached significance [$F(1, 56) = 4.34$, $p = .021$, Cohen's $d = 0.52$]. For the final interval ($T_3 – T_4$), the means reflected the hypothesized direction; however, the only

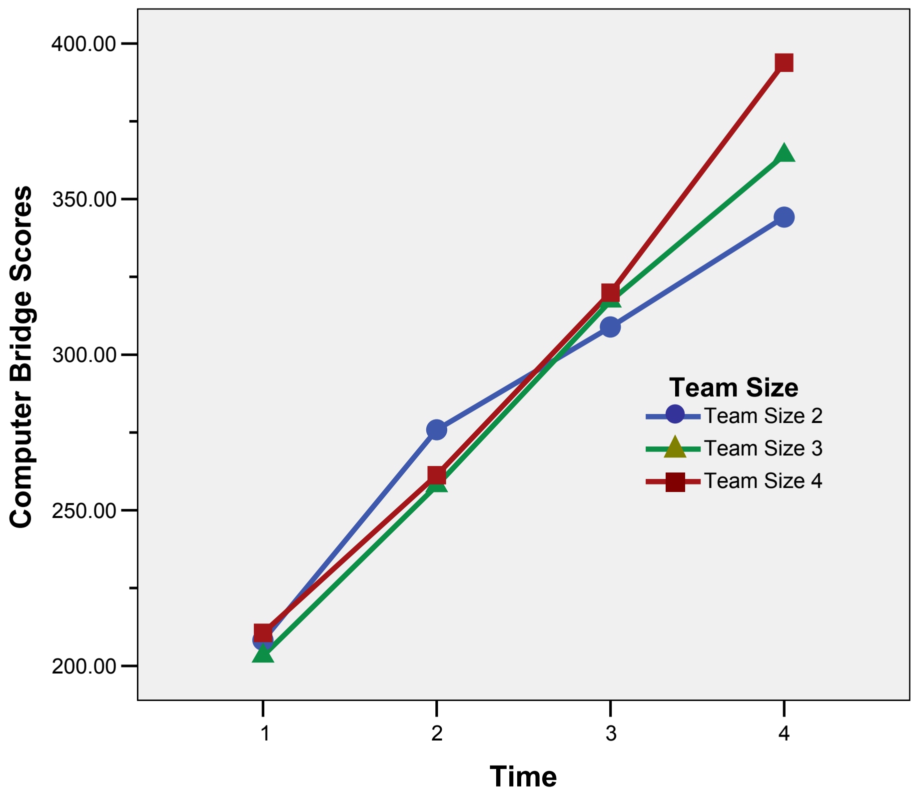

Figure 7. *Time x team size interaction over the four time periods.*

Note. From the start, until time two, teams were under low task load conditions (working on computer bridge task only). Starting with time two until time four, teams were under high task load conditions (simultaneously working on the computer bridge and truss model tasks). There was not a significant time x team size interaction under low task load; however, under the two high task load intervals there were significant time x team size interactions [(Δ2) T_2 - T_3 and (Δ3) T_3 - T_4].

significant difference was between team size of two and of four [$F(1, 59) = 6.39$, $p = .007$, Cohen's $d = 0.65$], while the difference between team size of three and of four approached significance [$F(1, 56) = 5.34$, $p = .024$, Cohen's $d = 0.50$]. During the final interval, the rate of change, between team size of two and of three was not significantly different [$F(1, 59) = 1.02$, $p = .159$, Cohen's $d = 0.25$]. Overall ($T_1 – T_4$), H_3 is supported when increasing team size from two to four, but it is not supported with a team size of three. Under low task load, there was not a significant difference in the rate of change for bridge scores. However, under high task load, teams of two had a significant decrease in their rate of change when compared with teams of three and four. H_3 is partially supported under high task load conditions, especially between team size of two and of four.

If the post hoc analyses comparing team sizes of 2, 3, and 4, were conducted without the factors of teamwork and problem structure, two more contrasts become significant. The overall ($T_1 - T_4$) time x team size interaction between team size of two and of four becomes significant [$F(1, 62) = 4.94$, $p = .015$]. Similarly, for the second interval ($T_2 - T_3$), the time x team size interaction between team size of two and four becomes significant [$F(1, 62) = 4.77$, $p = .016$]. The reason for this change is that the other factors did not contribute much to the explained variance in the main omnibus, and without them, the error term is reduced by the increased *df* for the tests.

Close inspection of the data revealed that some of the teams did not have iteration changes, or computer bridge score changes, between adjacent time periods. For example, four teams had no changes in either iteration or computer bridge scores for the second interval (Δ2), while there were 13 teams during the last interval (Δ3). This possibly indicates inactivity with the bridge design software. It may also indicate that teams actually did have additional iterations with the software, but were unable to make additional changes to computer bridge scores. For example, if a team made several iterations with the computer bridge, but was unable to lower its score, then they may have regressed in iterations to the last successful bridge. In that case, the room proctors would have recorded an iteration amount that was lower than the team's actual iteration amount. During the second interval (Δ2), there were two teams of team size 2 and of team size 3 that each had no change in iterations or computer bridge scores. With the last interval, there were nine teams of team size 2, three of team size 3, and one of team size 4 that had no changes in either score.

In order to determine the impact of teams that had no changes in either iteration or computer bridge scores on significant findings displayed in Table 10, all the post hoc analyses for time by team size interactions were conducted again. The computer bridge scores for these teams were replaced with the mean corresponding to their team size for that time period. With the bridge scores from these teams not affecting the mean, the result of the time x team size interaction during interval two (Δ2) for team size of two and of four changed, so that it was now significant [$F(1, 56) = 6.14$, $p = .008$]. It appears this finding became significant because a team of two had a relatively high score from a previous time period and did not make any additional changes to their score. On the other hand, the previously significant interaction between team size of two and four during interval three (Δ3) now only approached significance [$F(1, 56) = 3.70$, $p = .030$]. It appears this finding was previously significant, because of teams of two that did not change their scores during the last interval. No other significant findings or findings that approached significance changed with the new tests.

Iteration Score

Room proctors recorded the number of iterations at the same four 30-minute intervals as bridge scores. The mean iteration scores increased across the four time periods as follows: $M_{T1} = 21.89$, $SD = 12.48$; $M_{T2} = 45.58$, $SD = 23.37$; $M_{T3} = 62.53$, $SD = 32.36$; and $M_{T4} = 86.30$, $SD = 48.04$. Of the 392 iterations scores, fourteen were outliers (3.57%). At times one and two there were three upper bound outliers, while at times three and four there were four upper bound outliers. Except in two cases, teams that had outlying scores continued to have outlying scores at successive time periods. Stated differently, the fourteen outlying values came from a total of six teams. As seen in Table 10 with computer bridge scores, the difference in adjacent time periods was calculated for iterations. The mean T_1 to T_2 change in iterations was similar to the T_3 to T_4

change ($M_{\Delta T1\text{-}T2} = 23.69$, $SD = 17.00$; $M_{\Delta T3\text{-}T4} = 23.77$, $SD = 27.02$), while the mean change from T_2 to T_3 was less ($M_{\Delta T2\text{-}T3} = 16.95$, $SD = 17.36$). Of the 297 iteration difference scores, fourteen were outliers (three at interval one, four at interval two, and five at interval three). Two of the six teams mentioned previously, with extreme iteration scores for individual times, did not have outlying values for the three interval changes. This is because these teams made a lot of iterations from the start to time one, but did not continue to do so relative to other teams with high iteration scores. In addition, there were four teams with outlying iteration scores for interval changes that had not had outlying values for the four individual time periods.

Relationship Between Iterations and Computer Bridge Scores

$H4_a$: There will be a relationship between the change in iteration scores and the change in computer bridge scores over time.

$H4_0$: $r_{\Delta T1\text{-}T2} = 0$; $r_{\Delta T2\text{-}T3} = 0$; $r_{\Delta T3\text{-}T4} = 0$

$H4_a$: $r_{\Delta T1\text{-}T2} \neq 0$; $r_{\Delta T2\text{-}T3} \neq 0$; $r_{\Delta T3\text{-}T4} \neq 0$

To test H_4, three Pearson correlation coefficients were calculated between the change in iteration scores and the corresponding interval change in computer bridge scores. For intervals one and two, the correlation coefficients were significant, positive, and moderate in strength ($r_{\Delta T1\text{-}T2} = .28$, $r^2 = .079$, $p = .005$; $r_{\Delta T2\text{-}T3} = .29$, $r^2 = .085$, $p = .003$). The positive coefficients indicate that teams which tended to make more iterations between time periods, tended to increase computer bridge scores more than teams that made fewer iterations. With time interval two, there was one standardized residual greater than three. The scatter plot revealed that this outlying team had a large change in their computer bridge scores with relatively few iterations. When this case was excluded from the analysis, the correlation coefficient changed little ($r_{\Delta T2\text{-}T3} = .30$, $r^2 = .090$).

During the last time interval, the magnitude of relationship between iterations and computer bridge scores was strong ($r_{\Delta T3\text{-}T4} = .54$, $r^2 = .293$, $p < .001$). With this time interval, there were two standardized residuals greater than three. The scatter plot revealed that these two teams had the same characteristic as described with the outlying team at interval two. Excluding these two teams from the analysis resulted in a stronger relationship ($r_{\Delta T3\text{-}T4} = .59$, $r^2 = .344$). With all three intervals, there was a significant positive correlation, so H_4 is supported; there is a relationship between the change in iterations and computer bridge scores. However, correlation does not imply causality. For example, the teams that observed either changes or a lack of changes may have become excited or frustrated, increasing or decreasing their number of iterations. In addition, there could be some other variable that influences iterations. For example, teams having prior experience with the software may have known that it was possible to keep increasing their scores, while teams with no experience may have erroneously thought they were at the lower limit in costs.

Post Hoc Analysis of Team Size and Iteration Scores

There was a team size effect on computer bridge scores, and there was a consistent relationship between iterations and computer bridge scores. Therefore, the researcher decided to investigate the team size effect on iteration scores over time. Unlike the computer bridge score, which has a variety of scores for the first successful bridge by a team, there was a starting iteration score of one for all teams. This allowed for an additional time interval to be analyzed, which is from T_0 to T_1 ($\Delta 0$). In addition, the interval score lends itself to time comparisons within each team size, because it is interval data and is a behavior with the computer bridge score. Repeated measure ANOVAs were conducted to make the contrasts within each time interval. Each repeated measure ANOVA had one team size excluded. The Bonferroni technique was applied to the alpha level of the three time by team size post hoc *F* tests within each time interval (α = .05/3 = .0167). Because the time contrasts only included two levels of a within subject factor, no *df* correction was necessary. For the between interval comparisons within each team size, two team sizes were excluded from each repeated measures ANOVA. All tests are two-tailed, because no a priori hypotheses were made. In order to report effect sizes, the estimated marginal mean differences and the *SEM* were used to calculate Cohen's *d*, based on having one team size excluded from the analysis.

Table 11
Marginal Mean Differences for Iteration Scores by Team Size

Interval (Δ)		**(Δ0) T_0 - T_1[a]**		**(Δ1) T_1 - T_2[a]**		**(Δ2) T_2 - T_3[b]**		**(Δ3) T_3 - T_4[b]**		**ΔT_0 - T_4[c]**	
Team Size	***n***	***M***	***SEM***	***M***	***SEM***	***M***	***SEM***	***M***	***SEM***	***M***	***SEM***
2	34	19.74	1.75$_1$	$_{\mathbf{e}}$28.50	2.62$_1$	13.41$_d$	2.70$_1$	$_{\mathbf{e}}$12.44$_{\mathbf{e}}$	4.05	74.09$_d$	6.67
3	34	20.44	1.75	$_{\mathbf{e}}$18.68	2.62	15.79	2.70$_1$	$_{\mathbf{e}}$25.06	4.05$_1$	79.97	6.67
4	31	20.16	1.83	22.42	2.74	21.55$_d$	2.83	31.06$_{\mathbf{e}}$	4.24	95.19$_d$	6.99
Total (*N*)	99	20.11	1.03	23.20$_2$	1.54	$_3$16.92$_2$	1.59	$_3$22.85	2.38	83.08	3.91

Note. Bonferroni technique was applied to the alpha level of the three post hoc interaction tests (time x team size) within each column (α = .05/3 = .0167). Significance tests are two-tailed, since no a priori hypothesis was made.

[a]Change in iteration scores under low task load (working on computer bridge task only). The first interval is labeled (Δ0), so that subsequent interval numbers (e.g., Δ0) align with computer bridge score intervals.

[b]Change in iteration scores under high task load (simultaneously working on the computer bridge and truss model tasks).

[c]Change in iteration scores from first to last recording.

Means in the same column that share the same letter subscript (d) approached significance (.0167 < *p* < .05).

Means in the same column that share the same bold letter (e) represent a difference that contributed to a significant time x team size interaction (*p* < .0167).

Adjacent mean interval changes in the same row that share the same subscript number (1) on the *SEM* were significantly different (*p* < .01).

Adjacent mean interval changes in the total row that share the same subscript number (2) were significant at *p* < .01, whereas subscript (3) denotes significance at *p* < .05 level.

Box and whisker plots were examined for each team size by time period. Six of the teams had upper bound outlying values in one or more of the four time periods for a total of 12 outlying values (3.06% of all scores). Each outlying value was winsorized to the first non-outlying value inside the whisker. A winsorized transformation was selected over a trimmed sample, so that each score could be included in the analysis. Outlying values can unduly influence mean differences in statistical tests and inflate variance (Keppel & Wickens, 1991), as well as cause a problem with the assumption of normal subsample distributions. Of the 12 subsample distributions, two had significant Shapiro-Wilk statistics ($p < .05$), which are described next. The T_2 iteration score for teams of three had a skewness and kurtosis values of 0.34 and -1.28, which indicated that the distribution deviated from normality because it was platykurtic. The T_3 distribution for a team size of four had skewness and kurtosis values of 0.80 and -0.17, respectively, which indicates the score distribution was slightly positively skewed. Coefficients of -1.0 to 1.0 for skewness, and -2.0 to 2.0 for kurtosis, are generally considered within acceptable limits.

Averaging across team sizes, *F* tests were conducted to compare adjacent time intervals (see Table 11). Less iterations were made by teams during the first interval ($\Delta 0$) than the second interval ($\Delta 1$), but the difference did not reach significance [$F(1, 98) = 3.23$, $p = .075$]. Significantly more iterations were made by teams under the second low task load interval than the first high task load interval [$\Delta 1 > \Delta 2$; $F(1, 98) = 10.42$, $p = .002$]. Only teams of three did not increase iterations. Reversing the trend, significantly more iterations were made under the second high task load interval than the first one [$\Delta 2 < \Delta 3$; $F(1, 98) = 5.09$, $p = .026$]. During this interval, only teams of two did not increase the number of iterations.

Contrasting adjacent time intervals within each team size, only team size of two and of three had significant changes. For team size of two, there was a significant increase in iterations during the first low task load interval, while there was a significant decrease during the first high task load interval [$\Delta 1 > \Delta 0$; $F(1, 33) = 11.88$, $p = .002$ and $\Delta 3 < \Delta 2$; $F(1, 33) = 20.65$, $p < .001$].

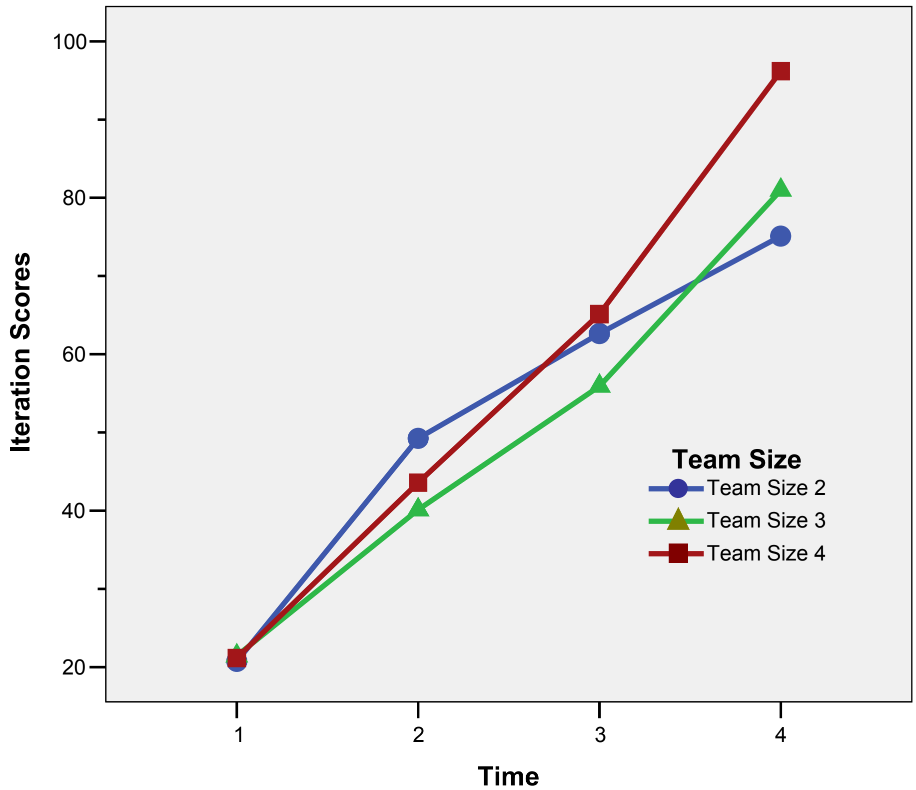

Figure 8. *Time x team size interaction on iterations over the four time periods.*

Note. Interval zero [(Δ0) $T_0 - T_1$] is not shown because all teams started at iteration one. From the start, until time two, teams were under low task load conditions (working on computer bridge task only). Starting with time two until time four, teams were under high task load conditions (simultaneously working on the computer bridge and truss model tasks). There was not a significant time x team size interaction under the first low task load interval zero [(Δ0) $T_0 - T_1$]; however, under the second low task load interval there was a significant interaction [(Δ1) $T_1 - T_2$]. The time x team size interaction approached significance under the first high task load interval [(Δ2) $T_2 - T_3$], whereas under the second high task load interval, there was a significant interaction [(Δ3) $T_3 - T_4$]. Averaging across all team sizes, teams made significantly less iterations during interval two (Δ2) than during interval one and three [(Δ1) and (Δ3)].

Though not significant, team size of three decreased their number of iterations over the first three intervals, and then significantly increased iterations in the final interval [$\Delta 1 > \Delta 0$; $F(1, 33) = 7.56$, $p = .010$]. For team size of four, iteration scores were similar across the first three intervals, and then increased in the final interval, though not significantly [$\Delta 3 > \Delta 2$; $F(1, 30) = 2.44$, $p = .129$].

Making pair-wise comparisons for team size, three post hoc repeated measure ANOVAs were analyzed for time x team size interactions on iterations (see Figure 8). Arbitrarily, a negative effect (-) was assigned if the mean of a smaller team size in a pairwise comparison had a greater change in iterations for an interval. During the first interval ($T_0 – T_1$), there were no significant time x team size interactions. During the second interval ($T_1 – T_2$), there was a significant time by team size interaction between team size of two and of three, with an effect size that was close to large [$F(1, 66) = 10.22$, $p = .002$, Cohen's $d = -0.78$]. Though insignificant, there were small effect sizes between team size of two and of four, as well as of three and of four [$F(1, 63) = 2.33$, $p = .132$, Cohen's $d = -0.38$ and $F(1, 63) = 0.80$, $p = .375$, Cohen's $d = -0.22$, respectively]. During the first high task load interval ($T_2 – T_3$), there was interaction between team size of two and of four that approached significance, with an effect size that was medium [$F(1, 63) = 4.16$, $p = .046$, Cohen's $d = 0.51$]. Though insignificant, there was a small effect size between team size of three and of four [$F(1, 63) = 2.02$, $p = .160$, Cohen's $d = 0.35$]. During the final interval, both time by team size interactions between team size of two and of three, and of two and of four, were significant and medium large [$F(1, 66) = 7.94$, $p = .006$, Cohen's $d = 0.68$ and $F(1, 63) = 8.88$, $p = .004$, Cohen's $d = 0.74$, respectively].

Over all of the four intervals, only the difference between team size of two and four approached significance and was medium in size [$F(1, 63) = 4.94$, $p = .030$, Cohen's $d = 0.55$]. There was small effect between team size of three and of four, and a below small effect between team size of two and of three [$F(1, 63) = 1.90$, $p = .173$, Cohen's $d = 0.34$ and $F(1, 66) = 0.53$, $p = .471$, Cohen's $d = 0.18$, respectively]. The homogeneity of variance assumption was not met for some of the above tests. According to Keppel and Wickens (1991), substantial differences in variance bias the *F* test positively, which leads to rejecting null hypotheses too often. They continue that the bias is less severe, if subsamples are nearly equal and tests have omnidirectional alternative hypotheses. Both of these criteria were met with the above tests. Keppel and Wickens state that the simplest method of handling heterogeneity of variance is to halve the nominal probability levels. Halving the probability levels in the preceding paragraph does not change any of the significant findings. Because the overall iteration scores ($T_0 - T_4$) between team size of two and of four approached significance and had a significant Levene's statistic, this probability level may be slightly higher than the reported one.

Prior Experience and Truss Efficiency Scores

The teams were coded as having a member with prior truss experience (n = 85) or not having a member with experience, which is no experience (n = 13). One team did not complete its truss, so the number of trusses (N = 98) is one less than the number of teams (N = 99). The teams with truss experience had a mean score (M = 354.50, SD = 165.17) that was significantly less (t = 3.07, df = 96, p = .020) than the teams with no truss experience (M = 452.75, SD = 108.04). The calculation for Cohen's d was a medium effect size of 0.62, in the direction of teams with no experience having a higher mean score. Since teams having experience with the technological task had a mean score less than teams with no experience, this possibly indicates that the technological task, as presented and with the construction materials provided, may have been a novel task for the teams, regardless of experience.

When sample sizes are unequal (e.g., n = 85 vs. 13), t-tests, like other parametric statistics, are not as robust to violations of two assumptions: normal distributions and homogeneity of variance (Gall, Gall, and Borg, 2003). The Shapiro-Wilk statistic confirmed that neither sample was significantly different from a normal distribution ($\text{Shapiro-Wilk}_{\text{no experience}}$ = 0.96, df = 13, p = .783; $\text{Shapiro-Wilk}_{\text{experience}}$ = 0.98, df = 85, p = .332). Levene's Homogeneity of Variance test failed to reject the null *H* of equal variance [H_0: $\sigma^2_{\text{no experience}} = \sigma^2_{\text{experience}}$; Levene(1, 96) = 3.71, $p = .057$]. Therefore, normal sample distributions and homogeneity of variance were assumed.

Truss Completion Time and Team Size

After the second or time two computer bridge score was recorded, the room proctors recorded the starting time, while simultaneously announcing that teams were allowed to start the construction of their truss models. Once a team had finished its truss, an ending time was recorded. The start and ending times were used to calculate a truss completion time, in minutes, for each team; however, seven ending times were not recorded for teams of three. Raw truss completion times ranged from a low of 92 minutes for a team of four to a high of 216 minutes for a team of two, with a mean score of 145.74 and a standard deviation of 19.57.

Team size is a factor that likely contributes to variance in truss completion times. Based on team size, the raw truss completion times were examined for normality and outliers. Outliers may reflect teams that: 1) did not remain on task, 2) overly desired to win prizes, 3) worked only on the computer bridge during the high task load periods, or 4) made frequent construction mistakes, which required them to start over. The Shapiro-Wilk statistic revealed the distributions of truss completion times for team size of two and of three were significantly different from normal ($p \leq .05$), while times for teams of four met the requirement of a normal distribution ($\text{Shapiro-Wilk}_{\text{team size 4}} = 0.97$, $df = 31$, $p = .634$). An upper bound of an unreasonable completion time was set at any value greater than three standard deviations, with one case being identified for team size of two and one for a team size of three. These two cases were winsorized to the first score less than three standard deviations from the mean for their respective team size. With these two cases winsorized, the distributions for team size of two and of three did not differ significantly from normal (Shapiro-Wilk $_{\text{team size 2}}$ = 0.08, *df* = 33, *p* = .942; Shapiro-Wilk $_{\text{team size 3}}$ = 0.95, *df* = 27, *p* = .332, respectively). Levene's Homogeneity of Variance test failed to reject the null hypothesis of equal variance [H_0: $\sigma^2_{\text{team size 2}} = \sigma^2_{\text{team size 3}} = \sigma^2_{\text{team size 4}}$; Levene(2, 88) = 0.18, *p* = .833]. Therefore, the necessary assumptions of normal sample distributions and homogeneity of variance were met with the transformed truss completion times.

ANOVA for Truss Completion Times and Team Size

To determine if truss completion times differed based on team size, a one-way ANOVA was conducted (H_0: $\mu_{\text{team size 2}} = \mu_{\text{team size 3}} = \mu_{\text{team size 4}}$). There was a significant overall difference in the mean truss completion times based on team size (see Table 12 and 13). Cohen's *f* is an index of effect size, similar to Cohen's *d* for two means, except Cohen's *f* is for a one-way ANOVA, with .10, .25, and .40 denoting small, medium, and large, respectively (Cohen, 1991). Therefore, the effect for team size on truss completion is considered large (Cohen's *f* = 0.46), explaining 17.7% of the variance in truss completion times ($\eta^2 = .177$).

The pattern of the means revealed the following relationship: as team size increased, mean truss completion times decreased. Three post hoc *F* statistics were calculated to compare the source of the main effect of team size on truss completion times (H_0: $\mu_{\text{team size 2}} = \mu_{\text{team size 3}}$; H_0: $\mu_{\text{team size 2}} = \mu_{\text{team size 4}}$; H_0: $\mu_{\text{team size 3}} = \mu_{\text{team size 4}}$). The Bonferroni technique was applied to the alpha level of the three post hoc *F* tests ($\alpha = .05/3 = .0167$), which decreases the risk of Type I errors associated with multiple pairwise comparisons. The alpha level reduction is considered a conservative approach to post hoc tests; it increases the probability of a Type II error (Howell, 2001). No *a priori* hypotheses were proposed, so the following tests are two-tailed. Team size post hoc comparisons revealed that the mean completion time for teams of two was significantly

Table 12
Mean Scores for Truss Completion Times by Team Size

Team Size	*n*	*M* [a]	*SD*
2	33[b]	154.42	16.68
3	27[c]	143.70	15.22
4	31	136.58	17.45
Total (*N*)	91	145.16	18.02

[a]Two extreme scores were winsorized, so that the truss completion times (in minutes) better approximated a normal distribution.

[b]One team did not complete its truss and [c]seven truss completion times were not recorded.

Table 13
Analysis of Variance for Truss Completion Times and Team Size

Source	*df*	*MS*	*F*	*p*
Team Size	2	2585.64	9.46	**< .001
Error	88	273.33		
Total	90[a]			

[a]One team did not complete their truss and seven truss completion times were not recorded.

** $p < .001$, two-tailed

greater than for teams of three [$F(1, 58) = 6.63$, $p = .013$] and teams of four [$F(1, 62) = 17.50$, $p < .001$]; however, there was not a significant difference between team size of three and of four [$F(1, 56) = 2.71$, $p = .106$]. If all scores had been recorded for team size of three, the increased power may have revealed a significant difference. In terms of effect size, the mean difference between teams of two and three is medium-large (Cohen's $d = 0.69$), while the difference between teams of two and of four is large (Cohen's $d = 1.05$). The effect size for the mean difference between team size of three and of four is medium-small (Cohen's $d = 0.43$, *ns*). With this technological task, therefore, it was found that teams of two used significantly more time to complete their trusses than teams of three and four.

Truss Completion Times and Truss Efficiency Scores

Three Pearson correlations were calculated between truss completion time and truss efficiency scores for each team size, with truss completion as the independent variable (H_0: $r_{XY} = 0$). Although there were positive correlations between truss completion times and truss efficiency scores for team size of two and of three, the correlations were not significantly different from zero ($r_{\text{team size 2}} = .28$, $p = .116$; $r_{\text{team size 3}} = .34$, $p = .086$). In addition, the correlation for team size of four was close to zero ($r_{\text{team size 4}} = -.004$, $p = .981$). Therefore, it was not supported that teams spending more time created an advantage for their team.

Truss Efficiency Scores

Truss efficiency scores ranged from a low of 46.15 to a high of 787.78 ($M = 367.50$, $SD = 16.84$), without deviating significantly from a normal distribution; no outliers were observed in the box plot (Shapiro-Wilk $_{\text{truss efficiency}} = 0.99$, $df = 98$, $p = .434$). In addition, none of the twelve sample means deviated significantly from a normal distribution (Shapiro-Wilk $_{\text{truss efficiency x 12 means}} > .05$). Levene's Homogeneity of Variance test failed to reject the null hypothesis of equal variance [H_0: $\sigma^2_{\text{condition 1}} = \sigma^2_{\text{condition 2}} \ldots = \sigma^2_{\text{condition 12}}$; Levene(11, 86) = 0.39, $p = .958$]. Therefore, the necessary ANOVA assumptions of normal sample distributions and homogeneity of variance were met for truss efficiency scores.

ANOVA for Truss Efficiency Scores

$H5_a$: Teams receiving teamwork exercises will have greater physical truss model scores than the control group for teamwork exercises. *Note.* Greater physical truss scores indicate greater technological problem solving.

$H5_0$: $\mu_{\text{teamwork}} \leq \mu_{\text{control}}$

$H5_a$: $\mu_{\text{teamwork}} > \mu_{\text{control}}$

$H6_a$: Teams receiving problem structure will have greater physical truss model scores than the control group for problem structure. *Note.* Greater physical truss scores indicate greater technological problem solving.

$H6_0$: $\mu_{structure} \leq \mu_{control}$

$H6_a$: $\mu_{structure} > \mu_{control}$

To test H_5 and H_6 of whether there were main effects for teamwork exercises and problem structure on truss efficiency, a 2 x 2 independent groups ANOVA, with three levels of team size, was conducted. As revealed in Table 14, there was a significant main effect for teamwork exercises [$F(1, 86) = 2.84$, $p = .048$]. With H_5, the null was rejected. Teamwork exercises seemed to have a positive effect on team truss efficiency scores. While problem structure appears to approach significance [$F(1, 86) = 1.93$, $p = .084$], the effect is not in the hypothesized direction. Therefore, with H_6, the null hypothesis was easily retained.

Post Hoc Analysis of Teamwork Exercises and Truss Efficiency Scores

Three *t* tests were calculated to compare the source of the main effect for teamwork exercises on truss efficiency scores for different team sizes. Conducting multiple post hoc *t* tests increases the probability of a Type I error; therefore, the Bonferroni technique was applied to the alpha level of the three post hoc tests ($\alpha = .05/3 = .0167$). The mean truss efficiency score (M = 396.94, SD = 158.27) for teams receiving teamwork exercises (n = 47) was greater than the mean score (M = 340.94, SD = 162.06) for control teams (n = 51). A small, but significant, main effect was revealed for teams receiving teamwork exercises [$t(1.71)$, $p = .045$, one-tailed; Cohen's d = 0.35]. After graphing team size and teamwork exercises (see Figure 9), it was revealed that teams of four receiving teamwork exercises (n = 16) had the largest visual impact on the main effect between control (n = 15) and treatment teams (M = 309.66, SD = 157.54 vs. M = 441.04, SD = 138.49, respectively). Teams of two receiving teamwork exercises (n = 15) had a greater mean

Table 14
Analysis of Variance for Truss Efficiency

Source	*df*	*MS*	*F*	*p* > *F*
Team Size	2	2,423.15	0.09	.456
Teamwork	1	74,282.67	2.84	* .048
Structure	1	50,343.51	1.93	[a].084
Team Size x Teamwork	2	35,382.99	1.35	.132
Team Size x Structure	2	2,141.40	0.08	.461
Teamwork x Structure	1	31,091.21	1.18	.139
Team Size x Teamwork x Structure	2	29,018.55	1.11	.167
Error	86	26,147.22		
Total	97			

[a]Although this *p* value seems to approach significance, the effect is not in the hypothesized direction, because the control group had a higher mean than the treatment group.

* $p < .05$, one-tailed

score ($M = 388.93$, $SD = 155.23$) than the control teams of two ($n = 18$) mean score on truss efficiency ($M = 349.24$, $SD = 144.12$), while mean scores for teams of three receiving ($n = 16$) and not receiving teamwork exercises ($n = 18$) were nearly the same ($M = 359.22$, $SD = 177.43$ vs. $M = 358.71$, $SD = 186.49$, respectively).

Post hoc analyses, contrasting within each team size, did not reveal a significant difference for teamwork exercises for either team size of two [$t(0.75)$, $p = .231$, one-tailed; Cohen's $d = 0.26$] or team size of three [$t(0.01)$, $p = .497$, one-tailed]; however, there was a significant difference for team size of four [$t(2.47)$, $p = .010$, one-tailed]. In terms of standardized population differences, teams of size four that received teamwork exercises scored nearly one standard deviation above control teams of size four (Cohen's $d = 0.88$), which is considered a large effect. There was not a significant *F* for Levene's test for equality of variance, so the homogeneity of variance assumption was met for all four comparisons described in this section ($p > .05$). As shown in Table 14, H_5 was supported as a main effect, however, when making

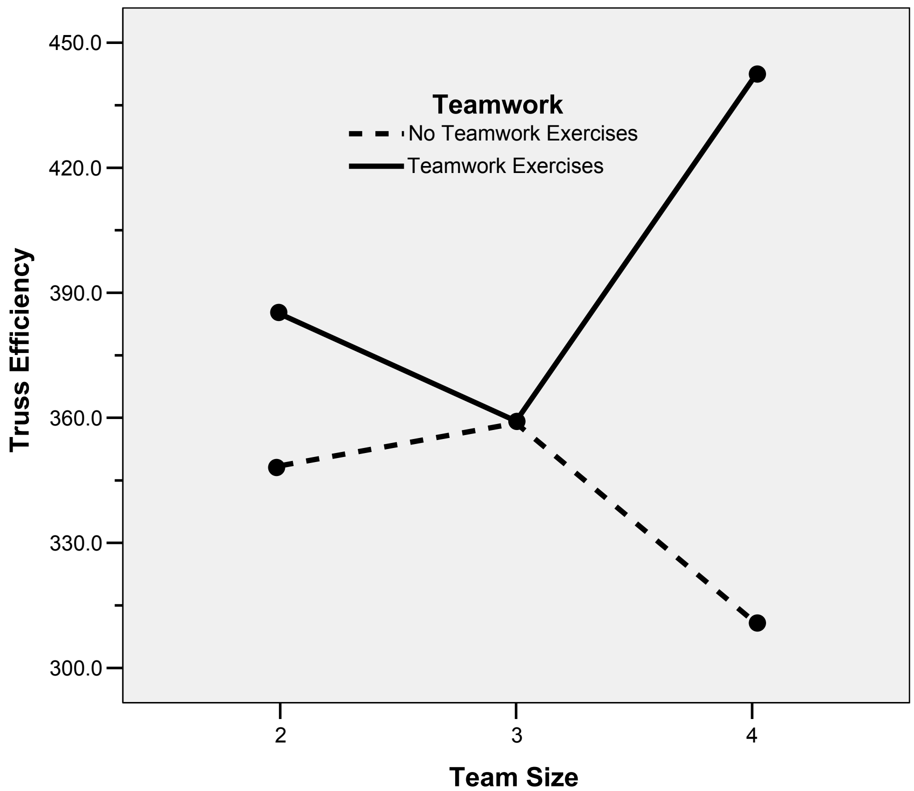

Figure 9. *Mean truss efficiency scores for team size and teamwork.*
Note. Although the graph shows an interaction pattern for teamwork across team size, the interaction (teamwork x team size) was not significant. Post hoc analysis revealed a significant simple teamwork effect only for teams of four.

comparisons within each team size, only with teams of four was the teamwork treatment effect statistically significant. Therefore, H_5 is only partially supported. Although the graph reveals an interaction pattern for the treatment and control groups across the three levels of team size, there was not enough statistical power to reach significance [$F(2, 86) = 1.35$, $p = .132$]. Leaving problem structure in the post hoc analyses would not change any of the above decisions, nor were there any significant interactions between teamwork and structure.

Problem Structure and Truss Efficiency Scores

As mentioned above, the main effect size for problem structure was small and not in the hypothesized direction: the control group's mean was higher than that of the treatment group

(Cohen's d = -0.27). Problem structure was more constant across the levels of team size [$F(2, 86) = 0.08$, $p = .461$] than shown in the graph for team size by teamwork exercises (see Figure 9). The effect sizes (Cohen's d) for problem structure on team sizes of two, three, and four were all small: -0.28, -0.29, and -0.19, respectively.

Technological Problem Solving Scores

Technological problem-solving scores are a combination of the final bridge score (plus bonuses) *and* truss efficiency scores. The participant teams were informed that prizes would be awarded based on equally weighting their final bridge score and truss efficiency score. In the design brief, teams were also informed that for each computer bridge time period in which they improved their score by at least $75, they would receive a $30 bonus. Therefore, a team could have their final computer bridge score improved by a maximum of $90. The median bonus received by the teams was $90 ($M$ = 72.73, SD = 26.45).

After including final bridge bonuses, total scores were calculated in the following manner. First, final bridge scores were raised to a power of -.983, so that they better approximated a normal distribution. This also makes a higher score indicate a better score with both measures. Second, both measures were converted to standardized scores (z). Third, with final bridge scores, one lower bound outlier was observed and winsorized. Fourth, the scores were converted to t scores. Both scores had similar ranges and equity of variance across scores ($\text{Levenes}_{\text{both scores}}$, $p > .05$). Neither score differed significantly from normal (Shapiro-Wilk, $p > .05$). The three preceding assumptions are necessary so that each score is weighted equally. Finally, the combined score had a very normal distribution, without any outliers [M = 100.13, SD = 15.33, Mdn = 98.75; Shapiro-Wilk(98) = 0.99, p = .949]. In addition, none of the twelve sample means deviated significantly from a normal distribution ($\text{Shapiro-Wilk}_{\text{tech problem solving x 12}}$

$_{means} > .05$). Levene's Homogeneity of Variance test failed to reject the null hypothesis of equal variance [H_0: $\sigma^2_{condition\ 1} = \sigma^2_{condition\ 2} \ldots = \sigma^2_{condition\ 12}$; Levene(11, 86) = 0.60, $p = .828$]. Therefore, the necessary ANOVA assumptions of normal sample distributions and homogeneity of variance were met for the technological problem-solving score.

Teamwork, Problem Structure, and Technological Problem Solving

$H7_a$: Teams receiving both teamwork exercises and problem structure will have a multiplicative effect on total technological problem-solving score (final computer bridge scores and truss efficiency scores combined). That is, teams receiving both teamwork exercises and problem structure will have higher scores than teams that only received teamwork exercises or problem structure.

$H7_0$: $\mu_{control} \geq \mu_{structure\ only}$; $\mu_{control} \geq \mu_{teamwork\ only}$; $\mu_{structure\ only} \geq \mu_{both\ teamwork\ and\ structure}$; $\mu_{teamwork\ only} \geq \mu_{both\ teamwork\ and\ structure}$

$H7_a$: $\mu_{control} < \mu_{structure\ only}$; $\mu_{control} < \mu_{teamwork\ only}$; $\mu_{structure\ only} < \mu_{both\ teamwork\ and\ structure}$; $\mu_{teamwork\ only} < \mu_{both\ teamwork\ and\ structure}$

An ANOVA was applied to the technological problem-solving scores with the factors of teamwork, structure, and team size (see Table 15). Although the factors and factor interactions explained 13.2% of the variance ($R^2 = .132$), only team size approached significance [$F(2, 86) = 2.59$, $p = .081$]. The pattern of the means was as team size increased, from two to three to four, total technological problem-solving scores increased ($M = 96.12$, $SE = 2.69$; $M = 99.24$, $SE = 2.61$; $M = 104.76$, $SE = 2.73$). In terms of effect size, the team size effect on total technological problem solving approached medium (Cohen's $f = 0.23$).

Dunnett's t test (> control) was conducted to compare the control group with each of the three experimental conditions on total technological problem solving (i.e., control compared with: structure, teamwork, and both structure and teamwork). Only the teamwork effect was in the hypothesized direction, and it was not significant ($M_{teamwork} = 103.41$, $SD = 16.01$ vs. $M_{control} = 101.05$, $SD = 13.64$; $p = .530$). Neither the mean of the structure only group ($M = 98.51$, $SD =$

15.70), nor the mean of the group that received both teamwork and structure (M = 97.33, SD = 16.35), were in the hypothesized direction (p = .917; p = .954, respectively). Therefore, H_7 was not supported. Teams receiving both teamwork and structure did not have a multiplicative effect on total technological problem-solving scores.

Table 15
Analysis of Variance for Technological Problem Solving

Source	*df*	*MS*	*F*	*p*
Team Size	2	595.23	2.58	.081
Teamwork	1	3.28	0.01	.905
Structure	1	492.25	2.14	.147
Team Size x Teamwork	2	443.07	1.92	.152
Team Size x Structure	2	115.62	0.50	.607
Teamwork x Structure	1	86.26	0.37	.542
Team Size x Teamwork x Structure	2	92.05	0.40	.672
Error	86	230.27		
Total	97			

Note. Technological problem solving is a combination of the t scores for final computer bridge score and truss efficiency score.

Relationship Between Final Bridge Scores and Truss Efficiency

$H8_a$: Final team bridge scores will be more positively correlated with physical truss model scores for teams receiving teamwork exercises than for the control group. That is, treatment teams will have better task transfer.

$H8_0$: $r_{teamwork} \leq r_{control}$

$H8_a$: $r_{teamwork} > r_{control}$

Pearson correlations were calculated between final scores with the computer bridge and truss efficiency scores. There was a small positive correlation between final bridge scores and truss efficiency scores (r = .19, p = .065). The correlation between final bridge scores and truss efficiency was stronger for teams receiving teamwork exercises than for control teams (r = .29, p

= .046; *r* = .14, *p* = .318). In addition, the correlation between final bridge scores and truss efficiency was stronger for teams receiving problem structure than for control teams (*r* = .26, *p* = .078; *r* = .11, *p* = .446;). Therefore, the correlations were in the hypothesized direction. However, to test the independence of correlation coefficients, Fisher *z* tests are necessary (Howell, 2002). After converting *r* to *r′* using Fisher's transformation, the *z* obtained was identical for the difference between teamwork and control, as well as between problem structure and control (*z* = .76, *p* = .224, one-tailed). Although the correlation coefficients were in the hypothesized direction, H_8 was not supported that the relationship between final bridge scores and truss efficiency is stronger in treatment groups than control groups.

Teamwork and Temperament

$H9_a$: With teams receiving teamwork exercises, heterogeneous temperament teams will have greater technological problem-solving scores than homogeneous temperament teams, while the opposite will occur in the control group. Teams not receiving teamwork exercises will not capitalize on the potential diverse contributions in their team, and the different temperaments will increase processing demands in control group teams.

$H9_0$: $\mu_{\text{teamwork hetero temp}} \leq \mu_{\text{teamwork homo temp}}$; $\mu_{\text{control hetero temp}} \geq \mu_{\text{control homo temp}}$

$H9_a$: $\mu_{\text{teamwork hetero temp}} > \mu_{\text{teamwork homo temp}}$; $\mu_{\text{control hetero temp}} < \mu_{\text{control homo temp}}$

To test H_9, whether there was an interaction between team temperament (heterogeneous, homogeneous) and teamwork exercises (treatment, control) on technological problem-solving scores, a 2 x 2 ANOVA was conducted. The assumptions of equality of error variances and normal subsample distributions were met [Levene(3, 94) = 0.11, *p* = .953; Shapiro-Wilk $_{\text{4 means}} >$ .05]. Neither the main effect for teamwork, nor for temperament, was significant [*F*(1, 94) = 0.01, *p* = .937; *F*(1, 94) = 0.81, *p* = .369]. Moreover, since there was not a significant interaction between teamwork and temperament, H_9 is not supported [*F*(1, 94) = 0.37, *p* = .543]. However, the means displayed an interactive pattern. For teams not receiving teamwork exercises, the homogeneous and heterogeneous temperament teams had similar scores (M = 99.18, SD = 14.37, n = 16; M = 100.16, SD = 14.83, n = 35, respectively), while with teams receiving teamwork exercises, the heterogeneous teams scored slightly higher than the homogeneous teams (M = 101.96, SD = 16.60, n = 33; M = 96.82, SD = 15.53, n = 14, respectively).

Teamwork and Gender

$H10_a$: With teams receiving teamwork exercises, heterogeneous gender teams will have greater scores than homogeneous temperament teams on total technological problem solving, while the opposite will occur in the control group.

$H10_0$: $\mu_{\text{teamwork hetero gender}} \leq \mu_{\text{teamwork homo gender}}; \mu_{\text{control hetero gender}} \geq \mu_{\text{control homo gender}}$

$H10_a$: $\mu_{\text{teamwork hetero gender}} > \mu_{\text{teamwork homo gender}}; \mu_{\text{control hetero gender}} < \mu_{\text{control homo gender}}$

To test H_{10}, whether there will be an interaction between team gender (heterogeneous, homogeneous) and teamwork exercises (treatment, control) on technological problem-solving scores, a 2 x 2 ANOVA was conducted. The assumptions of equality of error variances and normal subsample distributions were met [Levene(3, 94) = 0.58, p = .630; Shapiro-Wilk $_{\text{4 means}}$ > .05]. As shown in Table 16, the predicted interaction was significant [$F(1, 94) = 6.54$, p = .012]. Furthermore, as shown in Figure 10, the pattern of the means is in the hypothesized direction. The teamwork treatment teams that were of heterogeneous gender had a greater mean than the homogeneous gender teams (M = 102.63, SD = 17.50, n = 25; M = 97.94, SD = 14.81, n = 22), while concerning the control teams, the homogeneous gender teams had a higher mean than the heterogeneous teams (M = 102.91, SD = 13.96, n = 38; M = 90.93, SD = 12.86, n = 13). Therefore, H_{10} was supported through a significant teamwork x team gender interaction.

Table 16
Analysis of Variance for Technological Problem Solving and Gender

Source	*df*	*MS*	*F*	*p*
Teamwork	1	240.71	1.070	.304
Team Gender[a]	1	281.26	1.250	.266
Teamwork x Team Gender	1	1,471.47	6.540	*.012
Error	94	224.98		
Total	97			

Note. Technological problem solving is a combination of the final computer bridge score and truss efficiency score.

[a]Team gender is either all the same gender (homogeneous), or both male and female team members on the same team (heterogeneous).

* $p < .05$, two-tailed

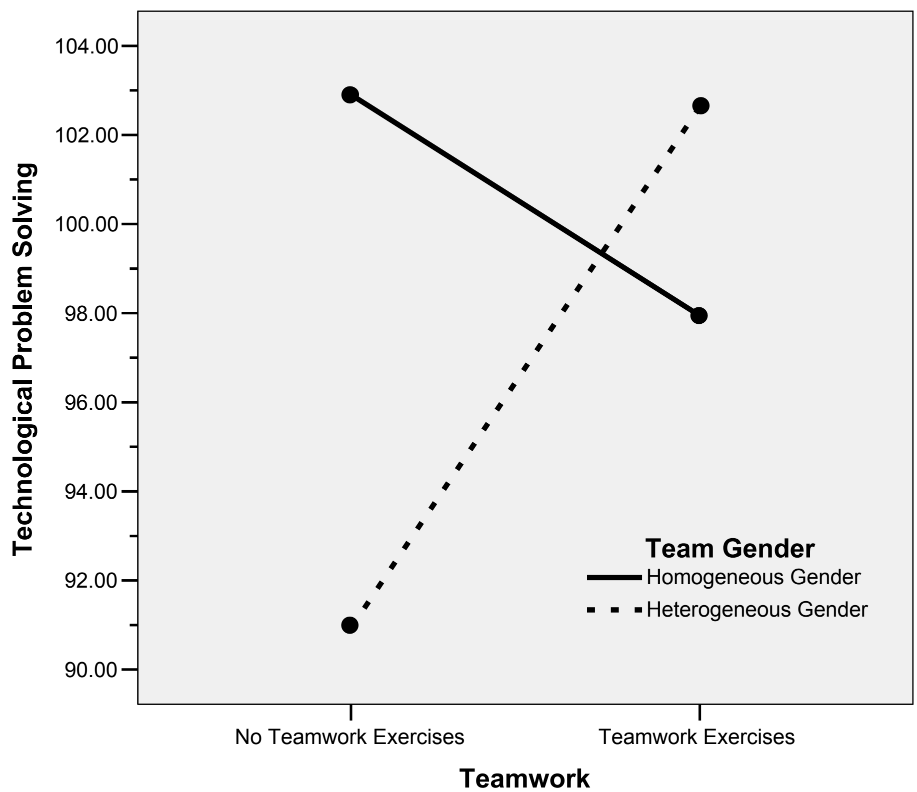

Figure 10. *Teamwork x team gender interaction on technological problem solving.*
Note. Technological problem solving is a standardized score (M = 100, SD = 15).

Relationship Between Team Orientation Scale and Technological Problem Solving

$H11_a$: There will be no relationship between average teamwork orientation scores and technological problem solving for teams that receive teamwork exercises. This is predicted, because the teamwork exercises have had an effect, regardless of teamwork orientation. If supported, the null will be retained.

$H11_0$: $r_{teamwork} = 0$

$H11_a$: $r_{teamwork} \neq 0$

$H12_a$: For teams not receiving teamwork exercises, there will be a positive relationship between technological problem-solving scores and average teamwork orientation scores for teams. In other words, as team teamwork orientation scores increase, technological problem-solving scores will increase for teams not receiving teamwork exercises.

$H12_0$: $r_{control} \leq 0$

$H12_a$: $r_{control} > 0$

To test H_{11} and H_{12}, Pearson correlation coefficients were calculated between technological problem-solving scores and a team's average on the teamwork orientation scale ($N = 98$). For the teams receiving teamwork, there was not a significant correlation between teamwork orientation scores and technological problem-solving scores ($r_{teamwork} = -.03$, $p = .831$, two-tailed). Similarly, for teams not receiving teamwork exercises, there was not a significant correlation between teamwork orientation scores and technological problem-solving scores ($r_{control} = .04$, $p = .394$, one-tailed). Therefore, H_{11} is supported, but H_{12} is not. There does not seem to be a relationship between team teamwork orientation scores and technological problem-solving scores.

Chapter 5. Summary, Conclusions, and Recommendations

Overview

This chapter begins with a summary of the findings from Chapter Four, followed by discussions of the effects of each independent variable on the two dependent measures. Cohen's *d* statistic is used throughout the discussion for simple effects. According to Keppel and Wickens (2004), there are several advantages to using the *d* statistic:

> The measure *d* is quite popular, because it is simple to use and makes good intuitive sense. If any measure can be called simply "*the* effect size" it is this. It is zero when there are no differences between the means … it is particularly useful in the field of **meta-analysis** … By working with *d* instead of actual differences between means, the disparate studies are put on a common basis (p. 161).

Within each section, findings are related to findings from previous research. In addition, the researcher proposes alternative explanations for the present findings. Chapter Five concludes with a section on recommendations for further research.

Summary of the Findings

From the analysis of the data, which is discussed in Chapter Four, this study yielded the following results:

1. No significant differences were found between the rates that teamwork or problem structure treatment groups and their respective control groups changed computer bridge scores over time. Differential rates between the treatment and control groups were investigated through time by independent variable interactions. The statistical tests revealed highly insignificant interactions, and the graphs revealed that the rate lines were almost parallel between treatment and control groups across the three time intervals.
2. Significant differences were found between the rates that different team sizes changed computer bridge scores over time. The researcher hypothesized that larger team sizes would change bridge scores at a faster rate than smaller team sizes. Under low task load conditions (computer bridge task only), the time by team size interactions were opposite to the hypothesis; as team size decreased, computer bridge scores increased at a faster rate. However, under high load conditions, simultaneously working on the computer bridge and truss model, larger team sizes

tended to increase computer bridge scores at a faster rate than team sizes of two. During the first interval under high task load (Δ2), there was a significant rate difference between team size of two and of three, while the rate difference approached significance between team size of two and of four. In the last interval under high task load (Δ3), the rate lines displayed the hypothesized direction. A significant difference was found between team size of two and of four, while the rate difference between team size of three and of four approached significance. Although in the hypothesized direction, there was not a significant rate difference between team size of two and of three during the last interval.

3. Positive correlation coefficients, which were significantly different from zero, were found between change in computer bridge scores and change in iteration scores for all three intervals. Teams that tended to make more iterations between time periods tended to increase computer bridge scores more than teams that made fewer iterations. This relationship was strongest in the final interval (Δ3).

4. Due to the two previous findings, the researcher added an analysis to investigate possible effects of team size on iteration scores. Comparing adjacent time intervals for team size of two, the iteration score was significantly greater for the second interval (Δ1), than for interval one (Δ0) or interval three (Δ2). Though not significant, team size of three decreased their number of iterations over the first three intervals (Δ0, Δ1, Δ2) and then significantly increased iterations in the final interval (Δ3 > Δ2). For team size of four, iteration scores were similar across the first three intervals and then increased in the final interval, though not significantly. Since all comparisons are within subjects, the Bonferroni technique was not applied to the nominal α level of .05; however, it was applied to the between subjects tests. During the first interval (Δ0), there were not any time by team size interactions. However, during the second interval (Δ1), there was a significant interaction between team size of two and of three (Cohen's d = -0.78). For this interval, team size of two changed iteration score at a greater rate than team size of three, while there were small effects between team size of two and of four, as well as of three and of four (Cohen's d = -0.38 and -0.22, respectively). During the first high task load interval, the interaction between team size of two and of four approached significance, while there were small insignificant effects between team size of three and of four (Cohen's d = 0.51 and 0.35, respectively). During the last interval, there were significant effects between team size of two and of four, as well as of two and of three (Cohen's d = 0.68 and 0.74, respectively).

5. As hypothesized, a significant main effect was found between teamwork exercise teams and control group teams on the truss efficiency score. Mean truss efficiency scores for team sizes of two and four were higher than their respective control group teams, while there was little difference between treatment and control group for team size of three. Post hoc analysis only revealed a significant difference between treatment and control group teams of four.

6. Contrary to the hypothesis for problem structure, treatment groups scored less on truss efficiency than the control group teams for all team sizes. If the hypothesized direction had been arranged to predict that the control groups would score greater

than the problem structure groups, none of the tests, comparing within team size, would have approached significance. However, the main effect for problem structure would have approached significance.

7. There was not a multiplicative effect on technological problem-solving scores for teams receiving both treatments: teamwork exercises and problem structure. The technological problem-solving score is a combination of the standardized final computer bridge score and the standardized truss efficiency score.
8. Although in the hypothesized direction, there was not a significantly stronger relationship between final computer bridge scores and truss efficiency scores in treatment groups (teamwork exercises and problem structure) than control groups.
9. There was not a significant interaction between teamwork exercises and team temperament on technological problem-solving scores.
10. There was a significant interaction between teamwork exercises and team gender on technological problem-solving scores.
11. No relationships were found between team average on the team orientation scale and technological problem-solving scores in either teamwork exercise teams or the control group for teamwork exercises.

Teamwork Exercises

There was not a rate difference between teamwork exercise teams and control group teams for the computer bridge scores over time. In fact, the only significant main effect for rate difference on the computer bridge scores was team size. Conversely, for the truss efficiency score, there was a significant main effect for teamwork exercises, but there was clearly not a significant effect for team size. The teamwork treatment seemed to have a positive effect on team size of two and of four, while it had no effect on team size of three. Post hoc analysis revealed a small and insignificant simple effect for teamwork exercises treatment on team size of two, while there was a large simple effect on team size of four (Cohen's $d = 0.26$ and 0.88, respectively). To guard against the chance of a Type I error, the Bonferroni technique was applied to α; however, this does not eliminate the possibility that a wrong decision was made in rejecting the null hypothesis for team size of four. There was no relationship between truss completion times and truss efficiency scores for team size of four. Furthermore, there was not a significant difference between treatment and control groups for team size of four on truss completion times. Therefore, the difference cannot simply be explained as the possibility that some teams spent more time on their trusses, which resulted in greater scores. Furthermore, the difference cannot be explained by prior experience, because teams having at least one member with truss or bridge construction experience scored less on truss efficiency than teams having no experience.

The large effect on truss efficiency score for teamwork exercise teams of four becomes more notable if the recent prior experience of participants in design teams is considered. Students enrolled in the *Engineering Exploration* course had already completed a MacGyver design brief in teams of four, as described in Chapter Three. The MacGyver team size of four was also used for in-class, problem-solving experiences. The truss model task is a design and build technological task, like those used in the MacGyver design briefs. Based on this prior experience with teams of four, it might be expected that teamwork exercises would have had a diminished effect on the truss efficiency scores. Moreover, as suggested by Gersick (1988), teams may quickly adopt patterns in the first few minutes of existence, so it is possible that the teamwork exercises might have given newly formed teams more flexible patterns of interacting. The teamwork teams may have been able to allow this flexibility to translate into higher truss efficiency scores, especially for team size of four.

In order to explain the effects, or the lack of effects, of teamwork exercises on the two tasks, it may be helpful to examine what is inherently different about them. The computer bridge requires no direct measurement of items, while all truss members on the model require measurement. It probably takes only one team member to operate the mouse in designing the computer bridge, but it probably is preferable to have more hands available for the construction of the truss model. The truss model construction bin had 138 truss members and a variety of tools to use. Therefore, the truss model may have required more organization on the part of teams in terms of sorting through materials and deciding who would be responsible for what.

The truss construction required teams to read and interpret a variety of instructions and diagrams, while the computer bridge required almost no reading. Not following the truss construction instructions carefully or misinterpreting the instructions may have led teams to make construction mistakes. However, there was a variety of tabular data available on the computer bridge to interpret. The design brief also included some tabular data on the truss model within the design brief. In addition, teams were capable of testing a design as many times as feasible with the computer bridge, while there was no way for teams to actually test the truss model. Due to this difference being unable to test the truss model, team members may have been required to negotiate more on the truss design than with the computer bridge, as well as create clearer hypotheses about future states of the truss model system. In addition, the problem of having to add mass that results in greater structural strength, like with the truss model, may have been inherently complex for these young engineers. An error or errors in prediction may have diminished the truss efficiency score of a team greatly.

Considering the findings and above discussion on task complexity, it is possible that the teamwork exercises only have an effect if team size is four or more, and the technological task demands a high level of team organization. One component of the teamwork exercises was that they required teams to organize their efforts. The teamwork exercises involved a high level of psychomotor cooperation, while the control group activities required none. Similarly, the truss model task required more coordinated psychomotor activity to complete than did the computer bridge task. The truss model may have been an additive task (McGrath, 1984), but without teamwork exercises, larger teams (team size four) may not have been able to combine their efforts together effectively.

Bray, Kerr, and Atkins (1978) found that the functional participation size of a group becomes proportionally less as the actual group size increases. Similarly, Stasser et al. (1989) found that larger groups are more likely to discuss shared information than unshared information. The unshared information, or information unique to one team member, may be the missing piece of the puzzle that helps the team solution evolve. One component of the teamwork exercises was active reflection, which larger teams may have transferred to the truss model task. In their meta analysis, Freeberg and Rock (1987) identified task complexity as an input variable and team coordination as a throughput variable (see Figure 2). Relevant to the current study, Freeberg and Rock found that team coordination had a large effect on accuracy. In addition, they found that task complexity had a large effect on production quantity. Production quantity is mentioned because the truss model required each team to produce a variety of truss members. Failure to make these members accurately may have affected truss efficiency scores. As mentioned in Chapter Two, team technological problem solving seems like a dependent measure that is not addressed in most team research studies.

In another meta-analysis, Salas, Rozell, Mullen, and Driskell (1999) found that a positive team building effect is more likely to exhibit itself in small groups and with subjective rather than objective measures. These researchers also commented on the lack of convergence of subjective and objective measures of team performance. It is important to distinguish teamwork exercises from teambuilding interventions, as in the meta-analysis of Salas et al. (1994), with the latter usually being done with intact organizational groups. This intervention is usually in interpersonal relations, role clarification, and/or problem solving. This type of problem solving means identifying problems within an intact organizational team, which is not the same meaning as with technological *problem solving* utilized in this study. Student teams may be much more transient in nature than in an organizational context, because they usually do not last longer than a semester. The norm is probably much less than a semester in the technology and engineering education classrooms. Contrary to common perception, Salas et al. found that shorter interventions with teams were more effective than ones over longer periods of time. Similarly, the short workshop of teamwork exercises used in this study had a large effect on truss efficiency scores for team size of four. Both of the measures, computer bridge and truss efficiency, used in this study were objective. Therefore, the current findings of a teamwork exercise effect on team size of four with truss efficiency, which was measured objectively, are opposite to those found by Salas et al. Those researchers found almost no effect on team performance with objective measures and only a weak effect with subjective measures.

Although beyond the scope of the current study, teamwork mental models may provide another explanation for the teamwork exercise effect on team size of four. For example, Hayes (2003) found that team mental model accuracy significantly predicted team performance of college student engineering teams. Hayes' research, unlike the rest of the studies investigating team performance, measured team technological problem solving. Marks et al. (2000) found that team interaction and leader briefing treatments had significant effects on team mental model similarity and accuracy. In addition, Marks et al. found that team mental model accuracy and similarity had a multiplicative effect on team communication processes, which in turn had an effect on team performance. Similarly, Mathieu et al. (2000) found that team processes (i.e., coordination, cooperation, and communication) had an effect on team performance. In addition, Mathieu et al. found that team and task models each had a unique effect on team processes.

In the future, it may be found that team mental models explain more variance in team performance for larger team sizes (≥ 4). In other words, the present study results may have occurred because the teamwork exercises affected the team mental models for team size of four, which in turn impacted their performance on truss efficiency. In addition, it seems like shared mental models would be more salient for larger team sizes to help ensure that team member coordination is used efficiently, as well as making sure that the team has an integrated strategy for developing a technological solution.

Teamwork Exercises and Team Temperament

The researcher hypothesized that with teams receiving teamwork exercises, heterogeneous temperament teams would have greater technological problem-solving scores than homogeneous temperament teams, while the opposite would occur in the control group. It was expected that teams not receiving teamwork exercises would not be able to capitalize on the potential diverse contributions in their team, and the different temperaments would increase processing demands in control group teams. However, there was not a significant teamwork by team temperament interaction. The heterogeneous temperament groups had higher scores in both teamwork and control group teams.

Volkema and Gorman (1998) found that heterogeneous temperament teams scored higher on two performance indicators. The task, which may differ substantially from the technological tasks in the current study, presented to teams in their study was to rank order items that would aid in survival during extreme conditions. The current study differed from Volkema and Gorman's study in that the present study did not randomly assign based on temperament, and the present study also included different team sizes. Therefore, the present study had a variety of team size by team temperament, even though they were categorized as either homogeneous (all

SJs) or heterogeneous. Volkema and Gorman had homogeneous team size of four (all SJs) and heterogeneous team size four, which included one of each of the four temperaments. With the present study, unlike the teamwork orientation score, the Keirsey Temperament Sorter was completed outside of class at the leisure of the participants. It is possible that some of the participants did not take the Keirsey Temperament Sorter with care. If approximately 3% of the participant temperaments were not identified correctly, this could change the team temperament for up to ten teams. These team compositional differences, possible misidentification of team composition, and the differences between the two tasks in the study, may account for the discrepancy in findings.

Teamwork Exercises and Team Gender

For the same reasons as with team temperament, the researcher hypothesized that there would be an interaction between team gender and teamwork exercises on technological problem-solving scores, so that heterogeneous gender teams receiving teamwork exercises would score higher than heterogeneous gender control teams. This hypothesis was supported through a significant interaction with a medium effect size (Cohen's $f = 0.26$). There is always the possibility of a Type I error. There was no random assignment based on gender. In addition, the error variance is pooled across problem structure and team size. However, Bowers, Pharmer, and Salas (2000) found in their meta-analysis that even though team sizes showed some differences, these differences between homogeneous and heterogeneous teams followed no predictable pattern. In addition, the researchers found that homogeneous teams tended to do better with low difficulty tasks, whereas heterogeneous teams tended to perform better with high difficulty tasks. As discussed earlier, it is thought that the student teams may have experienced the truss model task as more complex than the computer bridge. Overall, Bowers et al. (2000) found that homogeneous teams significantly outperformed heterogeneous teams on performance tasks. Similarly, with technological problem-solving, when given no teamwork exercises, the current study found that homogeneous teams scored higher than heterogeneous teams without teamwork exercises; however, it seems that the inclusion of teamwork exercises may have reversed this pattern.

Teamwork Orientation

No relationship was found between team teamwork orientation scores and technological problem-solving scores in either the teamwork exercises group or the control group for teamwork exercises. Teams that were one standard deviation below the mean on the team teamwork orientation score still had higher scores than a neutral score on a seven-point Likert scale [i.e., *M*(98.2) – *SD*(12.25) is greater than 21 items x 4]. Because the participants self-selected to be a part of the research study, one might expect participants to have high scores on the teamwork orientation scale. The present study investigated the relationship between team average on the teamwork orientation scale and technological problem solving. Similarly, with college student management teams, Mohammed and Angell (2003) found that mean team orientation did not significantly predict team performance on either a written or an oral presentation project. In addition, they found that team dispersion or variance on teamwork orientation also did not predict team performance on the two tasks. The present researcher was unable to find any published studies in which the teamwork orientation scale had been administered to secondary school students.

Problem Structure

As with teamwork exercises, there was not a rate difference between problem structure teams and control group teams for the computer bridge scores over time. However, there were effects for problem structure on truss efficiency, albeit insignificant and not in the hypothesized direction. It was hypothesized that during the initial period, when teams were formulating ideas on the two technological tasks, a treatment might influence subsequent technological problem solving. First, many research studies have revealed how production blocking can happen during group brainstorming (Diehl & Stroebe, 1987). Second, researchers have found that groups tend to discuss more shared than unshared information, and once an idea is shared, that groups return to that information with greater frequency (Cruz et al., 1997; Gignone & Hastie, 1997; Stasser et al., 1989; Stasser & Titus, 1985). Therefore, it was thought that having team members read over the design brief separately would help each team member become clear on his or her own ideas and unique knowledge. Then, a team member, having had these ideas recently in working memory, might be more likely to share that information in any subsequent team discussion, which would in turn create a more robust problem-solving exploration. However, if this occurred, it did not affect technological problem solving in the hypothesized direction.

The questions were added to the treatment design brief to help team members start organizing their knowledge during the problem formulation stage. It was also thought this would help team members develop shared task mental models, which were proposed by Cannon-Bowers et al. in 1993. Furthermore, Nutt (1984) found that teams tend to focus on problem solutions, without fully understanding the parameters of the problem. Similarly, Volkema and Gorman (1998) state that teams often rush the problem formulation phase. Volkema and Gorman found that half the teams rated in their study did not engage in problem formulation. Therefore, it was thought that the added questions would help teams members try to fully understand the parameters of the problem. The researcher designed the problem structure questions so as not to give the treatment groups any extra content knowledge.

Although the difference between the problem structure and the control group was statistically insignificant, overall there was a small negative effect on truss efficiency scores (Cohen's d = -0.27). In addition, when contrasting within team size, all the effects, though insignificant and small, were opposite to the hypothesized direction for team sizes of two, three, and four (Cohen's d = -0.28, -0.29, and -0.19, respectively). Regardless of team size, all the effects were in the same direction, possibly suggesting that the scores were not just due to chance. Cohen (1988) states that an effect size of 0.20 is small, but it may be meaningful. Hypothetically speaking, if the test had been set up in the direction that providing problem structure would hinder groups, then the test would have approached significance.

It is impossible to determine whether the sharing together had a positive influence (control group), or the ideation separately, followed by sharing together (treatment group), had a negative influence. If it were the former, then this may be due to the control groups having an extra twenty minutes to share. During the problem structure period, all teams did not have any task load on them. The problem structure treatment group may have needed more time to share without any task demands. In addition, it could be that not being able to share with teammates was foreign to the participants. The teams had, at no other time during the day, been given such a restrictive request on their behavior as "You should not talk during this time." Different results may have been achieved if participants were told the reason why they were delaying sharing together. However, informing the problem structure teams of such would have made the study no longer a double-blind design. Another possibility for the results is that the questions included in the design brief had a negative effect on the problem structure group. For example, the team members may not have found the questions meaningful, or the questions may have made teams try to take the truss design beyond their current abilities to understand. Finally, it is also possible that it is a combination of the two preceding effects, or as stated previously, simply due to chance.

There may be several reasons why the problem structure treatment resulted in an effect opposite to the hypothesized direction. The production blocking effect, well established in brainstorming research, may not apply in technological problem solving. For example, different brainstormed ideas must be put together into something meaningful to have a successful end product. Diehl and Stroebe (1991) found a trend to reduce production loss when the participants were allowed to take notes during brainstorming. In addition to notes, engineers may communicate through design sketches, which may allow them to offload ideas from short-term memory to the environment. For example, Brown, Collins, and Duguid (1989) suggest that using the environment to reduce cognitive task demands is important in problem solving:

> This sort of problem solving is carried out in conjunction with the environment and is quite distinct from processing solely inside heads that many teaching practices implicitly endorse. By off-loading part of the cognitive tasks onto the environment, the dieter [problem solver] automatically used his environment to solve the problem (p. 35).

Conversely, the causes of production blocking have been attributed to individuals forgetting their own ideas while waiting their turn, mental rehearsal not allowing for generation of new ideas, and participants becoming distracted by the ideas of others (Diehl & Stroebe, 1991). All of these causes seem to have the common thread of limitations with both working and short-term memory.

MacDonald and Gustafson (1994) view design drawing as more than just object representation in design technology; rather, they view sketching and drawing as a source of ideation and a tool for furthering visual thinking. Therefore, in the problem structure treatment, the team members may have been busy writing answers to the questions, instead of sketching.

This may have allowed the control group more time to refine their ideas through sketching. Furthermore, Reid and Reed (2000) investigated the interactions of student engineering design teams for rhythmic cycles over time. They found that figural reasoning (sketching, pointing, or gesturing) entrained the phases of turn-taking cycles and conceptual reasoning (understood without visual information) in the majority of face-to-face design episodes. A figural argument has direct bearing to communicating on the design idea with other people, while conceptual arguments usually deal with design requirements or constraints. Reid and Reed quote the following as examples of figural and conceptual arguments:

> The bottom must be, you know, like this [*sketches*, figural argument], so that here, there is a connection. [*sketches*, figural argument] OK? The space below, it's only, you know, a semi-rectangular thing, at this end. [*gestures*, figural argument] … So if we try that … then we've got pump up manually, air hydraulic, pump-up electrical, electrical mechanical [*writes*, conceptual argument] (p. 362).

From their data analysis, they concluded that the figural and conceptual phases alternated with one another. The conceptual reasoning peaked with levels of frequent verbal turn taking by members, whereas the peaks in figural reasoning coincided with lows in these measures. The figural period was further characterized by the listening team members knowing when not to interrupt the creative visualization of a teammate during a figural argument.

Considering the preceding ideas on sketching and figural reasoning, it may be that the problem structure treatment did not allow these teams to become "in rhythm" with one another. On the other hand, the figural sketching and body gesturing may have been important components for the control group to develop common design understandings. In other words, developing the figural and conceptual cycle may have been missing for the problem structure treatment teams. Control group teams may have naturally known how to synchronize the endogenous with the demands of the team interaction, so as to not interfere with the conceptual or figural reasoning of themselves and teammates. Problem structure teams may have been focusing on the conceptual to the detriment of the figural, which Reid and Reed (2000) found to take a prominent role in design engineering teams. For consistent methodology reasons, none of the teams were allowed to explore the materials in their construction bin, even though they could see the construction examples. Therefore, if the teams had been allowed to explore the materials, there may have been an even larger negative treatment effect. The encouraging matter in all of this is that the problem structure seems to have affected the technological solutions by the student engineering teams in this study.

Team Size and Task Load

The pattern of the mean differences for team size with computer bridge scores reversed, when transitioning from low to high task load. Though not significantly different, under low task load conditions, the rates of change for team size were opposite to the hypothesized direction. Team size of two had higher rate changes than team size of three and of four. Both of the effect sizes were small and insignificant (Cohen's d = -0.24 and -0.30). A possible explanation for this is that the larger team sizes had to incorporate the ideas of more team members, which resulted in slower initial progress. If this is true, lower scores with larger team sizes indicate a process loss. In addition, it might also be expected that the first time interval revealed more of a trial and error approach. Therefore, larger team sizes may have had more discussion in trying to determine what may help lower computer bridge scores, which subsequently slowed progress. An alternative explanation is that the differences were just random fluctuation in rates. During the first high task load interval ($\Delta 2$), team size of two had a significantly lower rate change than team size of three, while the difference between team size of two and of four approached significance. Both the effect sizes were medium (Cohen's d = 0.57 and 0.52, respectively). The rate differences between team size of three and of four for the low task load interval was insignificant and very small (Cohen's d = -0.14).

Under high task load, when working simultaneously on both the computer bridge and truss model, teams must decide which tasks teammates are going to work on. Teams with two members can only have one member fully devoted to each task at any given time. With another team member, team sizes of three are able to have at least two members on one of the tasks. Team sizes of three may also have one member who transitions back and forth between the two tasks, serving as a communication liaison between the two related tasks. With an additional team member, team size of four can devote at least two members to work on each task. If teams of three and four devoted at least two members to work on the computer bridge during high task load, then this may be suggestive of process gain. In other words, if teams of two left only one team member on the computer bridge, this member may have run out of ideas for changing bridge designs in order to improve computer bridge scores.

It might be expected that the last computer bridge interval is psychologically the highest task load, because teams realize that this is the last opportunity to improve computer bridge scores. Furthermore, it is roughly the halfway point to task completion on both tasks for the technological problem solving. Gersick (1988) identified that teams change roles to meet the task demands at the halfway point to task completion. Therefore, additional rate changes might be expected if team sizes adjust differentially to task load during the transitional period identified by Gersick. During the final interval, the means are in the hypothesized pattern of higher rate changes for larger team sizes.

The effect size for the final interval (Δ3) between team size of two and of three was small and insignificant (Cohen's d = 0.29, *ns*), while the effect size between three and four was medium, but the difference only approached significance (Cohen's $d = 0.50$, *ns*). The effect size between team size of two and of four was medium large and significant (Cohen's $d = 0.64$). This may suggest that larger team sizes were using their human resources effectively. Because of this, the difference between teamwork and control groups on truss efficiency within team size of four seems even greater. It may be that teams of four without teamwork exercises diversified into two distinct teams during the high task load. Then, after the computer bridge task had ended, they were not able to coordinate the efforts of the two team members who had been working solely on the computer bridge.

With the last interval, there were nine teams of team size 2, three of team size 3, and one of team size 4 that had no changes in either computer bridge scores or iterations. As explained in Chapter Four, with these teams, it is impossible to know whether they attempted to make additional changes to their computer bridge scores or not. While the teamwork and problem structure treatments were double blind, the team size factor was not hidden from researchers or participants. Since it was impossible for the levels of this factor to remain hidden from participants, this information was made available through the registration web site. Therefore, when comparing team sizes on performance, this may have created a bias, if smaller team sizes thought they were somehow disadvantaged. However, with the truss efficiency score, there was no main effect for team size.

Iterations

Iterations are a count score for either of two behaviors by the team with the computer bridge software. One behavior is *testing* to see whether a *new* computer bridge design is successful. Design in this sense means a change in the pattern of members on the bridge, as well as changing the type or cross section of members. The simulation mode in the software allows teams to see the qualitative amount of compression or tension on a bridge member. The other behavior is regressing to an earlier design iteration and making a change to that iteration. This behavior may be thought of as *comparing* designs. This behavior is similar to the "undo" command in a word processing program, though it may serve a greater function than simply "undoing" a mistake. Comparing the different design iterations may allow teams to start to learn the concepts that will lead to a lower cost bridge. Without making a change to a previous design, the iteration score will not increase. Therefore, teams may simulate any of the earlier iterations, without increasing the iteration score. Both iteration behaviors with the computer bridge software may be thought of as *activity*.

It is beyond the scope of the present study to differentiate counts for each iteration behavior described above. However, the average team engaged in one of these two behaviors, or alternated using both behaviors, with great frequency. The average team made an iteration approximately every 90 seconds. In the final interval, teams of four made more than one iteration per minute. In addition, as is common with count scores, there was a lot of variation within each team size, which became more dispersed with each successive interval. According to Keppel and Wickens (1991), it is a characteristic of count scores to become more dispersed as the total count number moves away from the lower bound.

Significant positive correlations were found between iterations and computer bridge scores for intervals one through three ($\Delta 1$ to $\Delta 3$). The positive value indicates that teams which made more iterations tended to change computer bridge scores more for that interval. The relationship was strongest in the final interval, explaining approximately 29% of the variance in computer bridge scores. It was noted that several teams did not make a change in iterations or computer bridge scores for the final interval; however, excluding these teams from the analysis did not change the relationship noticeably. No correlation can be conducted for the first 30 minutes (Δ0), because the starting computer bridge score is hypothetical. Furthermore, teams would have varied when they achieved their first successful computer bridge. The reason for the relationship between iterations and computer bridge changes is beyond the scope of this research study.

One might expect that random testing or regressing to earlier design iterations, without forming new hypotheses, would not lead to significant changes in computer bridge scores. For earlier time periods, it may be that some teams did not test after making meaningful changes. Making changes to member properties, then making changes to layout members, without testing in between, may make it hard to learn what makes a lower cost bridge. The relationship in the later intervals may be due to differential use in the computer bridge. For example, if the computer bridge was left idle for some time, then low changes in one score may become paired with low changes in the other score. Furthermore, a successful change by a team may increase iteration activity. Conversely, an unsuccessful change may prompt a team to view previous designs; however, until the team comes to a decision on which design to change, the iteration score does not increase. So possibly, the team may have inactivity on iterations, until the team members have agreed upon which design to change or what to try next.

The team sizes seemed to respond differently on iteration activity over every time interval, except for the first one (Δ0), which may indicate that teams were still becoming familiar with the computer bridge software. During the second interval (Δ1), team size of two significantly increased iteration activity (44.3%), while team size of three slightly decreased iteration activity (8.6%). This resulted in a significant time by team size interaction (Cohen's d = -0.78). Though not significant from other team sizes, team size of two also had the greatest change in computer bridge scores for this interval. Therefore, it seems that team size of two may have been responding to their last opportunity to work in tandem on the computer bridge task, without leaving the truss model task neglected. This may indicate a strategy used by some of the teams of two to compensate for their lack of team members compared to the larger-sized teams.

During the first high task load interval (Δ2), team size of two decreased iteration rate significantly (52.9%). This was also the largest total change in iterations from a previous time interval. The interaction on iterations between team size of two and of four approached significance, while the interaction for these teams on computer bridge scores also approached significance (Cohen's d = 0.51 and 0.52, respectively). Therefore, under the high task load interval, it seems that team size of four was able to translate increased iterations into a greater rate with computer bridge scores. There was only an insignificant interaction with a less than small effect between team size of two and of three on iteration activity; however, there was a significant interaction with medium effect between these teams on computer bridge scores (Cohen's d = 0.16 and 0.56). There was an insignificant interaction with a small effect between team size of three and of four on iterations; however, this increased activity did not result in an increased computer bridge score rate for team size of four (Cohen's d = 0.35 and -0.02).

During the final computer bridge interval (Δ3), both team size of three and of four increased their iteration rate. Though not significant, the mean rate for team size of four increased by 44.1%, while team size of three increased their rate by 58.7%, which was significant. Overall there was not a significant interaction between team size of three and of four on iterations for the final interval, but the interaction on computer bridge scores for these teams approached significance (Cohen's d = 0.23 vs. 0.50, respectively). This suggests that team size of three was able to have somewhat similar activity, but could not translate this activity into improving computer bridge scores as much. This may indicate process gain for team size of four. Team size of three had almost twice the number of iterations as team size of two, which was significantly more iteration activity (Cohen's $d = 0.68$). Although team size of three had a greater computer bridge rate, this rate was not significant (Cohen's $d = 0.25$). This suggests a process loss for team size of three. Team size of four had nearly 2.5 times as many iterations as team size of two, while team size of four also had a greater rate change in computer bridge scores (Cohen's $d = .74$ and .68). This seems to suggest that team size of four had reached a high level of performance, but once again, this translated into better performance on truss efficiency for only those teams receiving teamwork exercises. From the findings and the patterns in the research data, it seems that different team sizes both responded and performed differently under low and high task load conditions.

Strengths and Limitations

One strength of this study is that teams were involved in two technological problem-solving tasks that many educators would consider an authentic engineering design activity for the developmental level of participants. Before the day of the study, participants did not know the technological tasks that would be assigned to them, which prevented any advance preparation and possible bias to the study. Another strength of this study is that participants were randomly assigned to treatment and control conditions, while at the same time the study was conducted within the context of an educational environment. For example, Keppel and Wickens (2004) state:

> … experimental settings, are less interested in overall population means than in differences among the treatments that define the groups. Here we are on much more solid ground. When the assignment to groups has been made randomly, any bias in recruiting the subjects applies equally to all groups. Differences among the groups are due to treatments, not the exclusion of subjects (pp. 137-138).

Moreover, the participants were rather homogeneous in academic achievement, which creates a greater likelihood of having equivalent groups on such characteristics as mathematics, science, and verbal ability.

One limitation of this study is that replication of the teamwork exercises may be difficult, unless the teamwork consultant has experience working efficiently with large groups in a short amount of time. However, all the teamwork exercises were selected based on the resources available to a classroom teacher. On the other hand, the problem structure treatment seems like it would be straightforward to replicate with other populations or modify for different research questions. Another limitation is that participants were not randomly assigned based on gender or temperament. In addition, the temperament and teamwork orientation scales are self-report measures, which could possibly limit the findings on these two variables. Any observed effects in this study may be larger or smaller with other populations, even with first-year engineering students.

Recommendations for Further Research

The following recommendations are made based on the findings of this study and the researcher's experience from conducting this study:

1. One obstacle to overcome in conducting team research is the total number of participants needed for inferential statistics. In part, this was overcome in the present study by working within the educational context of an introductory engineering course. Multiple regression analysis may be useful in identifying factors that influence team technological problem solving, without requiring the number of teams needed in an experimental design. In this effort, meaningful continuous and interval measures need to be developed.
2. Future studies may want to include teamwork and task work mental models. This will provide an interval measure to relate to team technological problem-solving performance. The measurement of team mental models was beyond the resources available for this study. Furthermore, in its current form, it may be too complex for students of public school age. For example, S. Mohammed (personal communication, Summer 2004) suggested that administering a team mental model

instrument to first-year college students could prove difficult due to the complexity of the relational matrix that must be comprehended by participants.

3. The data of the present study seem to suggest that how team member interactions are structured during problem formulation may have an influence on their solutions with some technological tasks. Different treatments could be designed to determine what influences student team problem formulation. In addition, teams comprised of younger members may respond differently to problem structure.

4. The teamwork orientation scale may work with high school populations; however, some modification of the wording will be needed in order to have reliability with this age group. Teamwork orientation may be related to the benefits students perceive they are receiving from team experience.

5. The present study investigated face-to-face technological problem solving. Future studies may want to investigate how teams try to organize themselves to complete technological tasks outside a classroom. For example, many college students complete design activities outside of class. Furthermore, how do competitive teams, such as TECA (Technology Education Collegiate Association) and TSA (Technology Student Association), prepare themselves for competitive events? What behaviors lead to successful coordination of team members? What are the feedback mechanisms that student teams use to evaluate process instead of performance?

6. This study did not evaluate individual learning from the team experience. Further research could investigate whether or not learning is distributed equally among all team members. In addition, researchers could investigate which technological problems are experienced as additive tasks (McGrath, 1984) versus “division of labor” tasks by student teams.

7. This study did not investigate the psychosocial benefits of teamwork exercises for promoting development in public school students. Future studies could be conducted on the use of teamwork exercises to promote the acceptance of diversity in the technology education classroom.

8. This study employed a large number of personal computers. It seems like simulation software may be a good tool to track participant behavior during problem solving, especially as it becomes easier to write complex monitoring software. For example, a limitation with the present study was the inability to differentiate between the iteration behaviors. Separate counts on either or both behaviors may be worthy of future study. However, software that automatically keeps track of these behaviors via time stamps may make data collection more meaningful. Moreover, software that records all of the design iterations may give insight into the design decisions made during technological problem solving by student teams.

9. Researchers could investigate various factors of technological task complexity that exceed the organizational capabilities of a student team. Further research is needed to determine which factors facilitate the ability of a student team to solve complex technological tasks.

10. Students are participating in team-related design activities in many classrooms. How can the team environment be enriched for greater learning experiences of the team members? How does a student team create technologies to extend their capabilities and rewards?

Conclusion

Depending upon the type of technological task, different variables may be more relevant in explaining team performance. This research study reveals that student teams, depending on the team size, may both respond and perform differently under low and high technological task load conditions (one vs. two or more technological tasks). In this study, response was measured through iterations, while performance was measured through computer bridge scores. In addition, the experiment suggests that teamwork exercises may have greater saliency with some technological tasks, especially tasks that require a student team to coordinate a variety of resources and tools. Moreover, future studies may reveal that teamwork exercises have greater relevancy as technological task complexity interacts with larger team sizes (≥ 4). In addition, the structure that occurs for a student team during the problem formulation stage may influence the technological solutions produced. Once again, this may depend upon the complexity of the technological task, as well as the developmental level of the team members. Finally, teamwork exercises may be more relevant for student teams with heterogeneous gender than those with homogenous gender.

When one walks through a technology or engineering education classroom, one may see students working individually, but many times one is also likely to see students interacting in teams. The quality of the team environment may influence student learning. Therefore, changing the quality of that team environment and improving team functioning may be a worthwhile endeavor. One step in this pursuit is to gain a greater understanding of the many influences that facilitate team functioning during technological problem-solving activities.

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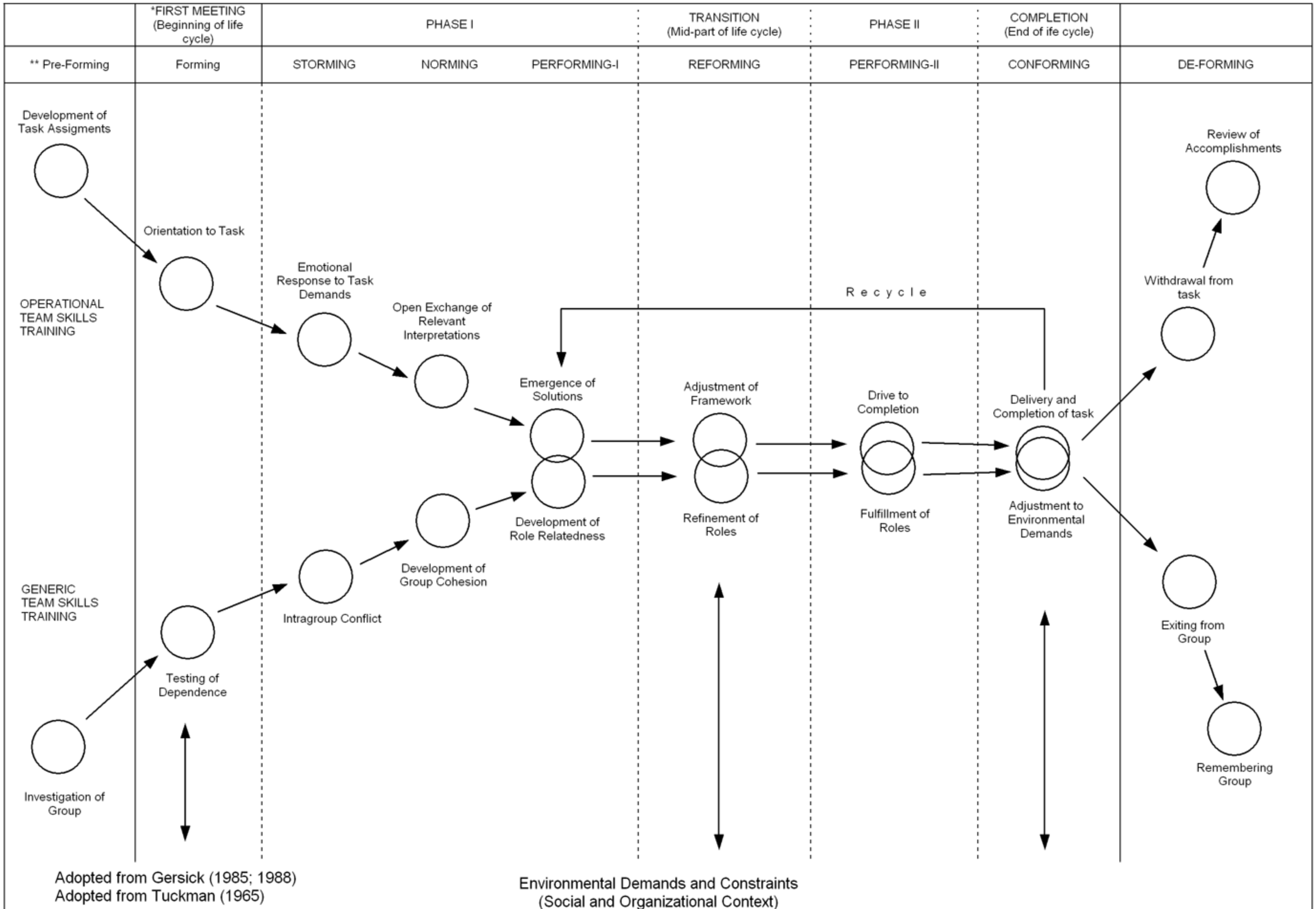
Appendix A: Team Evolution and Maturation Model

A General Model of Team Evolution and Maturation



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Appendix B: West Point Bridge Designer V4 Graphic User Interface

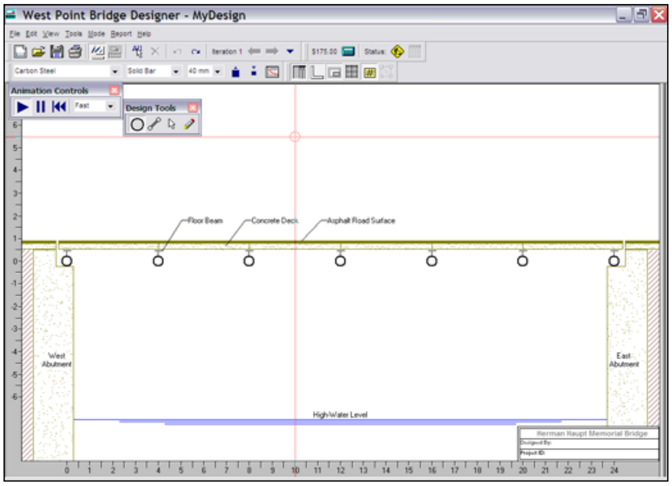


Figure B1. *Computer bridge participants started with.*

Note. Teams opened up the above design from a CD to make sure all teams were designing the same length bridge.

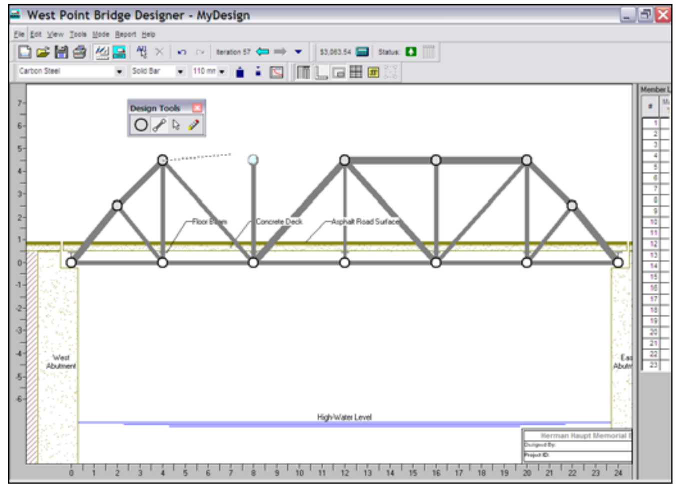


Figure B2. *Computer bridge interface in the design mode.*

Note. Once joints have been placed, member sizes can be specified and drawn.

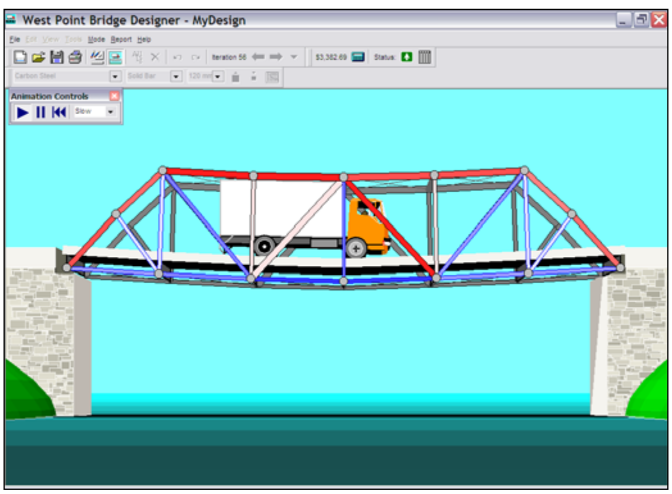


Figure B3. *Computer bridge in the load test simulation.*

Note. As the 20 kiloton truck drives across the bridge, the members change colors. If a member is in compression it will be a shade of red. If a member is in tension, it will be a shade of blue. The darker the color, the more the internal stress that is on the member.

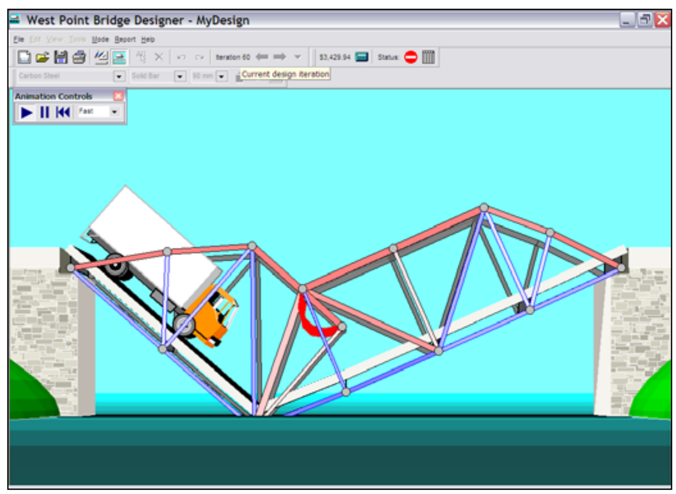


Figure B4. *Computer bridge failure from buckling.*

Note. If a member has too much compressive force for its strength, it will buckle.

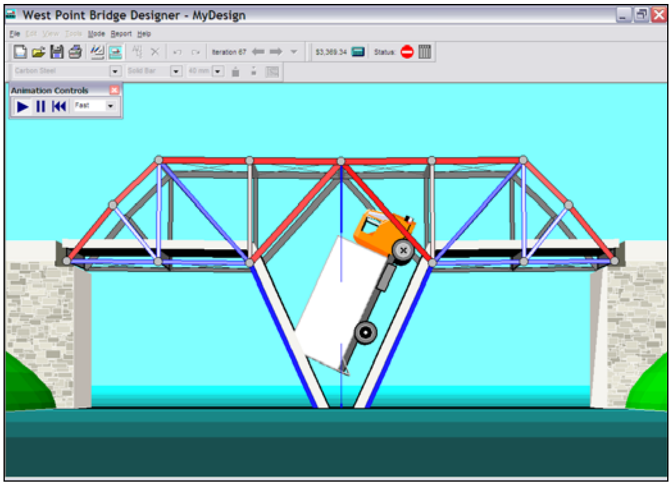


Figure B5. *Computer bridge failure from yielding.*

Note. If a member has too much tensile force for its strength, it will yield.

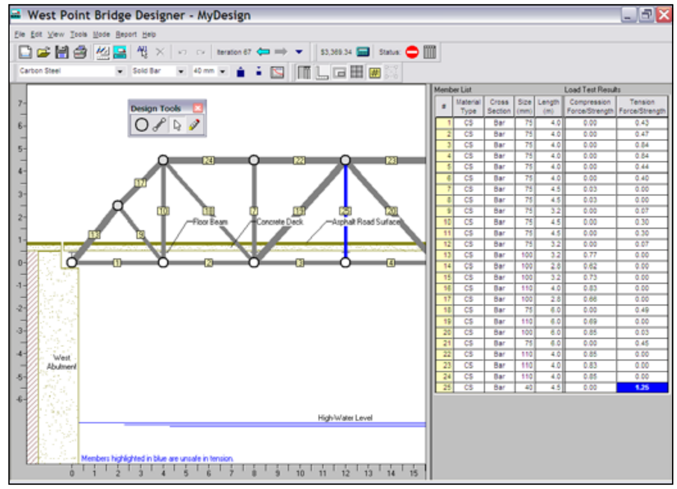


Figure B6. *Computer bridge with stresses and strengths displayed.*

Note. The blue color in the tabular data indicates that the force to strength ratio was greater than one, causing the member to fail.

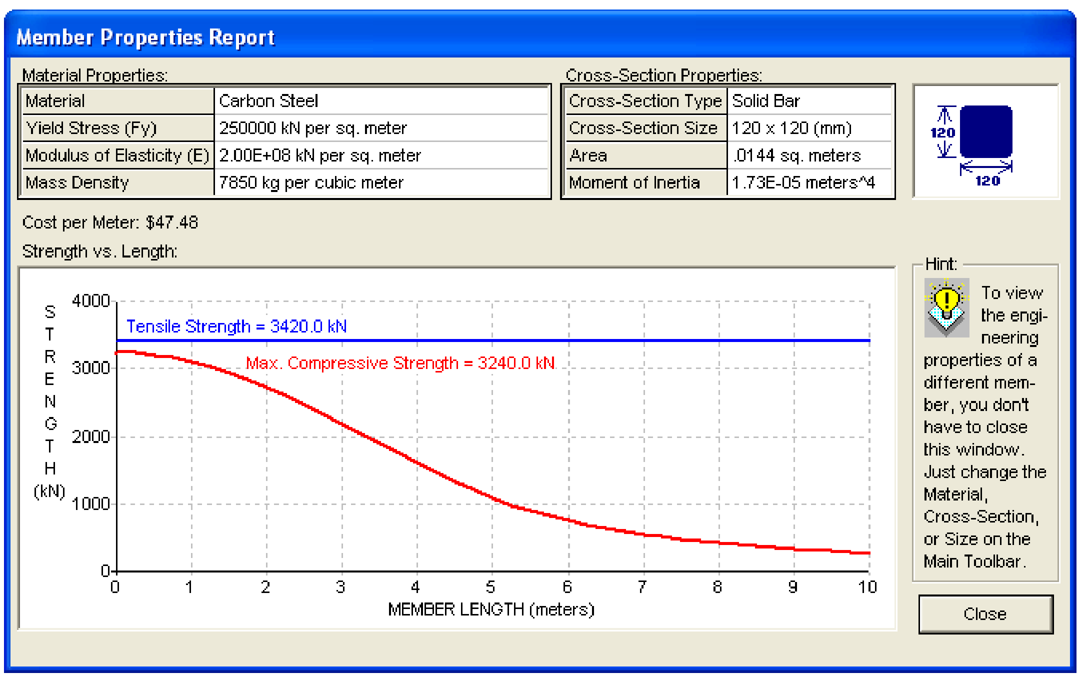


Figure B7. *The computer bridge produces member properties reports.*

Note. The chart displays tension and compressive concepts, such as decreasing compressive strength as length of a member increases.

Load Test Results Report (Design Iteration #57)

#	Member Size	Section	Matl.	Length (m)	Compr. Force (kN)	Compr. Strength (kN)	Status	Tension Force (kN)	Tension Strength (kN)	Status
1	75 x 75	Bar	CS	4.0	0.0	257.6	OK	569.1	1335.9	OK
2	75 x 75	Bar	CS	4.0	0.0	257.6	OK	630.7	1335.9	OK
3	40 x 40	Bar	CS	4.0	0.0	20.8	OK	1121.5	380.0	**Yields**
4	75 x 75	Bar	CS	4.0	0.0	257.6	OK	1121.5	1335.9	OK
5	75 x 75	Bar	CS	4.0	0.0	257.6	OK	592.8	1335.9	OK
6	75 x 75	Bar	CS	4.0	0.0	257.6	OK	535.1	1335.9	OK
7	75 x 75	Bar	CS	4.5	5.9	203.6	OK	0.0	1335.9	OK
8	75 x 75	Bar	CS	4.5	5.9	203.6	OK	0.0	1335.9	OK
9	75 x 75	Bar	CS	3.2	0.0	402.2	OK	98.6	1335.9	OK
10	75 x 75	Bar	CS	4.5	0.0	203.6	OK	401.1	1335.9	OK
11	75 x 75	Bar	CS	4.5	0.0	203.6	OK	407.2	1335.9	OK
12	75 x 75	Bar	CS	3.2	0.0	402.2	OK	92.5	1335.9	OK
13	100 x 100	Bar	CS	3.2	911.1	1177.8	OK	0.0	2375.0	OK
14	100 x 100	Bar	CS	2.8	838.4	1357.6	OK	0.0	2375.0	OK
15	100 x 100	Bar	CS	3.2	856.5	1177.8	OK	0.0	2375.0	OK
16	110 x 110	Bar	CS	4.0	980.8	1181.2	OK	0.0	2873.8	OK
17	100 x 100	Bar	CS	2.8	892.0	1357.6	OK	0.0	2375.0	OK
18	75 x 75	Bar	CS	6.0	0.0	113.7	OK	656.5	1335.9	OK
19	110 x 110	Bar	CS	6.0	362.4	526.2	OK	11.2	2873.8	OK
20	100 x 100	Bar	CS	6.0	305.2	359.4	OK	68.5	2375.0	OK
21	75 x 75	Bar	CS	6.0	0.0	113.7	OK	599.5	1335.9	OK
22	110 x 110	Bar	CS	4.0	1004.8	1181.2	OK	0.0	2873.8	OK
23	110 x 110	Bar	CS	4.0	980.8	1181.2	OK	0.0	2873.8	OK
24	110 x 110	Bar	CS	4.0	1004.8	1181.2	OK	0.0	2873.8	OK
25	50 x 50	Bar	CS	4.5	0.0	40.2	OK	475.8	593.8	OK

Close

Figure B8. *Load test results for a computer bridge design.*

Note. This is and other tabular information is available to the user under the report menu.

Cost Calculations Report (Design Iteration #108)

Type of Cost	Product	Cost Calculation	Cost
Material Cost	Carbon Steel Bars	(1767.9 kg) x ($0.42 per kg) =	$742.52
	Carbon Steel Tubes	(1214.9 kg) x ($0.63 per kg) =	$765.40
	High Strength Steel Bars	(0.0 kg) x ($0.48 per kg) =	$0.00
	High Strength Steel Tubes	(0.0 kg) x ($0.72 per kg) =	$0.00
	Quenched & Tempered Steel Bars	(0.0 kg) x ($0.70 per kg) =	$0.00
	Quenched & Tempered Steel Tubes	(0.0 kg) x ($1.06 per kg) =	$0.00
Connection Cost		(14 Joints) x ($25.00 per Joint) =	$350.00
Product Cost	14 - 60 x 60 Carbon Steel Bars	($100.00 per Product) =	$100.00
	3 - 90 x 90 x 4 Carbon Steel Tubes	($100.00 per Product) =	$100.00
	8 - 160 x 160 x 8 Carbon Steel Tubes	($100.00 per Product) =	$100.00
Total Cost			$2,157.92

Close

Figure B9. *Cost calculations for a computer bridge design.*

Note. Without understanding how the bridge costs are calculated, it may be difficult to design a low cost bridge.

Appendix C: Tension and Compression Concepts

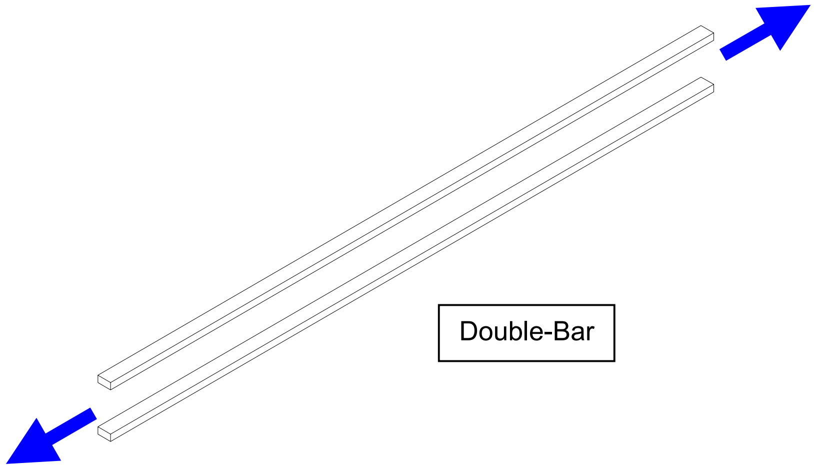


Figure C1. *Example of a solid member under tension.*

Note. Both the computer bridge and truss model incorporate tension and compression concepts. Unlike with a balsawood truss, when a load is applied to a paper truss, it will be obvious if a double bar member is under tension. The concepts of tension and compression were not presented to teams; rather, it was up to them whether or not they learned the concepts from the computer bridge and applied them to their truss model. When made of card stock, double-bars have little or no compressive value.

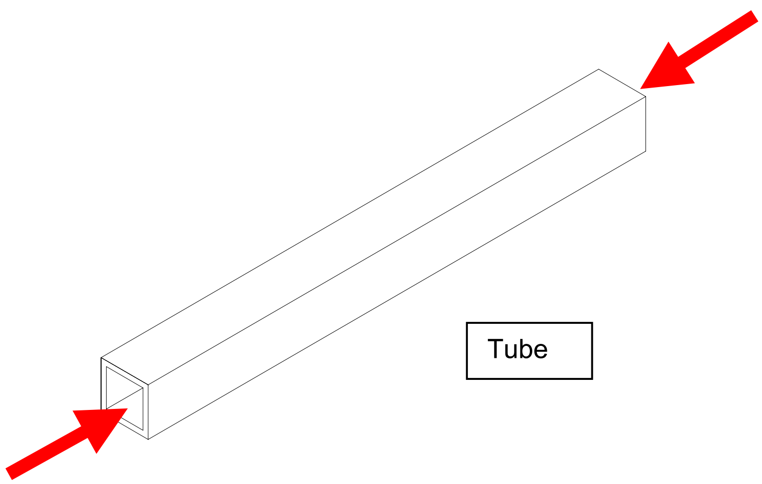


Figure C2. *Example of a hollow member under compression.*

Note. Tubular card stock members have good compressive strength. According to Ressler (2002), file folder members, which are similar to card stock members, model the concept of a steel bridge very well.

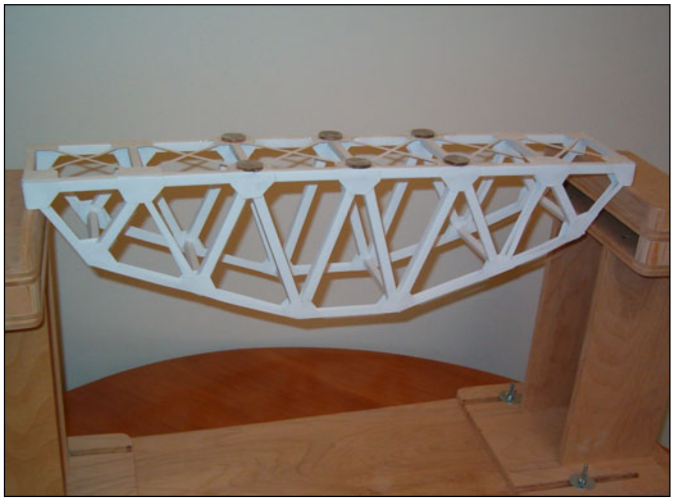


Figure C3. *Card stock bridge with no extra load applied.*

Note. Quarters are placed on the roadbed, so that forces are applied to the three middle joints. In classroom settings, bridges are sometimes incorrectly loaded along the entire top or bottom chord. For a truss bridge, the loads should always be applied at the joints (D. Agudelo, personal communication, Summer, 2004).

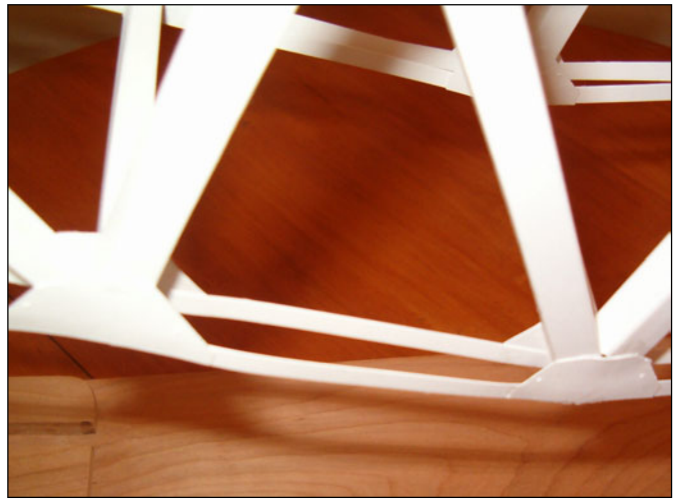


Figure C4. *Double-bars under no load.*

Note. The double bars are not parallel, indicating that they are slack (see below for their appearance under load).

Figure C5. *Card stock bridge with static load applied.*

Note. The books loaded on the bridge in the photo have a mass of approximately 5 kg.

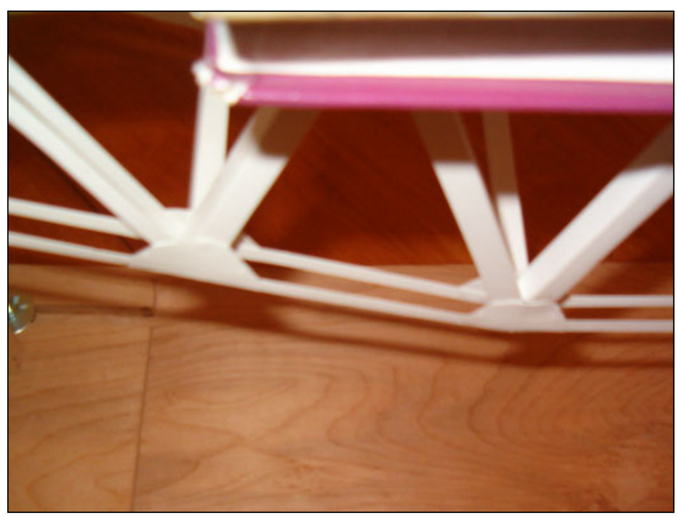


Figure C6. *Double-bars under load.*

Note. The double bars are parallel, indicating that they are now taut. This concept is impossible to see or model with a balsawood truss or bridge.

Appendix D: Typical First-Year Engineering Curriculum

First Semester

CHEM 1074: General Chemistry for Engineers	(3)
CHEM 1084: General Chemistry Lab for Engineers	(1)
ENGE 1024: Engineering Exploration	(2)
ENGL 1105: Freshman English	(3)
MATH 1205: Calculus I	(3)
MATH 1114: Linear Algebra	(2)
Core Curriculum Elective	(1-3)
Credits	**(15-17)**

Second Semester

(Total recommended course load is 15-18 credits. Students interested in degree programs requiring only 14 credits should consider selecting a course from Area 2 or Area 3 of the University Core Curriculum.)

ENGL 1106: Freshman English	(3)
MATH 1206: Calculus II	(3)
MATH 1224: Vector Geometry	(2)
PHYS 2305: Foundations of Physics I	(4)
Students interested in Computer Engineering or Electrical Engineering:	
ENGE 1104: Exploration of the Digital Future	(2)
ECE 1574: Programming and Problem Solving for EEs and CPE's	(3)
Students interested in Aerospace Engineering, Biological Systems Engineering, Chemical Engineering, Civil & Environmental Engineering, Engineering Science & Mechanics, Industrial & Systems Engineering, Materials Science & Engineering, Mechanical Engineering, Mining & Minerals Engineering, and Ocean Engineering:	
ENGE 1114: Exploration of Engineering Design	(2)
Students interested in Chemical Engineering should also take:	
CHEM 2114: Analytical Chemistry	(3)
CHEM 2124: Analytical Chemistry Lab	(1)

Appendix E: Team Temperament Compositions

Table E1
Team Temperament Composition

Team Temperament	*n*	%
NF ● NF	1	1.0
NF ● SJ	4	4.0
NF ● SP	2	2.0
NT ● SJ	5	5.1
SJ ● SJ	12	12.1
SJ ● SP	10	10.1
NF ● NF ● NT	1	1.0
NF ● NT ● NT	1	1.0
NF ● NT ● SJ	3	3.0
NF ● SJ ● SJ	7	7.1
NF ● SJ ● SP	2	2.0
NT ● SJ ● SJ	1	1.0
NT ● SJ ● SP	3	3.0
SJ ● SJ ● SJ	10	10.1
SJ ● SJ ● SP	4	4.0
SJ ● SP ● SP	2	2.0
NF ● NF ● NF ● NT	1	1.0
NF ● NF ● SJ ● SJ	1	1.0
NF ● NF ● SJ ● SP	1	1.0
NF ● NT ● SJ ● SJ	1	1.0
NF ● NT ● SJ ● SP	1	1.0
NF ● SJ ● SJ ● SJ	5	5.1
NF ● SJ ● SJ ● SP	3	3.0
NF ● SJ ● SP ● SP	1	1.0
NT ● SJ ● SJ ● SJ	3	3.0
SJ ● SJ ● SJ ● SJ	8	8.1
SJ ● SJ ● SJ ● SP	5	5.1
SJ ● SJ ● SP ● SP	1	1.0
Total (*N*)	99	100.0

NF = Intuitive Feeling
NT = Intuitive Thinking
SJ = Sensing Judging
SP = Sensing Perceiving

Appendix F: Letter to the Engineering Education Faculty

Confidential Information for ENGE Instructors

8-17-04

Dear ENGE Instructor,

Since this past May, I have named the research study the *Engineering Challenge Workshop*. As you distribute the flyer for the workshop to your students, please read them the announcement for the workshop/study. The flyers for the workshop will be available in the main office (please distribute/announce to your sections on Monday, 8/30 and/or Tuesday, 8/31). In order to keep communication consistent with students, regardless of their 1024 instructor, it is important ***not*** to answer students' specific questions on the *Engineering Challenge Workshop*. Instead, please refer them to the information/registration site (www.ec.tandl.vt.edu) that describes the study and also includes a FAQ page in which students may submit additional questions.

It is important that ENGE students do ***not*** know the following:

1. Any information on the engineering design problem that will be presented to them at the workshop.
2. It is important that ***no*** information be given on the specific alternative activity, until after the workshop. That is, the alternative activity may have similar content to the engineering design problem presented at the research study. The alternative activity will be posted to Blackboard on Monday, October 25th (due for check off on 11/1 or 11/2).
3. What the study specifically investigates: "Do teamwork exercises promote technological problem solving with engineering design activities?"
4. That the study is an experimental design, involving treatment and control groups.
5. Please do ***not*** use the term 'teams' (please use small groups instead).
6. Please do ***not*** give out my name or my e-mail. I will respond to student questions by adding answers to the FAQ page in October.

Keeping the above restrictions in mind, please mention the following to the students:

1. You will be solving "hands on" engineering problems.
2. I think the *Engineering Challenge Workshop* will be a valuable learning experience.
3. The alternative activity will be like other classroom assignments, requiring approximately the same amount of time as the engineering challenge to complete.

While student participation incentives may be helpful, the enthusiasm with which you announce the study will be what leads to a good "turn out" on October 23rd. Therefore, your time and effort in promoting the study is greatly appreciated.

Sincerely,

Mark Springston

Appendix G: Study Announcement Read by Engineering Faculty

Student Announcement for the *Engineering Challenge Workshop*

[As your read the announcement below, please distribute one workshop flyer to each of your ENGE 1024 students. Please make the announcement and distribute the flyers on August 30th and 31st, so all sections receive the information on the same dates.]

"The flyer I am distributing is for the *Engineering Challenge Workshop,* which is a research study supported by the Department of Teaching and Learning at Virginia Tech. The research study investigates small groups (4 or less per group) solving "hands on" technological problems using engineering design activities. The *Engineering Challenge* is limited to engineering freshmen at Virginia Tech. The *Engineering Challenge* is on Saturday, October 23rd, from 9:00 am to 5:00 pm. If you are a participant in the *Engineering Challenge*, you and your group will be presented with engineering problems in which you design solutions. The specific engineering problems for your group will be announced at the *Engineering Challenge Workshop*.

The *Engineering Challenge Workshop* or alternative activity is 2% of your course grade. Both the *Engineering Challenge* and alternative activity will require approximately the same amount of time to complete. The alternative activity will be like other classroom assignments. If you are unable to attend the *Engineering Challenge*, or decide the workshop is *not* for you, then the alternative activity will be posted to Blackboard on the morning of October 25th. Information on the alternative activity will *not* be available before October 25th.

You will *not* be penalized in any way if you decide *not* to be a participant in the *Engineering Challenge*. If you are registered for the *Engineering Challenge*, then it is important that you keep your commitment to attend and arrive on time. If you want to register for or obtain more information on the *Engineering Challenge Workshop*, please visit www.ec.tandl.vt.edu. After reading through the site, if you have additional questions, you should submit them with the link from the FAQ page."

Appendix H: Research Flyer Distributed by Engineering Faculty

*Note***.** This flyer was printed on high quality blue paper. Original flyer has been reduced by approximately 25 to 30% to fit on the page below. Each student received one flyer.

E^c Challenge workshop

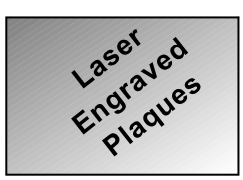
Engineering

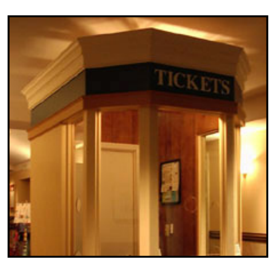
Don't miss this "hands on" opportunity to apply your engineering skills and knowledge.

- Design solutions to engineering problems
- Top 2 design groups win Pocket PCs
- Plaques for the top 6 design groups
- free movie ticket and key lanyard
- Pizza lunch and snacks
- Meet other people in your major
- Include the experience on your resume
- Register early—workshop space is limited
- Registration starts August 31st at 6:00 pm

Workshop is Saturday, October 23rd 9:00 to 5:00

Check it out today by visiting
www.ec.tandl.vt.edu





Appendix I: Electronic Communication with Participants

Note 1
Sept. 28th:

Subject: EC Workshop Important information

We currently have you registered for the Engineering Challenge (EC) Workshop on Saturday, October 23rd, from 9:00 am to 5:00 pm.

To participate in the EC workshop you must be available for all of the hours on October 23rd.

Are you available on October 23rd?
We hope you are available, but if you are NOT available on October 23rd, please submit your e-mail at the "EC workshop withdrawal" link today at www.ec.tandl.vt.edu. There is NO penalty for withdrawing and you can still complete the *alternative activity* assignment.

How old will you be on October 23rd?
If you are NOT 18 as of October 23rd, 2004, then you must withdraw from the workshop: www.ec.tandl.vt.edu. You will need to complete the *alternative activity* assignment. We have received an overwhelming response of interested participants and Virginia Tech requires that minors receive parental consent to be in any research investigation. The extra paperwork that parental consent requires will not be possible with the EC workshop. We appreciate your interest, but you must withdraw today at www.ec.tandl.vt.edu, using the "EC workshop withdrawal" link.

We will let you know by this Friday if there is space for you in the workshop.

Thank you for your interest in the EC workshop,

EC Workshop Staff

Please do NOT respond directly to this e-mail. If you have a question, please submit it on the FAQ page at www.ec.tandl.vt.edu.

Note 2
Oct. 1:
Subject: Welcome to the EC Workshop (Research Study)

Welcome to the Engineering Challenge (EC) Workshop. There is room for you in the workshop. We are glad you have decided to participate.

We will send out several informational updates in October. It is important that you read all informational notices.

On Monday, Oct. 11th, you will receive an e-mail with a "confirm link." You must click the link and enter your e-mail by Thursday, Oct. 14th.

If you become unavailable for October 23rd between now and October 11th, please withdraw at www.ec.tandl.vt.edu.

We look forward to seeing you on October 23rd,

EC Workshop Staff

Please do NOT respond directly to this e-mail. If you have a question, please submit it on the FAQ page at www.ec.tandl.vt.edu.

Note 3:
Oct. 1:
Subject: EC Workshop Waiting List (Research Study)

We received an overwhelming response of interested participants in the EC workshop. Unfortunately, at this point there is NOT enough space for you in the EC workshop. Registration was on a "first come—first served" basis.

You can complete the *alternative activity*, which will be announced during class on October 25th and 26th. It will require the same amount of time as the EC workshop to complete. The *alternative activity* is similar to any other classroom assignment. It is NOT any more difficult, and it will NOT be graded any more stringently.

We have currently placed you on a waiting list for the EC workshop. If you want to remain on the waiting list, you do NOT need to do anything.

If you want to be REMOVED from the waiting list, please submit your e-mail at the "EC workshop withdrawal" at www.ec.tandl.vt.edu.

Thank you for your interest in the EC workshop,

EC Workshop Staff

Note 4
Oct. 11:
Subject: EC Workshop Confirm Link

We are glad you have decided to participate in the EC workshop. We have exciting "hands-on" activities planned. In order to participate, you must be able to attend from 9:00 am to 5:00 pm on Saturday, October 23rd. There will also be a short on-line survey (20 minutes) that is emailed out on Monday, October 25th.

In order to finalize your commitment to attend on Saturday, October 23rd, please use the link below to go to the final registration form.

EC Workshop Final Confirm

After final confirmation, you should have a good reason (e.g., doctors illness note, not "I overslept") for not showing up on Saturday, October 23rd.

You must confirm by this Thursday, October 14th, or you will NOT be allowed to participate. We will contact someone on the "waiting list" to take your place.

After final confirmation close, additional information will be sent out to you. Be sure to check your e-mail next week.

We look forward to seeing you on October 23rd,

EC Staff

Please do NOT respond directly to this e-mail. If you have a question, please submit it on the FAQ page at www.ec.tandl.vt.edu.

Note 5 [repeat every time it is necessary to go into the wait list]
Oct. 11:
Subject: EC Workshop Space Available

A couple of students said they will not be able to attend the EC workshop. You were not far down on the waiting list, so you may now participate.

We have exciting "hands-on" activities planned for the workshop. In order to participate, you must be able to attend from 9:00 am to 5:00 pm on Saturday, October 23rd. There will also be a short on-line survey (20 minutes) that is emailed out on Monday, October 25th.

In order to finalize your commitment to attend on Saturday, October 23rd, please use the link below to go to the final registration form.

EC Workshop Final Confirm

After final confirmation, you should have a good reason (e.g., doctors illness note, not "I overslept") for not showing up on Saturday, October 23rd.

You must confirm by this Thursday, October 14th, or you will NOT be allowed to participate. We will contact someone on the "waiting list" to take your place.

After final confirmation close, additional information will be sent out to you. Be sure to check your e-mail next week.

We look forward to seeing you on October 23rd,

EC Staff

Note: If the final confirm link above does not work, paste this link directly into the address bar of your web browser:
https://survey.vt.edu/survey/entry.jsp?id=1097331795573

Please do NOT respond directly to this e-mail. If you have a question, please submit it on the FAQ page at www.ec.tandl.vt.edu.

Note 6

Oct. 20:
Subject: Final Reminder

The EC Workshop is this Saturday, October 23rd, starting promptly at 9:00 am. Make sure you download and follow the instructions that are available on the EC Site main page: www.ec.tandl.vt.edu. Remember to bring an umbrella, if it looks like rain.

We look forward to seeing you on Saturday,

EC Staff

Note 7
Nov. 4:
Subject: EC Workshop Space Available
Important, Final Requirement

EC Workshop Participant:

Thank you for participating in the EC Workshop on October 23rd.

FINAL EC PARTICIPATION REQUIREMENT
The final participation requirement is an on-line personality survey (*Keirsey Sorter*). The survey and report normally cost $15.00, but as an ECW participant there is no charge to you. The survey requires only approximately 15 minutes to complete.

Please complete the survey by **12 midnight on Sunday, November 7th**, because we will submit final participation credit to your ENGE instructor next week.

SURVEY (KEIRSEY SORTER) INSTRUCTIONS
Please follow these instructions carefully:

Important Note: ***Once you log in,*** **you must answer all multiple-choice questions on the survey (*Keirsey Sorter*);** you **cannot** return at a later time to answer more questions. It is better to complete the survey when you are free from distractions. ******** Even though advisorteam.com states you can skip some questions**, ANSWER ALL QUESTIONS** or you will NOT receive an accurate personality report. *********

1. Click here for the Login Page: http://www.advisorteam.com/groups/credit.asp
2. Enter your unique *password credit number*: **[password credit]**
   If you experience technical difficulties with the survey or password credit, please submit your problem through the ECW FAQ page: http://www.ec.tandl.vt.edu/html/FAQ.htm Remember to include your e-mail, so we can respond to your problem.
3. *First Name*: Enter your first name
4. **Important**, **Instead of your *Last Name*: Enter your VT e-mail: [student e-mail]**
5. Click the *Keirsey Temperament Sorter II* button.
6. Answer **all** multiple choice questions
   The only way to receive an accurate personality report is to answer all of the questions honestly.
7. Click the "*finish*" button to submit your responses.

REPORT INFORMATION
After clicking the "finish" button, you will instantly receive an individualized personality report describing the strengths of your personality. You may return to this report as many times as you like by visiting: http://www.advisorteam.com/groups/credit.asp and entering: **[password credit]**.

After completing the survey (Keirsey Sorter), we will let your ENGE 1024 instructor know that you have met all participation requirements for full credit (2%) in the EC workshop.

Awards
If your group won an award (Pocket PC and/or plaque), you will be notified via e-mail to pick up your award in the ENGE main office. All awards will be delivered the week of November 29^{th}.

We wish you good luck in wrapping up the semester,

EC Staff

Please do not respond directly to this e-mail. Use the EC FAQ page to submit a problem or question: http://www.ec.tandl.vt.edu/html/FAQ.htm

Award Notes
First and Second Place Note
Subject: *Engineering Challenge* Award

Congratulations, your team came in [1st place or 2^{nd} place] in the *Engineering Challenge*. The event was very competitive. With 99 teams participating in the *Engineering Challenge*, this is an outstanding achievement.

You may pick up your 1st place plaque and pocket pc in the Main ENGE Office in room 332 Randolph Hall. Please pick up your awards this Monday or Tuesday. The main office staff is usually available from 8:00 am to 4:30 pm. You must present your VT photo ID to pick up your awards.

Neither *Engineering Challenge* Staff nor the ENGE department is able to provide technical support for your new pocket pc. If you experience problems with your pocket pc, please take advantage of the manufacturer's warranty.

Once again, congratulations on your achievement and we hope you enjoy your award.

Sincerely,

Mark Springston
ECW Coordinator

Third Through Sixth Places
Subject: *Engineering Challenge* Award

Congratulations, your team came in [3^{rd}, 4^{th}, 5^{th}, or 6^{th}] place in the *Engineering Challenge*. The event was very competitive. With 99 teams participating in the *Engineering Challenge*, this is an outstanding achievement.

You may pick up your plaque in the Main ENGE Office in room 332 Randolph Hall. Please pick up your plaque this Monday or Tuesday. The main office staff is usually available from 8:00 am to 4:30 pm. You must present your VT photo ID to pick up your award.

Once again, congratulations on your achievement and good luck with all your endeavors at Virginia Tech.

Sincerely,

Mark Springston
ECW Coordinator

Appendix J: Information for Participants Prior to the Study

*Note***.** The information flyer was made available through the registration web site. Original flyer has been reduced by approximately 25 to 30% to fit on the page below.

EC Workshop Saturday, October 23 - 1 -

Information for EC Workshop (Research Study), Saturday, October 23rd

We are glad you have decided to join us this Saturday. Please read the following carefully.

Some groups may finish their design project and exit survey a few minutes early Saturday afternoon, while others may need a few extra minutes. It is important that you finish both. We ask that you be flexible on the ending time. In case your group needs some extra time, please do not make plans for right after 5:00 on Saturday.

The morning orientation this Saturday in Litton Reaves will take approximately 15 minutes. In order that the day runs smoothly throughout, it is important that you listen to research assistants when they are giving instructions. Make sure you read and follow the instructions below.

What to Bring

You must bring the following items to the workshop to participate.

You must have your Passport ID to participate. *Have your ID out to present at the front doors of Litton Reaves.*

Laptop with fully charged battery. *Make sure you charge it Friday evening.*

The AC adapter for your laptop. *Don't forget this.*

Your book bag OR laptop case. Please leave your laptop in your book bag, until instructed otherwise.

What to Do

Make sure you have the following on your laptop computer for Saturday.

Make sure MS office is loaded on your laptop.

Place a short cut to the calculator that comes with XP on your desktop. Hand calculators are NOT allowed.

Make sure you label your book/laptop bag with your first and last name, so it is easily recognizable.

What NOT to bring

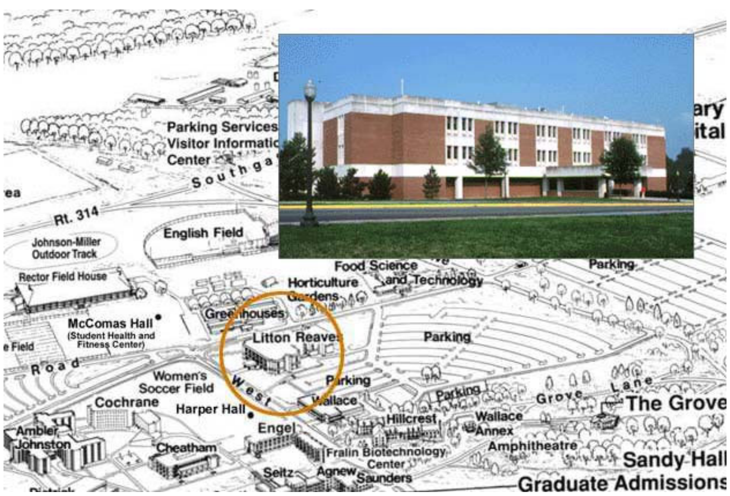
Make sure you DON'T bring any of the following:

Since the EC workshop is also a research study, do not bring any recording devices.

To keep the competitive events fair, you will be asked not to use your cell phone during the workshop. Let your "callers" know in advance that you will give return calls on Saturday evening. *If you feel uncomfortable without your cell phone, bring it in your book bag. Leave the ringer off.* Visitors are NOT allowed at the workshop.

Do not bring an external mouse. You must use the built in mouse or touch pad on your laptop.

The workshop starts **promptly at 9:00 a.m. Doors open at 8:50 a.m.** If you are late, there is the possibility that you will not be allowed to participate.



We look forward to seeing you at the EC workshop this Saturday.

Appendix K: MacGyver Box Tools and Materials

ENGE 1024
MacGyver Tool Box Contents

In tray:
(1) 9V hi-speed motor
(1) 9V hi-torque motor
(1) film canister containing:
- (3) jumbo paper clips
- (2) large safety pins
- (2) thumb tacks
- (2) #6 x 5/8 FH wood screws
- (3) #6 x 1/2 PH machine screws
- (2) #8 x 3/4 PH machine screws
- (4) 5/8 nails
- (2) 5/8 brads
- (2) 1-1/4 4d nails

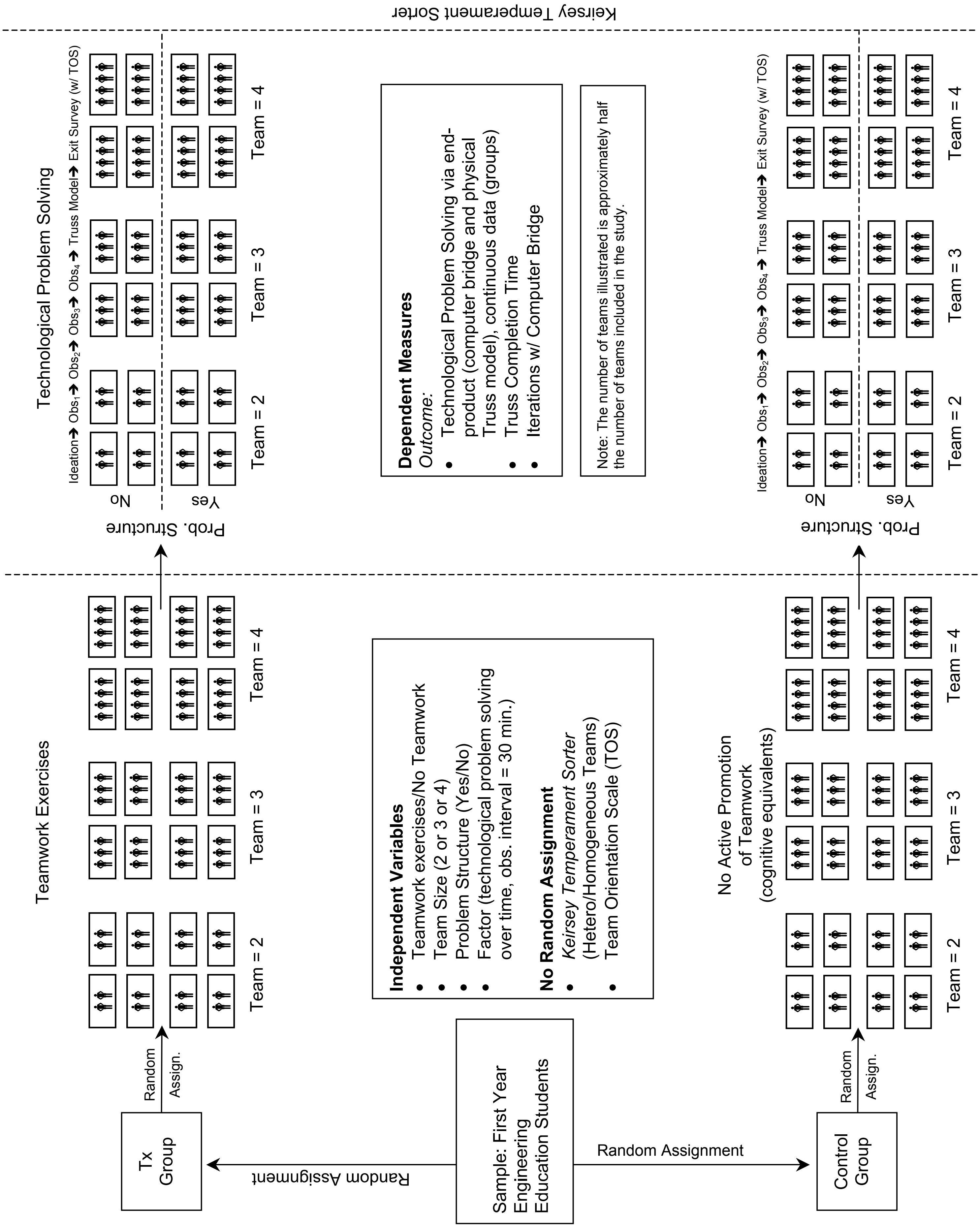
(1) zip-lock bag containing:
- (2) playing cards
- (2) 5” propellers (two blade)
- (2) round balloons
- (2) spring-type mouse traps
- (1) medium binder clip
- (2) 2-1/2” axle rods
- (2) clothes pins
- (1) 1” spring
- (4) medium rubber bands
- (1) 9V battery clip (T-type)
- (1) set of 24” pos/neg wires with alligator clips at both ends

(1) square center round toothpicks, box of 250
(3) Pitsco 1-1/2” plastic wheels
(1) Pitsco 1-1/2” Metric 500 plastic wheel
(1) axle rod
(8) flex staws
(4) AA batteries
(1) AA battery pack w/ 9V connector
(2) 9V batteries
(2) standard pencils, unsharpened
(15) craft sticks
(1) half length of hack saw blade
(4) #20 biscuits
(2) 8” plastic cable straps, colored
(2) 7-1/2” plastic cable straps, clear
(1) 7-7/8” plastic cable strap, black
(3) 5-1/2” plastic cable straps, clear
(3) 4” plastic cable straps, clear
(2) 4” plastic cable straps, colored
(4) #6-32 x 2” PH machine screws

(7) #6-32 nuts
(7) #6 washers

In box bottom:
(2) 1/16 DIA x 21” rods w/ orange flag at one end, bent in middle to fit in box
(1) rag
(1) plastic bag
(1) vinyl tubing, 1/4” o.d. x 13-1/2”
(1) angled aluminum flashing, 3”x4”x7”
(4) paint stirring sticks
(1) PVC pipe, 3/4” i.d. x 6-5/8”
(1) 2x4 block, 3”
(1) rubber cement, 4oz jar
(1) 6” adjustable wrench
(1) dowel rod, 1/4” x 9-1/4”
(1) 5 pc. tool set w/ plastic case (6” slip joint pliers, 8oz claw hammer, #2 x 3” Phillips screwdriver, 1/4” x 3” slotted screwdriver, 10’ x 1/2” tape measure)
(1) 12” flexible, non-skid steel rule w/ metric
(2) 9”x12” construction paper, colored

Appendix L: Conceptual Design of the Research Study



Appendix M: Random Assignment List

Table M1

Top 36 Participants Before Sorting Based on the Random Column

Serial[a]	N[b]	Room #	Team[c]	Member[d]	Org.[e]	Size[f]	Level i1[f]	Level i2[f]	Random[g]
s1	N1	334	11	i	A	2	2	1	601324
s2	N2	334	11	J	A	2	2	1	613624
s3	N3	212	12	i	A	2	1	1	856355
s4	N4	212	12	J	A	2	1	1	644591
s5	N5	134	13	i	B	3	2	1	472857
s6	N6	134	13	J	B	3	2	1	692162
s7	N7	134	13	K	B	3	2	1	57654
s8	N8	210	14	i	C	3	1	1	998570
s9	N9	210	14	J	C	3	1	1	524391
s10	N10	210	14	K	C	3	1	1	513994
s11	N11	320	15	i	D	4	2	1	759825
s12	N12	320	15	J	D	4	2	1	778218
s13	N13	320	15	K	D	4	2	1	107614
s14	N14	320	15	L	D	4	2	1	730119
s15	N15	204	16	i	D	4	1	1	672406
s16	N16	204	16	J	D	4	1	1	549426
s17	N17	204	16	K	D	4	1	1	607169
s18	N18	204	16	L	D	4	1	1	609330
s19	N19	209	17	i	E	2	2	2	181794
s20	N20	209	17	J	E	2	2	2	176148
s21	N21	240	18	i	E	2	1	2	495938
s22	N22	240	18	J	E	2	1	2	445029
s23	N23	120	19	i	F	3	2	2	714310
s24	N24	120	19	J	F	3	2	2	426575
s25	N25	120	19	K	F	3	2	2	611449
s26	N26	238	20	i	G	3	1	2	937515
s27	N27	238	20	J	G	3	1	2	494695
s28	N28	238	20	K	G	3	1	2	36943
s29	N29	220	21	i	H	4	2	2	357281
s30	N30	220	21	J	H	4	2	2	491211
s31	N31	220	21	K	H	4	2	2	555783
s32	N32	220	21	L	H	4	2	2	825816
s33	N33	232	22	i	H	4	1	2	750363
s34	N34	232	22	J	H	4	1	2	573679
s35	N35	232	22	K	H	4	1	2	658409
s36	N36	232	22	L	H	4	1	2	95277

[a]The serial number is the order the cards were stacked. [b]The N column is for the participant number. [c]Team numbers started at eleven, instead of one, to avoid the confounding variable of one being associated with "We're number one." [d]The member column is for the team member letter, which is I through L, depending on the team size. [e]Organizations were used for the teamwork exercises and control activities. An organization consisted of two teams of 2, two teams of 3, and two teams of size 4. Team members were with their team, within their organization, for the teamwork exercises and control activities. However, team members were not with their organizations for the technological problem solving tasks. [f]Teamwork, problem structure, and team size are for the three independent variables in which participants were randomly assigned. [g]Numbers were randomly generated with the spreadsheet function (=RAND()*(1,000,000-1)+1) and then pasted as values into this column.

Table M2

Top 36 Participants After Sorting Based on the Random Column

Serial[a]	N	Room #	Team	Member	Org.	Size	Level i1	Level i2	Random[b]
s1	N55	209	29	i	F	2	2	2	1224
s2	N192	320	75	J	A	4	2	1	11022
s3	N65	220	33	i	A	4	2	2	15910
s4	N286	232	106	J	G	4	1	2	19300
s5	N219	212	84	i	G	2	1	1	33967
s6	N297	216	111	i	E	4	1	1	34078
s7	N83	320	39	i	F	4	2	1	36170
s8	N28	238	20	K	G	3	1	2	36943
s9	N45	210	26	J	D	3	1	1	40708
s10	N149	134	61	i	F	3	2	1	43570
s11	N142	232	58	J	C	4	1	2	55647
s12	N7	134	13	K	B	3	2	1	57654
s13	N216	232	82	L	E	4	1	2	60891
s14	N280	238	104	K	F	3	1	2	62896
s15	N251	232	94	K	F	4	1	2	67072
s16	N114	134	49	J	E	3	2	1	71158
s17	N260	210	98	i	B	3	1	1	76427
s18	N153	210	62	J	G	3	1	1	85683
s19	N104	220	45	L	B	4	2	2	86748
s20	N144	232	58	L	C	4	1	2	89005
s21	N312	216	112	L	F	4	1	1	90433
s22	N305	216	111	K	E	4	1	1	90802
s23	N259	134	97	K	A	3	2	1	93121
s24	N49	320	27	K	E	4	2	1	95134
s25	N36	232	22	L	H	4	1	2	95277
s26	N204	120	79	J	C	3	2	2	96341
s27	N92	209	41	J	G	2	2	2	99320
s28	N66	220	33	J	A	4	2	2	105107
s29	N13	320	15	K	D	4	2	1	107614
s30	N281	220	105	i	G	4	2	2	110201
s31	N137	220	57	i	C	4	2	2	116064
s32	N129	240	54	i	H	2	1	2	116384
s33	N156	320	63	J	H	4	2	1	117739
s34	N69	232	34	i	A	4	1	2	117874
s35	N191	320	75	i	A	4	2	1	120859
s36	N304	216	110	K	D	4	1	1	128937

[a]The serial number, which is also the stack order of participant nametags, was the only row not sorted based on the random number. [b]All other rows were sorted ascending based on the random number column.

Figure M1. *Participant nametags stacked in random order.*

Note. Nametags 253 and above were marked with a blue tag that included the N number of that nametag, so that they were easily removed from the set, based on the number of participants who arrived the day of the study. Two research assistants had the responsibility of counting the number of participants as they entered with the hand counters and then removing any N number above the number of participants.

Figure M2. *Participant nametag with key lanyard.*

Note. Participants wore the nametags around their neck during the research study. Participants wrote their first name, so that team members would feel comfortable with one another. In the above photo, the team number is 112. The N number and S number were never referred to during the study, because they were for research purposes only.

Figure M3. *Research assistant nametag.*

Note. Research assistants and room proctors wore a red nametag to contrast with the white participant nametags. Research assistants were asked to wear a white shirt and jeans the day of the study, so that they were easily identifiable.

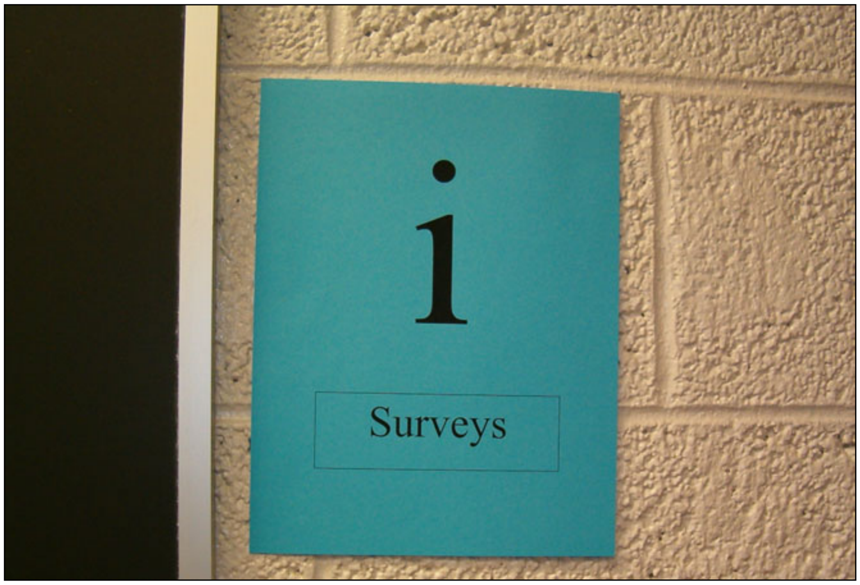


Figure M4. *Participants completed surveys based on their team member letter.*

Note. Based on the team member letters, teams separated from their former teammates to complete the exit surveys.

Appendix N: Computer Bridge Installation and Set Up

Software Installation Instructions

Place the blue card with your group's number on the back of the monitor for the bridge software.

Group

↑ Line even with the top of the monitor ↑
(visible when viewing the monitor)

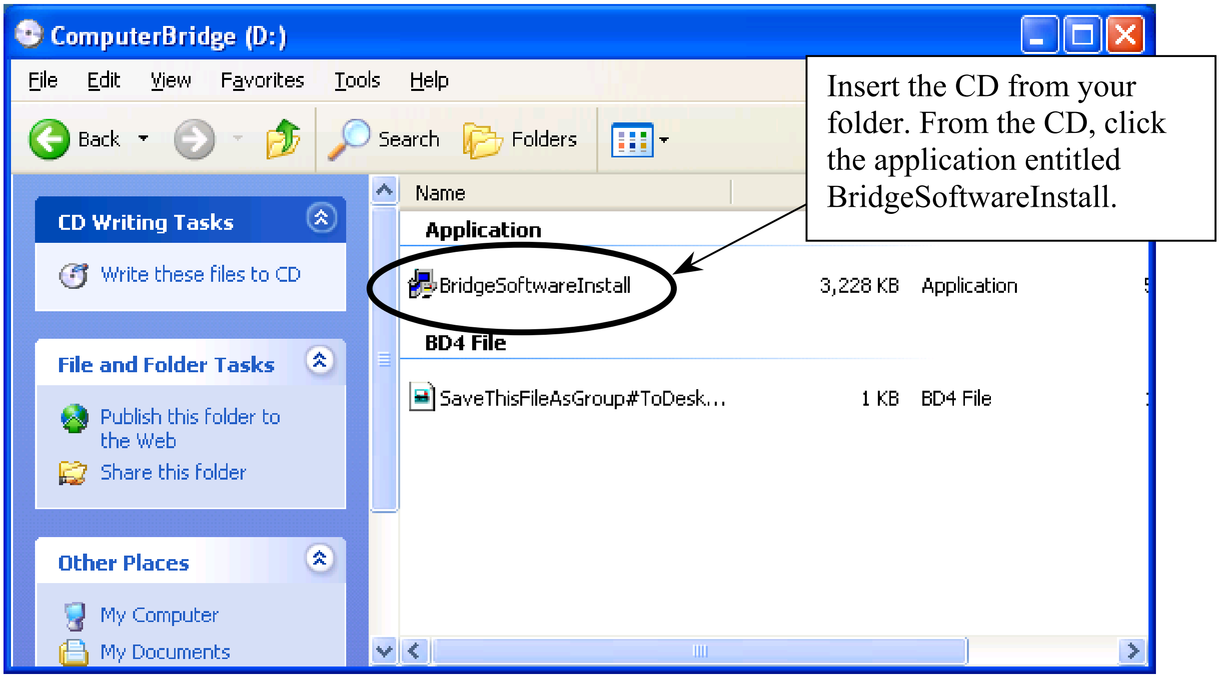
Removable Mounting Tabs x 4

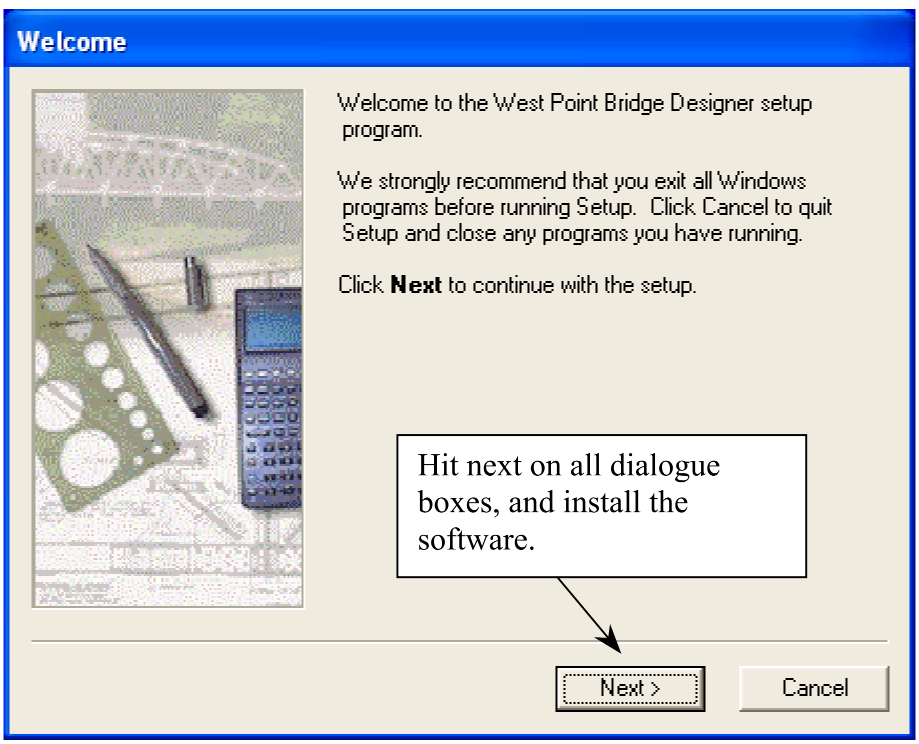
(Place on the laptop with the bridge software)

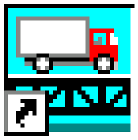
Group #

Removable Mounting Tabs x 4

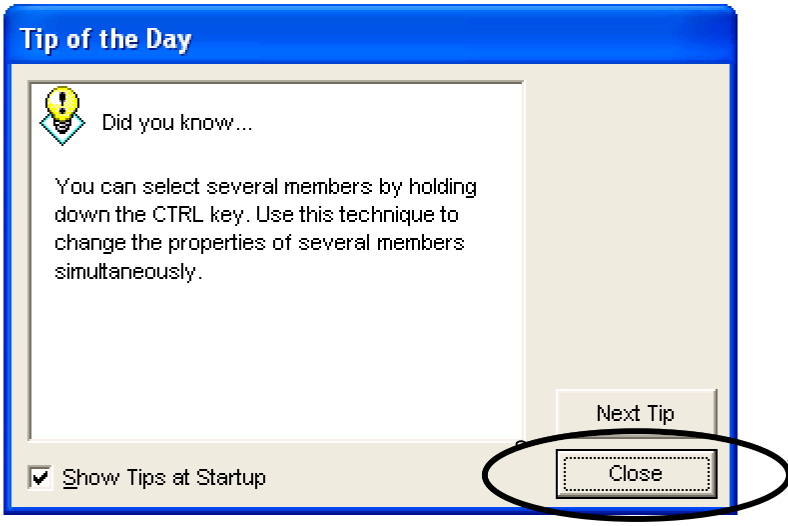
Make sure you follow the installation instructions below. There is important information on which files to use and open.


ComputerBridge (D:)
File Edit View Favorites Tools Help
Back Search Folders
CD Writing Tasks
Write these files to CD
File and Folder Tasks
Publish this folder to the Web
Share this folder
Other Places
My Computer
My Documents
Name
Application
BridgeSoftwareInstall 3,228 KB Application
BD4 File
SaveThisFileAsGroup#ToDesk... 1 KB BD4 File
Insert the CD from your folder. From the CD, click the application entitled BridgeSoftwareInstall.

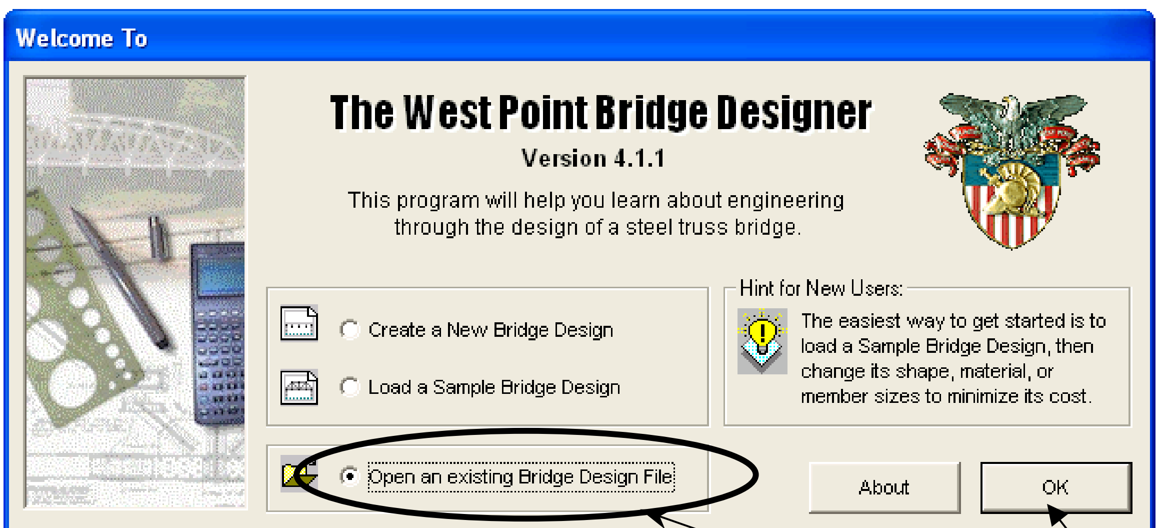

Welcome
Welcome to the West Point Bridge Designer setup program.
We strongly recommend that you exit all Windows programs before running Setup. Click Cancel to quit Setup and close any programs you have running.
Click Next to continue with the setup.
Hit next on all dialogue boxes, and install the software.
Next >
Cancel



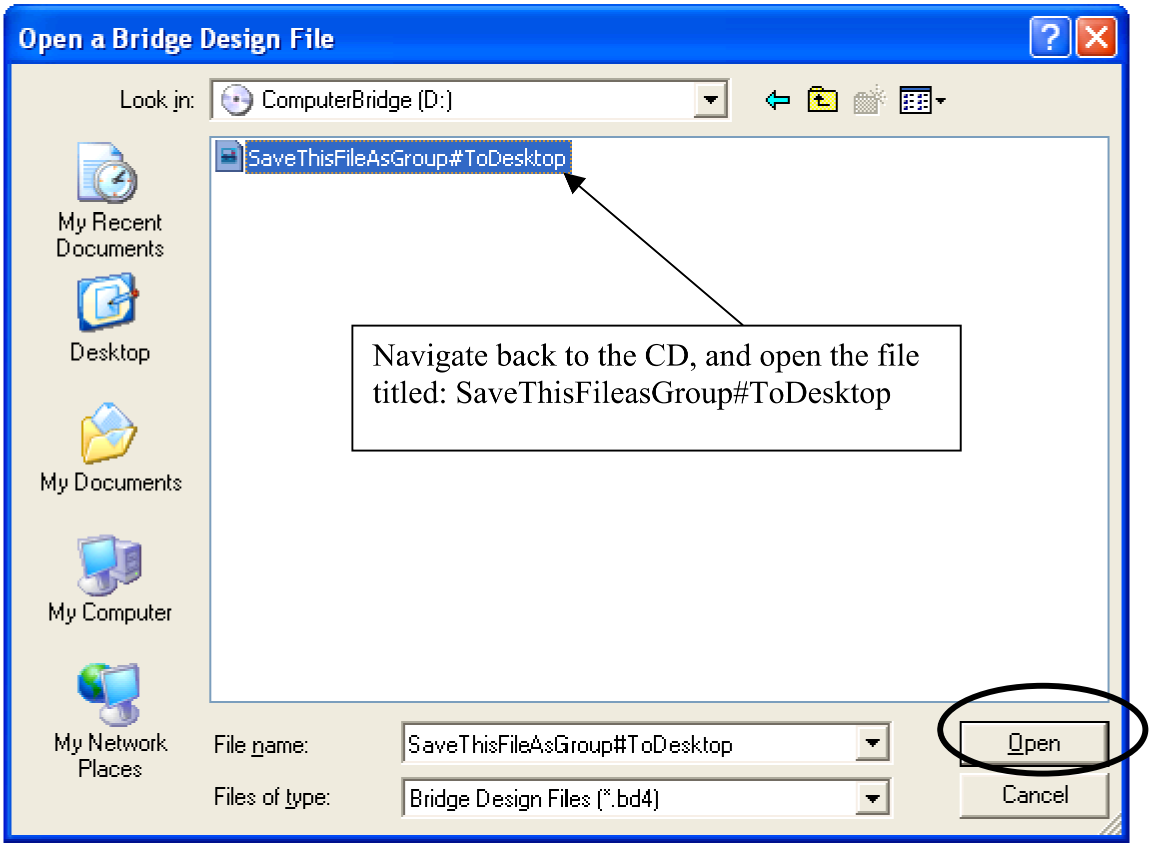
Launch the computer bridge shortcut that is placed on your desktop.



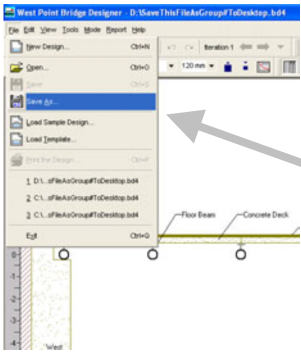
Skip the tips



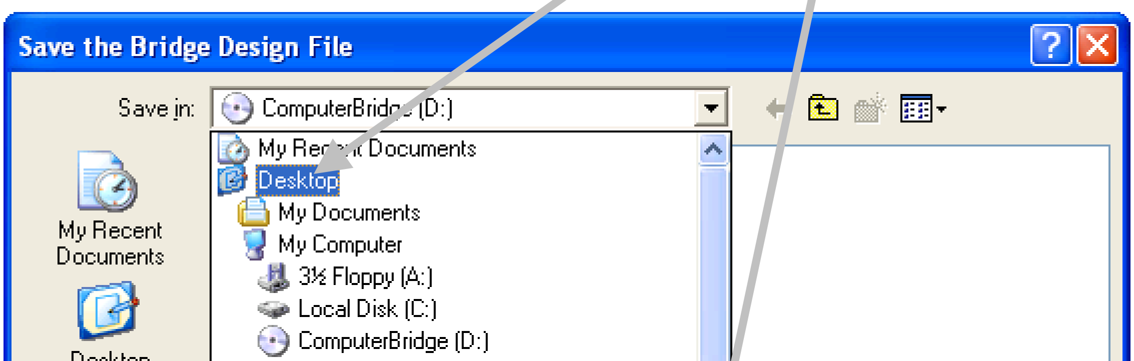
Select this and ok.

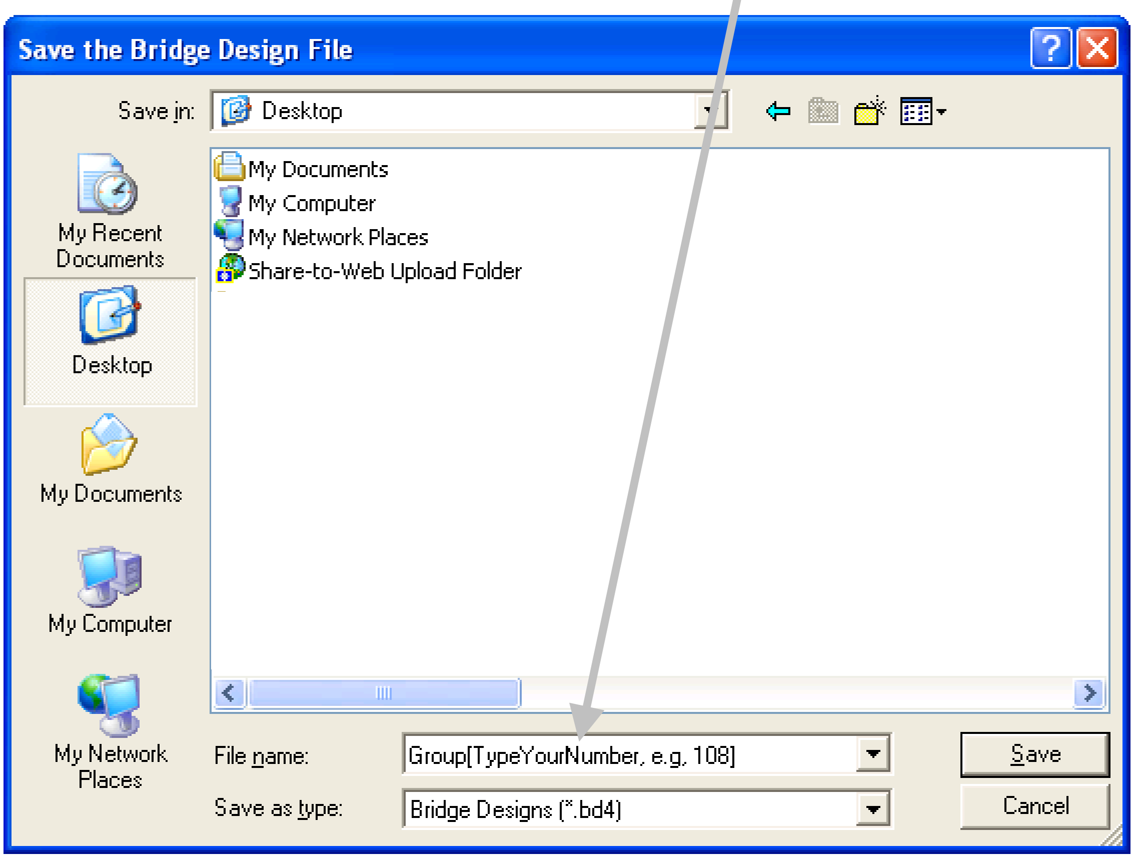

Open a Bridge Design File
Look in: ComputerBridge (D:)
SaveThisFileAsGroup#ToDesktop
My Recent Documents
Desktop
My Documents
My Computer
My Network Places
File name: SaveThisFileAsGroup#ToDesktop
Files of type: Bridge Design Files (*.bd4)
Open
Cancel
Navigate back to the CD, and open the file titled: SaveThisFileasGroup#ToDesktop

Note: This is the only bridge file that you are allowed to have. You canNOT have multiple versions, such as Group108V1, Group108V2.)



Save the file to the DESKTOP, naming it Group and your group number (e.g., Group108).





Appendix O: Room Proctor Script

Instructions for Afternoon (PM) Research Assistants

The entire event is a discovery lesson. However, there are times you can intervene on the truss. That is, if a group is doing any of the following:

1. Closing off the roadbed tubes where the truss will be tested.
2. Gluing member surfaces directly to one another (bar-bar, tube-tube, tube to bar). If you don't understand this, look at example C.
3. Forgetting to tape wax paper down, before pinning gussets.
4. Not building a 60 cm truss (too large or too small).

Never help students with design issues, or encourage them. Don't comment on their designs. Never give groups or individuals any information on design; even if you know, you should not interact with the groups in this way. If a group tries to get your advice, say, "As stated earlier, that is not my role here today." Even if you know what might be a good design choice, do not let the students know this.

Note: If a group does not understand the idea of mass-producing the needed members, there is NO intervention for this. Interventions are only necessary when groups are constructing a truss that will not be testable.

Familiarize yourself with all items in the room proctor's bin. There are extension chords in the room if necessary. Students may take breaks as needed, but they should not be visiting with other groups.

If a CD does not have the software on it, get a workable CD from your bin, or the software is also on your USB jump drive necklace.

Recording Data

When recording bridge scores, please make sure you walk quickly, but pause at each score and double check that you are making the correct entry. Put the clipboard up near the score after you record it to verify you truly have the correct score and you have the correct group number.

Double check that students have filled in their exit survey and correct information on the front. They will also do this for the design brief.

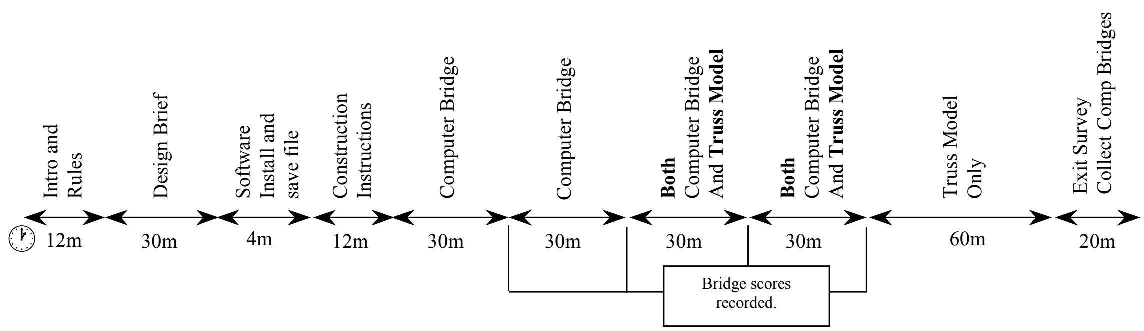
Make sure you check off student IDs on the back of their nametag at the end of the day. They must turn in their nametag but not their lanyard.

Research assistants must follow these instructions to insure consistency between rooms. It is important to keep the afternoon moving along. Wear the USB jump drive and watch around your neck.

[**Note** that there are four packets that you will instruct the student to open in the first hour. Do not let the groups open these ahead of time].

Intro and Rules (12 minutes max)

[Greet participants just inside the classroom door, and ask them to take a seat and wait for further instructions. Students should not have their laptops out of their book bags. Instruct them to set their book bags in the floor near their seat.] **[Record the intro time (the time you start addressing the participants) on the data collection sheet clip board: use the watch that is on the clipboard, because all of these watches are set to the same time.]** Once everyone is seated, start:

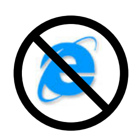


This is an overview of the afternoon activities.

[Instruct groups to open their Introduction and Rules packet.]
[Read in a stern manner, ask for quiet as you read the instructions.]
My name is [Your Name]. I will be your research assistant. My role is to proctor the problem solving session. I am NOT here to help your group design its project, nor to answer content questions. Please do NOT ask me these types of questions, because I will NOT answer them. Please listen to, read, and follow all instructions carefully.

I will present your group with two engineering problems to solve: a computer bridge and a truss model design. Both problems count 50% of your total score. Therefore, your group should try to obtain the highest scores possible on each of the problems. It is impossible to have a good final score, if you ignore one of the problems. ***How each problem is scored is described in the design brief. Make sure you know how each problem is scored and that they will be weighted equally towards your total group score.***

Everyone must follow these rules and constraints:

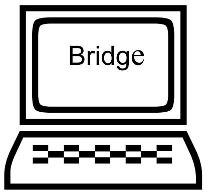


1. *You are NOT allowed to access the Internet at any time.*
2. *You may NOT access any information already stored on your computer. This includes any preexisting designs or data.*
3. *You are NOT allowed to help any other group, nor look at their work.*
4. *Do not distract or disrupt other groups from their work.*
5. *Remember, the honor code is in effect, because you are receiving course credit.*
6. *No one is allowed to use an external mouse: it has to be the built in one on the computer.*

Computer Bridge

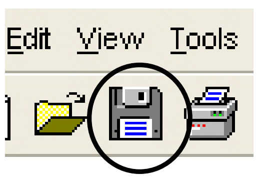
7. *Your group may only use two computers.*
8. *You may only load the bridge software on one computer.*
9. *The only other programs that you are allowed to use are the Windows® computer calculator and Microsoft excel. These may only be used on the second computer.*

Computer 1



Computer 2

10. *No graphing software or programming languages are allowed.*
11. *You must name your bridge file as your group name. For example, [point to the closest group] this group would name their bridge file [state whatever their group number is]. Resave your work approximately every 10 minutes.*



12. *You may NOT look at the example bridges. You may NOT use the templates that are in the bridge software.*
13. *I will record your computer bridge score (dollar amount) every thirty minutes. Every 25 minutes, I will announce "five minutes" until test. You should continue to work on your bridge during this time, but make sure you will have a testable bridge within the next five minutes. At 30 minutes, I will announce, "Place your bridge into test mode." At this point you have 45 seconds to make any last changes, and hit the simulation button on the software. Once I say "stop," do NOT touch the laptop keyboard or mouse. I will come around and record the dollar amount that you currently have. Once I have recorded the score for ALL groups, I will announce, "start work again." I cannot tell you any of your previous bridge scores. You need to make a note of them.*

Truss Model

14. *During the first hour of working with the bridge software, you may NOT open the materials for the truss bridge [point to equipment bin], or draw on the grid paper [point to grid paper].*
15. *After the fourth and final bridge score at 2 hours, you will have an additional 60-75 minutes to finish up your truss. If you finish the truss model before the end of three hours, you may continue to work with your computer bridge. However, this will NOT increase your group score.*
16. *You must construct a deck truss model that spans 60 cm, plus or minus .25 centimeters* [pass around example A]. *Your truss size CANNOT exceed one of the grid areas* [point to the lower grid on one of foam core boards]. *You can have as many connecting triangles*

or squares as you desire. Your roadbed must be made of all tubes: you should refer to example A. You must use either 7 mm or 9 mm tubes, not both, throughout your truss model. You will give me the other one, so it is not in your way. You can use combinations of bar sizes (3, 4, 5, or 6), or you may use all the same size. All tubes must remain hollow. You may use any size bars that you desire. Each member must be a tube or doubled bar. I will now pass around an example of a section of a truss. No face-to-face gluing of truss members is allowed [pass around example B]. *All connections must be made with gusset plates on both sides of the truss. The ends of the truss must remain open for testing.*

17. *Make sure you follow the construction suggestions to save time constructing the truss model. This is an example of part of the truss being constructed.* [pass around example C].
18. *After several groups have finished their trusses, we will complete an exit survey. After you complete your exit survey, I will collect your nametag, verify your student ID, and give you a movie ticket.*
19. *You may now open your packet labeled design brief. You will have exactly 30 minutes to read through the design brief and formulate solutions.*

Design Brief

[The following paragraph was only in the instructions for room proctors in the problem structure treatment, not the control room proctors. Instruction on how to implement this part of the design brief was provided in separate room proctor training sessions].

Directions: *You have 20 minutes to individually read over the design brief and write out answers to the questions. You should not talk during this time. After 20 minutes your room proctor will announce that you can share your ideas with other group members*. [Make sure students are working on their Design Brief during these 20 minutes. You must use your watch.] After this, give them exactly an additional 10 minutes to discuss as a group: "*You may now share your formulations with other group members*."

Note: Even though their design brief states that they will be given a bonus for every improvement of over 75 dollars in a 30-minute interval, **you do NOT calculate this. Record their raw scores from the computer.**

[During the design brief, continue to walk around the classroom, showing the groups the examples: do not say anything about the examples, but if they ask to see them, let them have them for about two minutes, then request them back, so other groups may look at them: Do not leave them with the groups for long periods of time]. GROUPS SHOULD NOT BE ALLOWED TO DRAW ON THE GRID. This is part of construction and starts after time 2.

Software Installation

[Do this process as quickly as possible.]
At the end of the timer, instruct the groups to open up the software installation sheet. *"Ok, open up your software installation packet, and follow the instructions carefully, because you must open up a certain file from the CD after installation. You must save your computer bridge file to the desktop as your group number. Also, place your group number so you can see over the top of your monitor.*

[If a group has a problem, have them try a different laptop, or if it is a room with groups of three or four, you can ask to borrow someone else's laptop.] If this issue is not solved quickly, call for help.]

Construction Instructions

"Now you may open the truss construction instructions." Continue: *"You may also load the construction instructions onto computer number two.* Note the time on your watch and write it down to insure the 12 minutes (do not reset the timer for this).

Time Intervals

After that, announce, *"Ok, you may now start using the bridge software."* Note this time on the data collection sheet. Don't forget to set the timer, because we want all groups, regardless of room or building to have the same consistency.

Follow the instructions on the data collection for your announcements. **You must make sure that all groups stop keyboard entry while you are recording data.** Always go around the room in ascending order (e.g., group 12, 24, 36 …96). Remember, you must record three things for each time interval: iterations, dollars, and whether the bridge is successful or not.

Both Computer and Truss

After you record all groups' scores for time 2, then announce that they may start constructing their truss. At some point they will be turning a set of tubes back into you. Place these in the grocery bag. You can probably place this around your wrist until everyone has returned 1 set.

Continue to record all scores, keeping all intervals a total of 30 minutes.

Complete Truss

Reset one of the timers to one hour. After time 4, announce, "Ok, I am not going to record any more bridge scores: You want to take this last hour or so to finish up your truss." Remember, to let me know when you are finished with your truss." "Leave your truss on top of the wax paper, and you can continue to work with the software." At the end of three hours, let groups that have completed their truss separate from their groups to take the exit survey. If some students are not finished let them continue to work on their truss for as long as they are willing to stay. Still note their ending time.

[Monitor groups and record the time that they finish in the last column of the data collection sheet]

Exit surveys

Please double check that each student has completed the survey. Students must separate from their group to the member letter that is on the wall (I, J, K, L). You must organize this so it happens effectively. Take control.

Figure O1. *Instructional packets for teams.*

Note. To make sure that teams were presented information in the same order, each team had the above four informational packets which were placed in envelopes. There was an envelope for each of the following: introduction and rules; design brief; bridge software installation; and construction instructions (hard copy). There was a design brief for each team member.

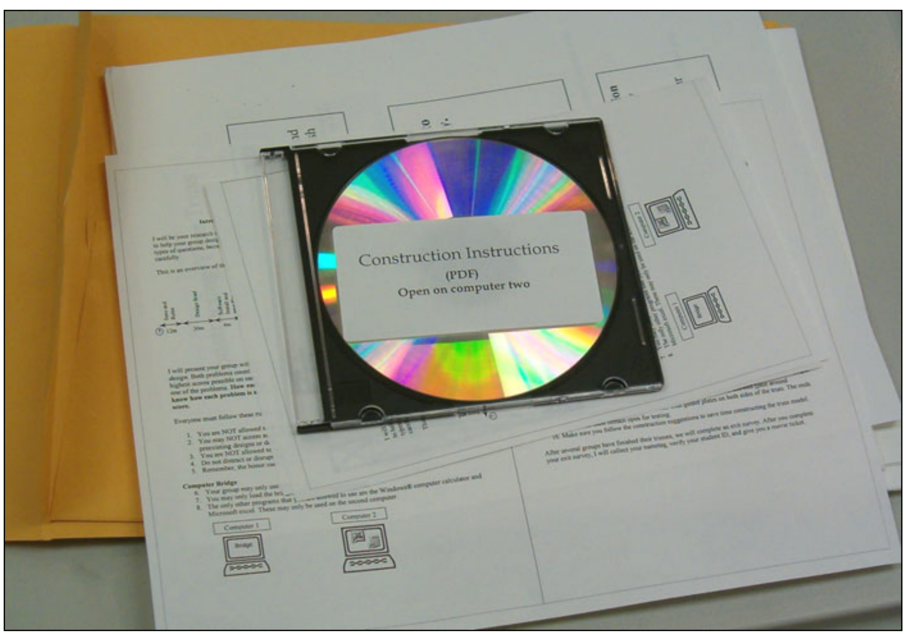


Figure O2. *Every team was provided with two compact discs.*

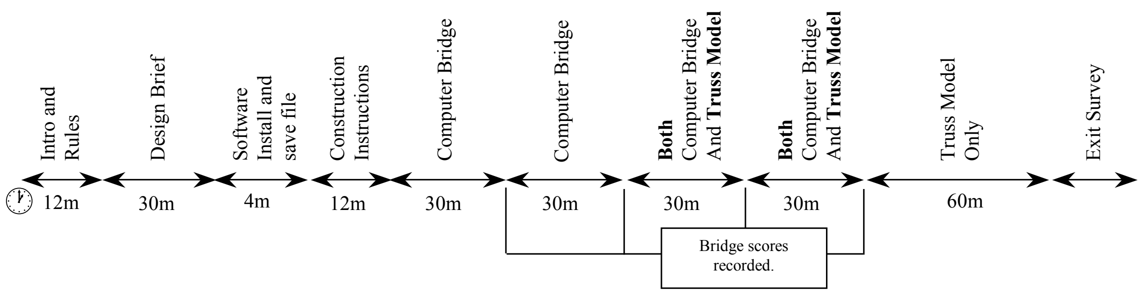
Note. One CD had the construction instruction as a PDF, while the other had the software installation instruction and the blank bridge design file, which teams were required to use for the computer bridge. Labels were used extensively to communicate to the participants. For example, the above CD instructs them to open the construction instructions on the 2nd computer they were allowed to use.

Appendix P: Participation Rules for the Design Activity

Introduction and Rules for the Afternoon Engineering Challenge

I will be your research assistant today. My role is to proctor the problem solving session. I am NOT here to help your group design their project nor to answer content questions. Please do NOT ask me these types of questions, because I will NOT answer them. Please listen to, read, and follow all instructions carefully.

This is an overview of the afternoon activities.



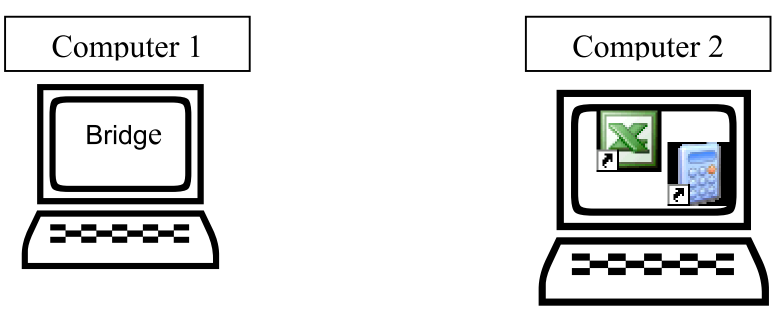
I will present your group with two engineering problems to solve: *a computer bridge and a truss model design*. Both problems count 50% of your total score. Therefore, your group should try to obtain the highest scores possible on each of the problems. It is impossible to have a good final score, if you ignore one of the problems. **How each problem is scored is described in the design brief. Make sure you know how each problem is scored and that they will be weighted equally towards your total group score.**

Everyone must follow these rules and constraints:

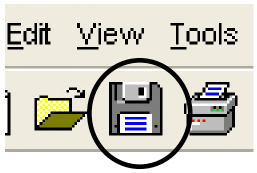
1. You are NOT allowed to access the Internet at any time.
2. You may NOT access any information already stored on your computer. This includes any preexisting designs or data.
3. You are NOT allowed to help any other group nor look at their work.
4. Do not distract or disrupt other groups from their work.
5. Remember, the honor code is in effect, because you are receiving course credit.
6. No one is allowed to use an external mouse: it has to be the built in one on the computer.

Computer Bridge

7. Your group may only use two computers.
8. You may only load the bridge software on one computer.
9. The only other programs that you are allowed to use are the Windows® computer calculator and Microsoft excel. These may only be used on the second computer.



10. No graphing software or programming languages are allowed.
11. You must name your bridge file as your group name. Resave your work approximately every 10 minutes.



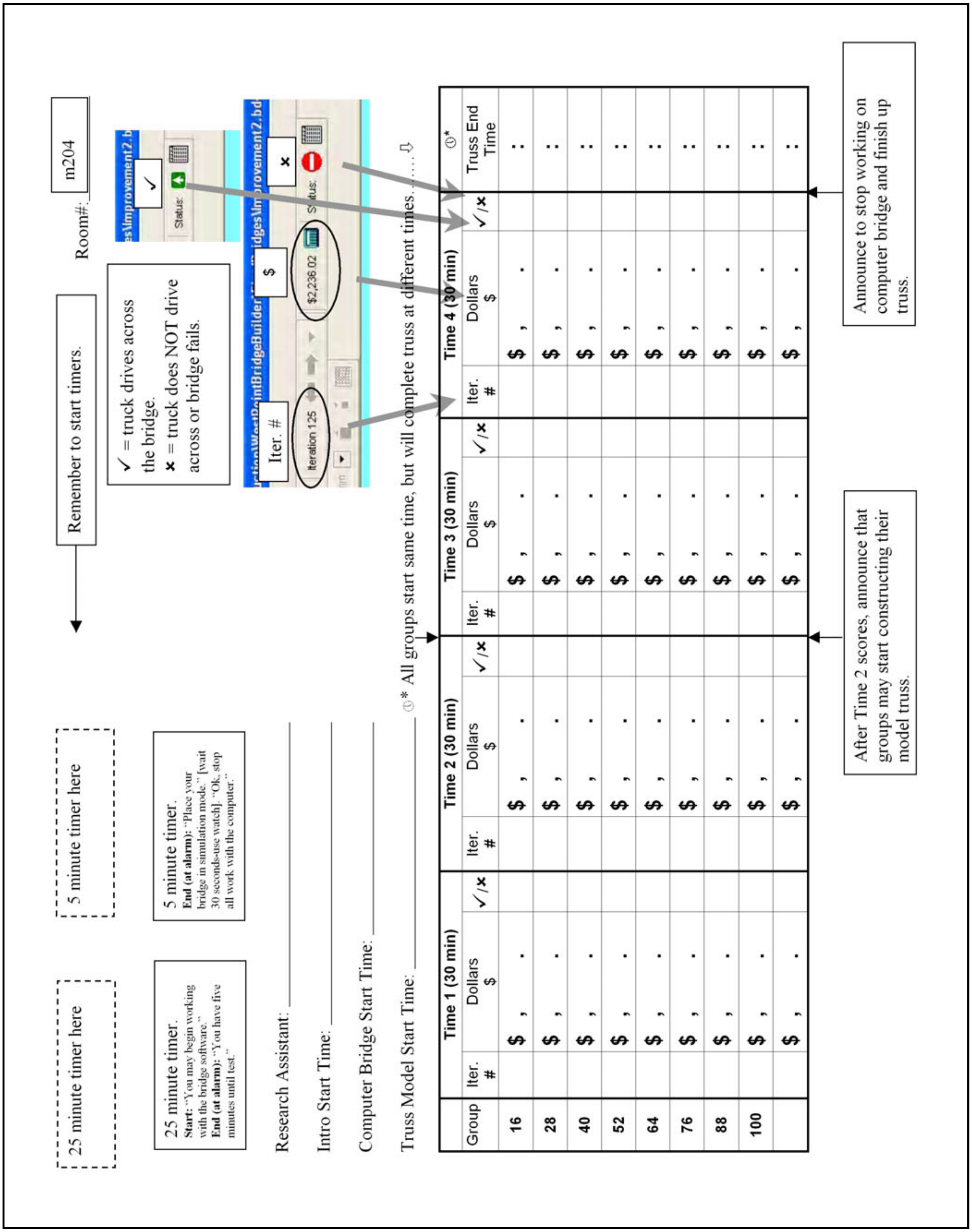
12. You may NOT look at the example bridges. You may NOT use the templates that are in the bridge software.
13. I will record your computer bridge score (dollar amount) every thirty minutes. Every 25 minutes, I will announce "five minutes" until test. You should continue to work on your bridge during this time, but make sure you will have a testable bridge within the next five minutes. At 30 minutes, I will announce, "Place your bridge into test mode." At this point you have 45 seconds to make any last changes, and hit the simulation button on the software. Once I say "stop," do NOT touch the laptop keyboard or mouse. I will come around and record the dollar amount that you currently have. Once I have recorded the score for ALL groups, I will announce, "start work again." I cannot tell you any of your previous bridge scores. You need to make a note of them.

Truss Model

14. During the first hour of working with the bridge software, you may NOT open the materials for the truss bridge or draw on the grid paper.
15. After the fourth and final bridge score at 2 hours, you will have an additional 60-75 minutes to finish up your truss. You must let me know as soon as you finish constructing your truss. Please raise your hand when you finish. If you finish the truss model before the end of three hours, you may continue to work with your computer bridge. However, this will NOT increase your group score.
16. You must construct a deck truss model that spans 60 cm, plus or minus .25 centimeters. Your truss CANNOT go outside of the grid area. You can have as many connecting triangles or squares as you desire. Your top chord must be made of all tubes. You must use either 7 mm or 9 mm tubes (not both) throughout your truss model. You can use combinations of bar sizes (3, 4, 5, or 6), or you may use all the same size. All tubes must remain hollow. You may use any size bars that you desire. Each member must be a tube or doubled bar. I will now pass around an example of a section of a truss. No face-to-face gluing of truss members is allowed. All connections must be made with gusset plates on both sides of the truss. The ends of the truss must remain open for testing.
17. Make sure you follow the construction suggestions to save time constructing the truss model.
18. After several groups have finished their trusses, we will complete an exit survey. After you complete your exit survey, I will collect your nametag, verify your student ID, and give you a movie ticket.

Appendix Q: Room Proctor Data Collection Sheet and Timers

Note. The original document has been reduced by approximately 25 to 30% to fit on the page below. There is some quality loss in the conversion from a document to an image.



25 minute timer here

5 minute timer here

Remember to start timers.

Room#: m204

25 minute timer.
Start: "You may begin working with the bridge software."
End (at alarm): "You have five minutes until test."

5 minute timer.
End (at alarm): "Place your bridge in simulation mode." [wait 30 seconds-use watch]. "Ok, stop all work with the computer."

✓ = truck drives across the bridge.
✗ = truck does NOT drive across or bridge fails.

Research Assistant: ______

Intro Start Time: ______

Computer Bridge Start Time: ______

Truss Model Start Time: ______ ⓘ* All groups start same time, but will complete truss at different times……⇨

Group	Time 1 (30 min)			Time 2 (30 min)			Time 3 (30 min)			Time 4 (30 min)			ⓘ*
	Iter. #	Dollars $	✓/✗	Iter. #	Dollars $	✓/✗	Iter. #	Dollars $	✓/✗	Iter. #	Dollars $	✓/✗	Truss End Time
16		$, .			$, .			$, .			$, .		:
28		$, .			$, .			$, .			$, .		:
40		$, .			$, .			$, .			$, .		:
52		$, .			$, .			$, .			$, .		:
64		$, .			$, .			$, .			$, .		:
76		$, .			$, .			$, .			$, .		:
88		$, .			$, .			$, .			$, .		:
100		$, .			$, .			$, .			$, .		:
		$, .			$, .			$, .			$, .		:

After Time 2 scores, announce that groups may start constructing their model truss.

Announce to stop working on computer bridge and finish up truss.

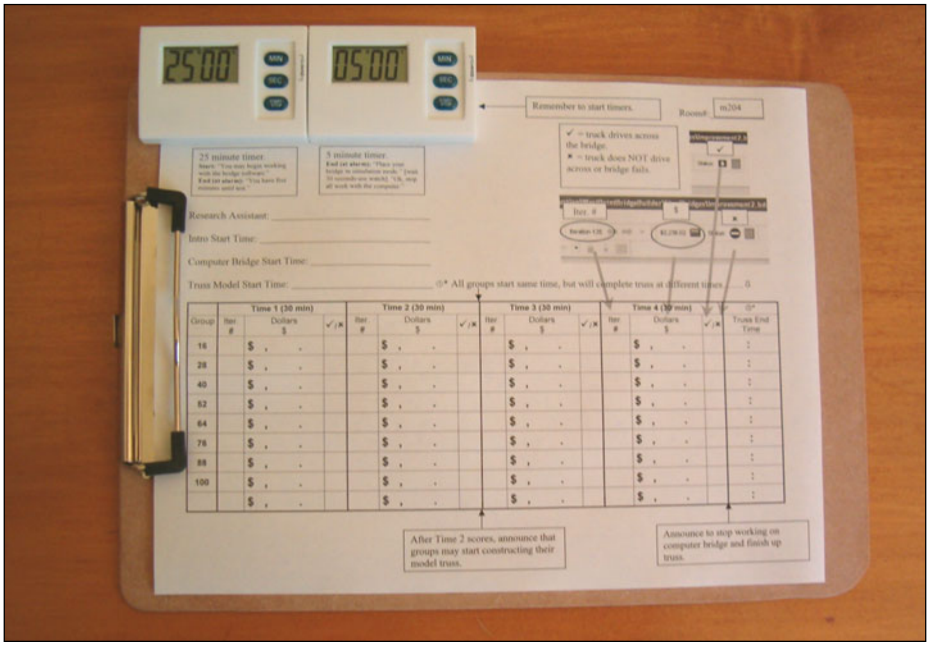


Figure Q1. *Clip board proctors used for recording computer bridge information.*

Note. Graphics of the computer bridge GUI were placed on the data collection sheet corresponding to the information that room proctors needed to record from the monitor of teams.

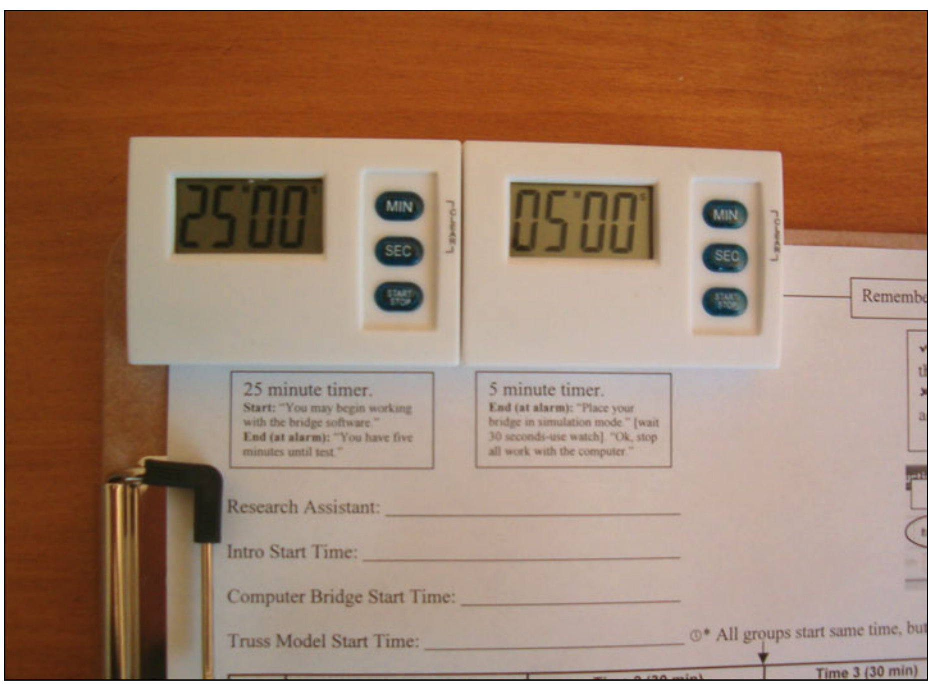


Figure Q2. *Timers used to record bridge scores every 30 minutes.*

Note. One timer was set to 25 minutes for the announcement, "Five minutes until test," while the other had five minutes to make up the other five minutes of a 30 minute interval. Once the alarm sounds, pressing the bottom button resets the time. Room proctors were trained to use the timers during a training session.

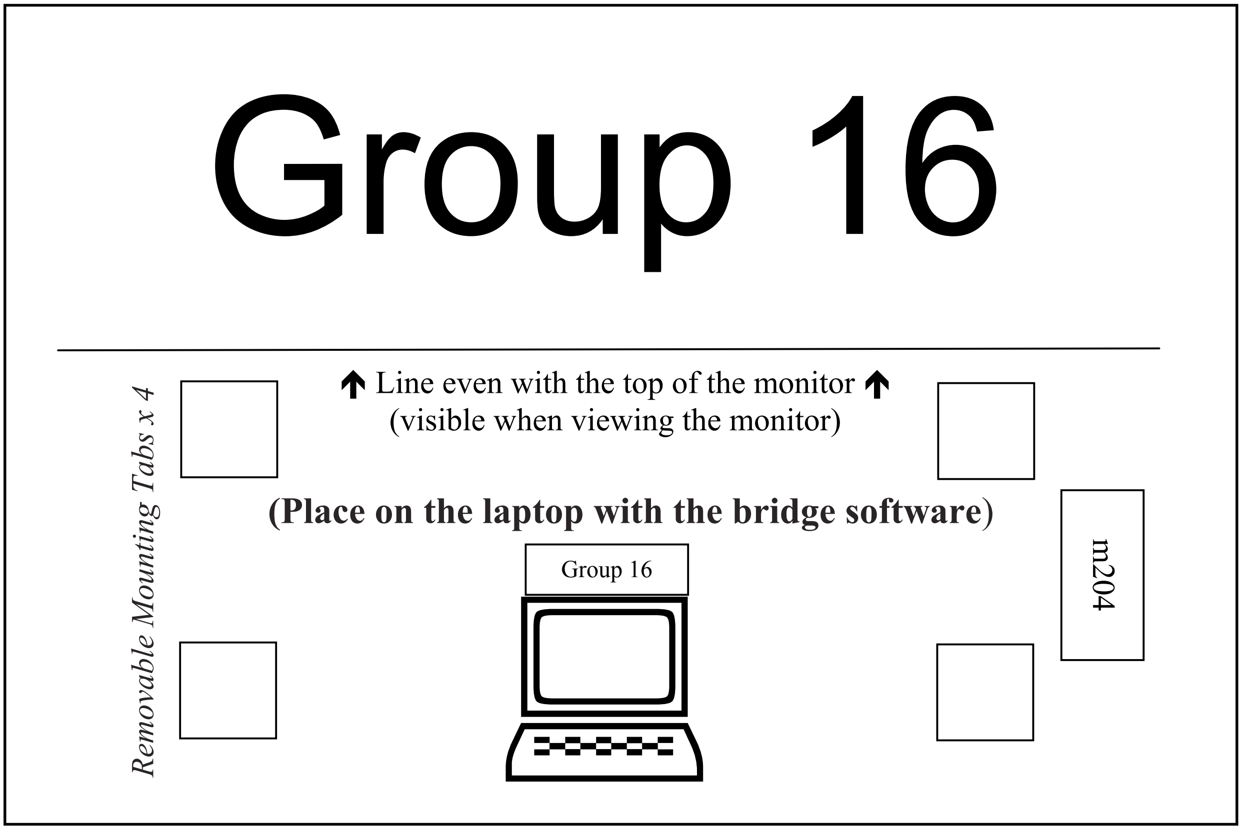


Figure Q3. *Group numbers placed on computer to help insure correct recording of data.*
Note. Numbers correspond to the numbers on the data collection sheet for that room.

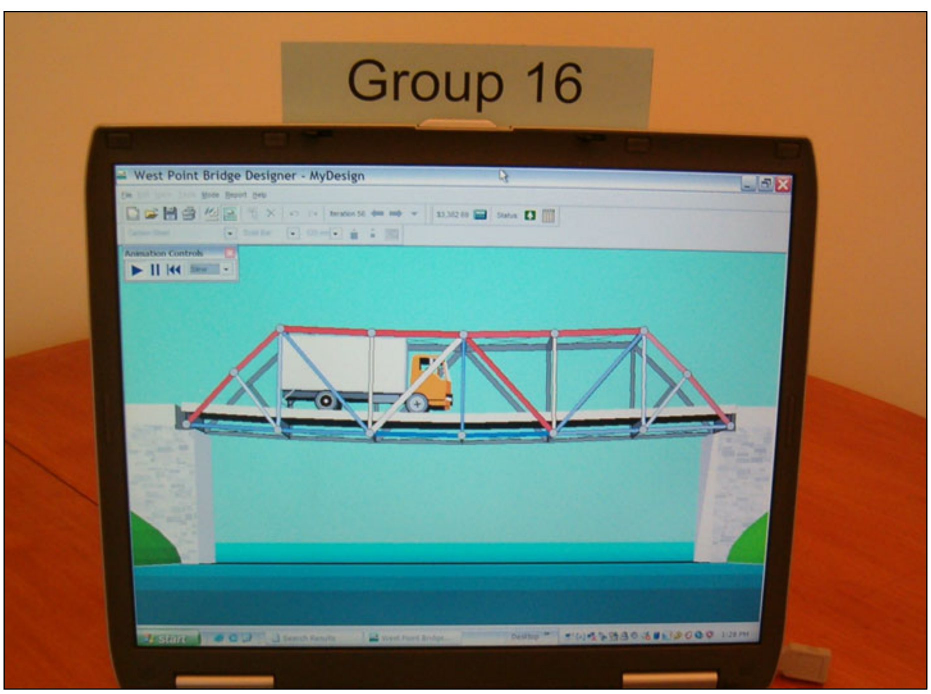


Figure Q4. *Position of group number on a team's monitor.*
Note. Teams were only allowed to load the bridge software on one computer.

Appendix R: Morning Orientation Script

CONFIDENTIAL INFORMATION
Orientation and Name Tags for Sat. Oct. 23

Cell phone information for Saturday October 23rd:

RA13: 111-111-1111 (call with research related problems).

RA14, R.N.: 111-111-1111 (call if a participant becomes sick or injured).

Please arrive no later than 8:10 am, in case you have any last minute questions.

Bowman and Litton Reaves Morning Activities are covered in a separate packet.

All research assistants are asked to wear a white shirt, so we are easily identifiable from the participants.

Note. The real names of research assistants have been replaced with RA1, RA2, etc. Positions (🚹) and roles were covered during the training session.

Litton Reaves Orientation and Nametags
RA1 will proceed to the lectern, once he gets the OK from **RA13**, **RA2**, and **RA3**. They will determine when there are enough participants to commence. If there is a short delay, you may tell the participants to talk to their neighbor while others are being seated.
RA1: "Welcome to the Engineering Challenge Workshop. My name is **RA1**. I will be the director of orientation this morning. In order for the day's schedule to proceed smoothly, it is important for you to listen carefully to the instructions given to you by the Research Assistants. They will guide you from one activity to another today."
The lack of seating will be alleviated in a few minutes. The following are rules and information for participating in the *Engineering Challenge Workshop*:

1. Once you are with your small group, it is important that you stay with your group throughout the day's competition in order for you to receive credit.
2. Leave your laptop in your book bag this morning so your batteries will remain fresh for the afternoon's competition.
3. As stated in the flyer, no cell phones will be allowed throughout the day. Remember, you are on the honor code. We want the events to be fair for everyone. This also includes lunchtime.
4. No cameras or other recording devices are allowed, because this is a research study.
5. When you make building changes, stay with your Research Assistant and walk rapidly. [**RA1**, give an example of creeping and rapid walking.]
6. There will be refreshments mid morning and again in the afternoon. It is important that you recap your bottle and set it on the floor to avoid damage to your laptop.
7. All decisions regarding design awards by EC judges are final.
8. In order to finalize your participation for course credit, a short on-line survey will be mailed to you this week."

RA1 [If the nametags have been okayed by **RA2** and **RA3**, proceed with the nametags. Have the Research Assistants come forward with the name cards].

Instructions For The Nametags [**RA1** needs to watch the timing of how things are going with the distribution and speak up as needed (e.g., we have someone without a nametag over here).
1. RA's pass nametags down the rows.
2. Take one stapled set from the stock and pass the others down. [Gesture the action of passing the nametags.]
3. "When you receive your nametag, do not pull it apart and do not start filling it out but WAIT for further instructions."
4. " Does everyone have a nametag? Raise your hand if you do not have a nametag." [Look around room to make sure everyone has a nametag: If someone does not have a nametag, and all the assistants have distributed their stack, then **RA2** and **RA3** will determine which one to give to them.]
5. "I'm going to go over how to fill out your nametag, so listen carefully. It is important that you fill out the card accurately, so we can let your ENGE instructor know to give you credit for participating today.
6. "Ok, you will fill out both cards identically." [**RA1** holds up the small ID that is in the lanyard.]
7. "First, write your FIRST name only on the front of both tags."

8. "Flip over to the back and put your PID on both cards. [Hold up the large example.] Copy the student number from your Hokie Passport onto both cards."
9. "Raise your hand if you need more time." [PAUSE] "Now take the 2 cards apart. Now, pass one back down the row and put the other identical one in your lanyard holder [put your example into the lanyard]. You must wear this around your neck all day, so that we will be able to call you by name and know that you are a participant in this research study."
10. [Once all cards are collected and you have checked to see that no one is still holding a card, announce] "At the end of the day, you must give your Room Proctor your other card and present your ID. We will give the second card to your ENGE instructor so you will receive credit and to award prizes if your group wins." [**RA1**, make sure one nametag has been turned in.]

TRANSITION

"Now we need to create more space in here so half of you will go to another building. I want everyone to look at his or her nametag. If you have the circle on yours, like this" [Hold up the example] exit to the back and follow your Research Assistants out the back doors to the next building. Make sure to take your book bag with you. You will have time to use the restroom when you get to the next building." "If your nametag has a square, stay seated. [PAUSE until the circles have left the room.]

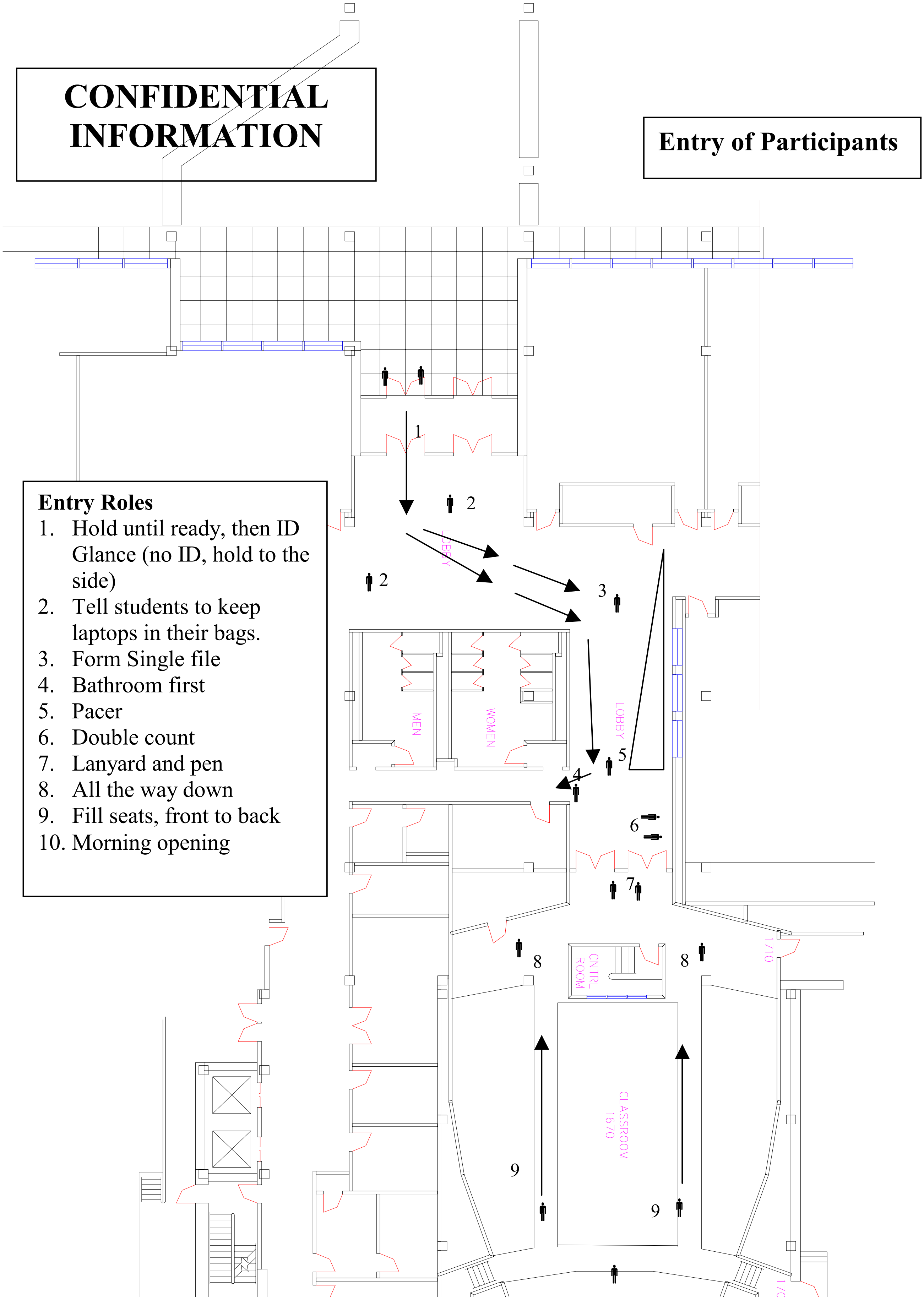
Distribution of Nametags (Information for RA2 and RA3)

Once a student enters, give them a reentry pass, so they don't get double counted.

1. The box of nametags must remain in the serial or stack number (S1, S2).
2. After confirming the count, take out any N (e.g., N306) number higher than the count. Ns 253 and above will have a special marker (blue tag), so that they are easy to find.
3. Place the unused cards (greater than count) in ascending N order to confirm that you pulled out the correct ones. If you are missing N(s), use the randomized N Chart to find the corresponding Stack number.
4. If count is greater than 300, cards are ready to give out, otherwise continue with steps five and six.
5. Using the table with the boxes of nametags, check that the N number is not exactly an (I) letter in a group number. This process is to eliminate any team of 1.
6. If number step 5 is true, find the next team of 2, and change all information on the (I) card, so that they are Member K in that group.

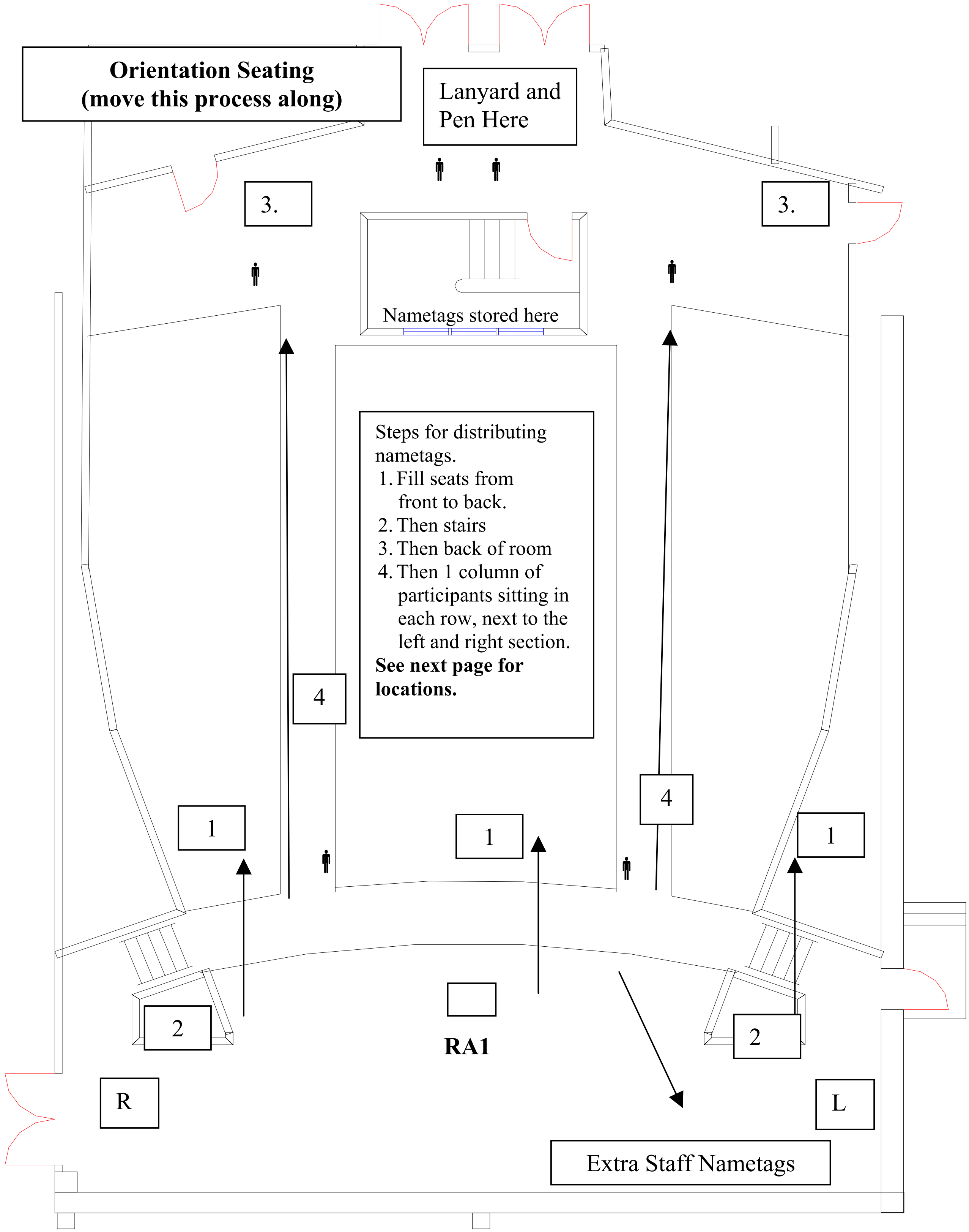
CONFIDENTIAL INFORMATION

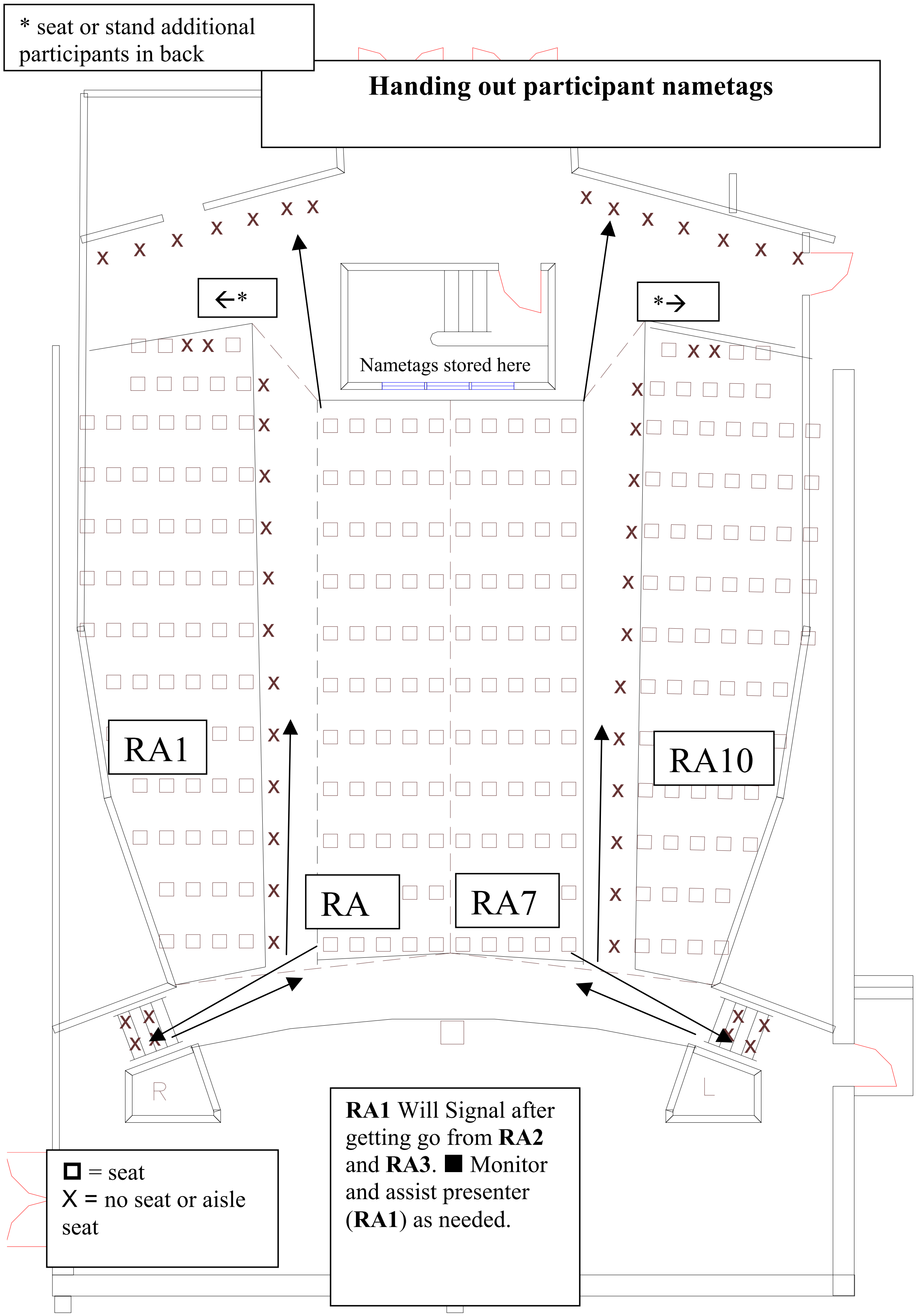
Entry of Participants

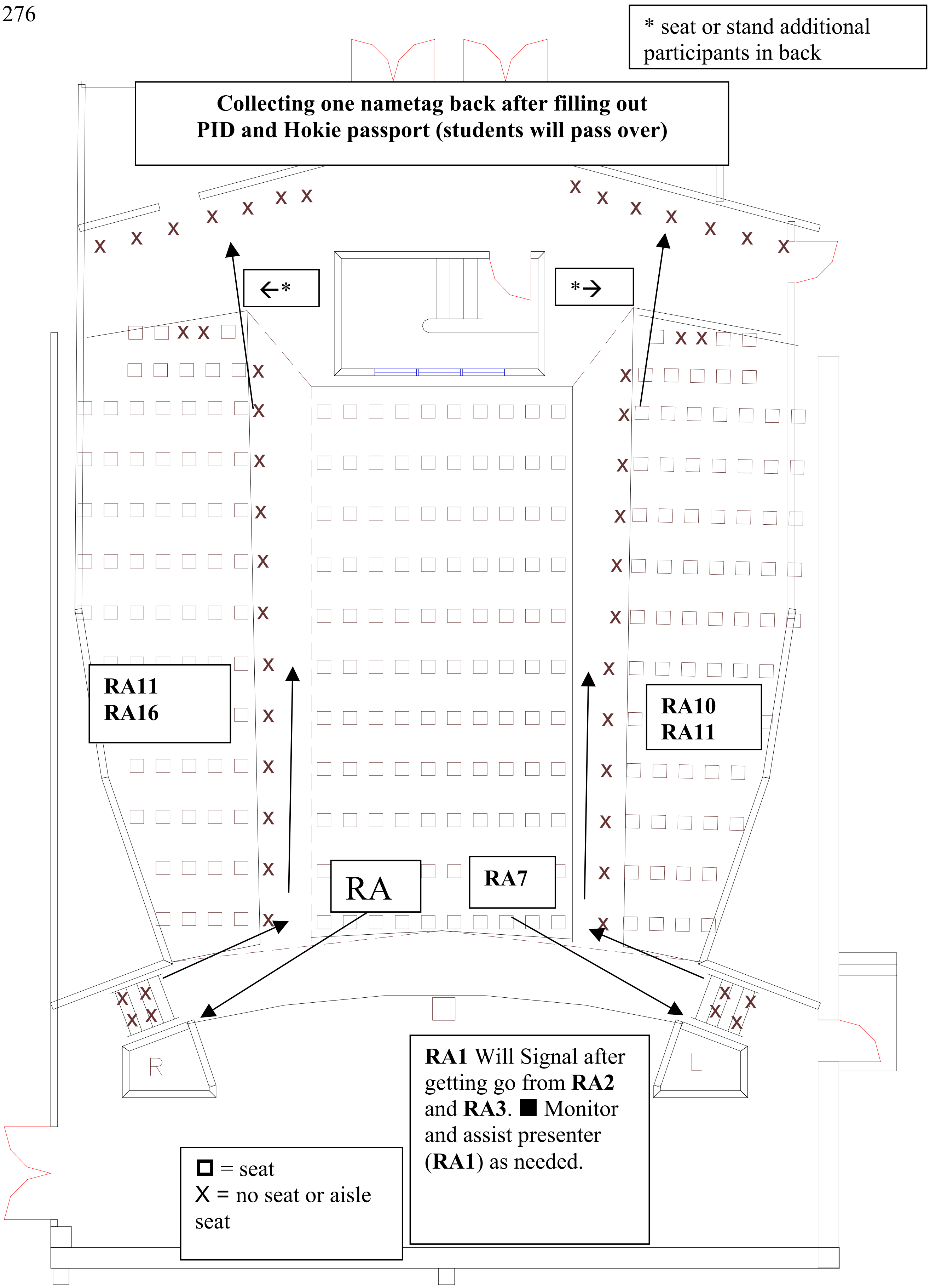


Entry Roles

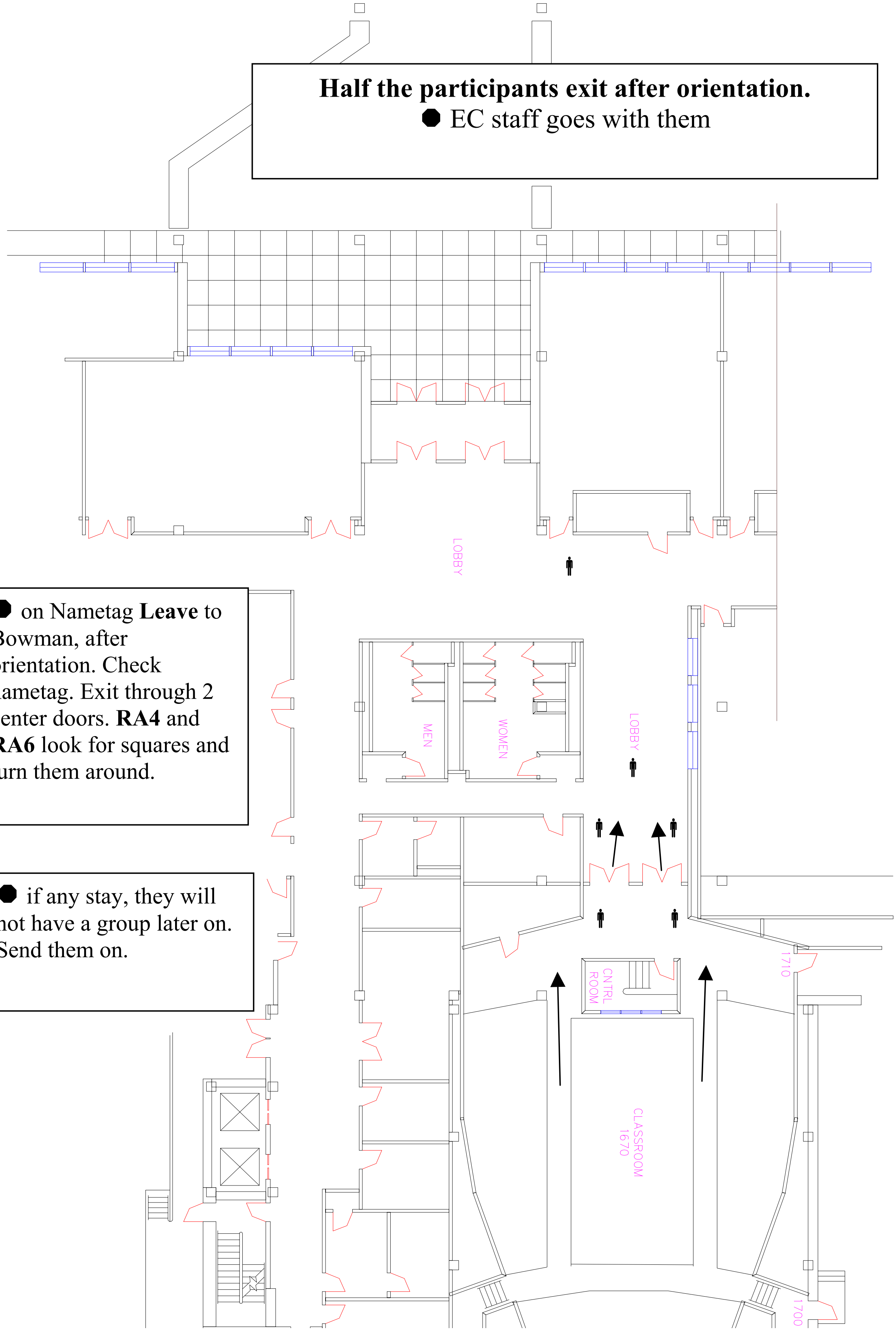
1. Hold until ready, then ID Glance (no ID, hold to the side)
2. Tell students to keep laptops in their bags.
3. Form Single file
4. Bathroom first
5. Pacer
6. Double count
7. Lanyard and pen
8. All the way down
9. Fill seats, front to back
10. Morning opening


Orientation Seating
(move this process along)
Lanyard and Pen Here
3.
3.
Nametags stored here
Steps for distributing nametags.
1. Fill seats from front to back.
2. Then stairs
3. Then back of room
4. Then 1 column of participants sitting in each row, next to the left and right section.
See next page for locations.
4
4
1
1
1
2
2
RA1
R
L
Extra Staff Nametags


* seat or stand additional participants in back
Handing out participant nametags
←*
*→
Nametags stored here
RA1
RA10
RA
RA7
R
L
☐ = seat
X = no seat or aisle seat
RA1 Will Signal after getting go from RA2 and RA3. ■ Monitor and assist presenter (RA1) as needed.

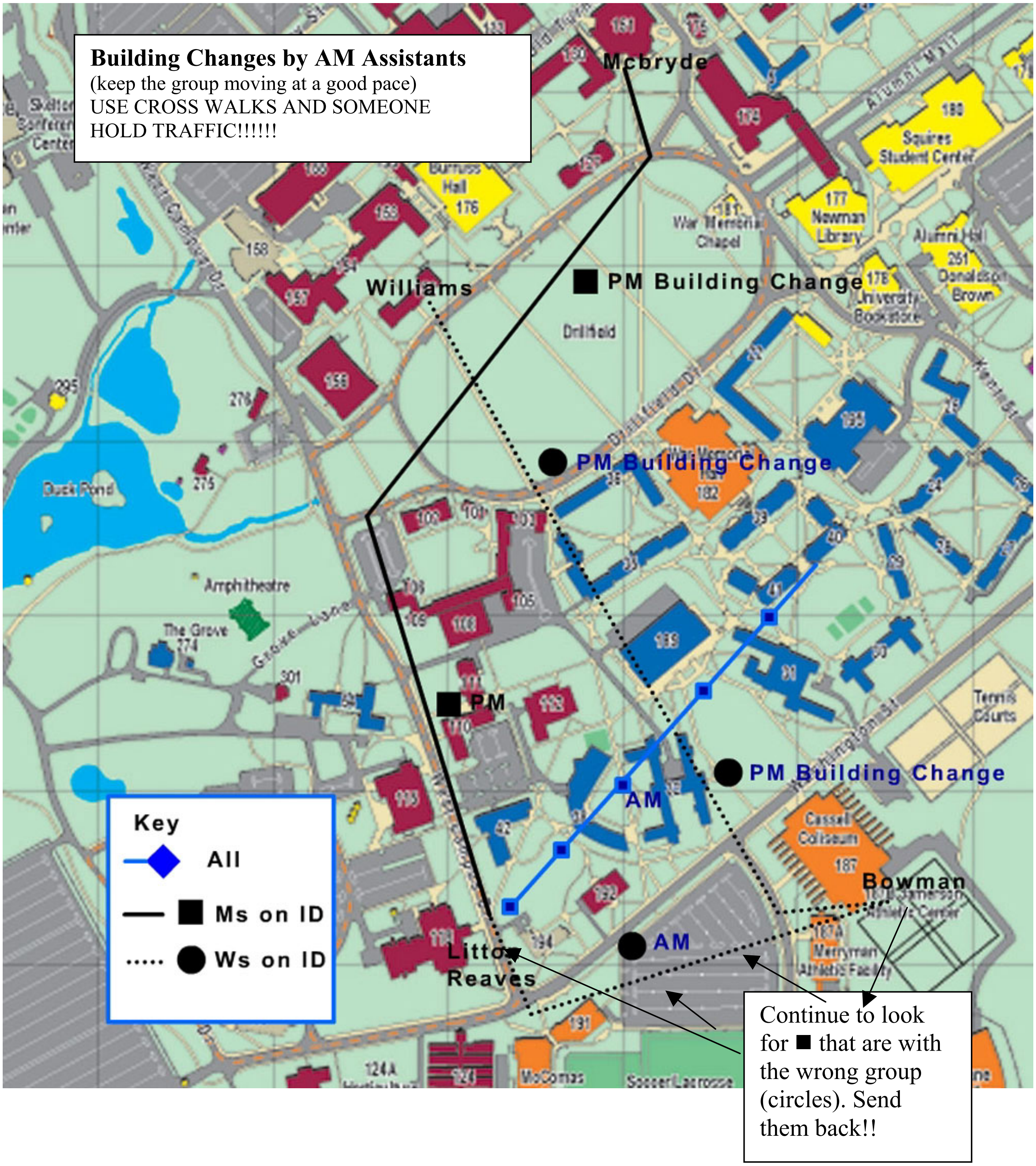

* seat or stand additional participants in back
Collecting one nametag back after filling out PID and Hokie passport (students will pass over)
←*
*→
RA11
RA16
RA10
RA11
RA
RA7
R
L
RA1 Will Signal after getting go from RA2 and RA3. ■ Monitor and assist presenter (RA1) as needed.
□ = seat
X = no seat or aisle seat

Half the participants exit after orientation.
● EC staff goes with them



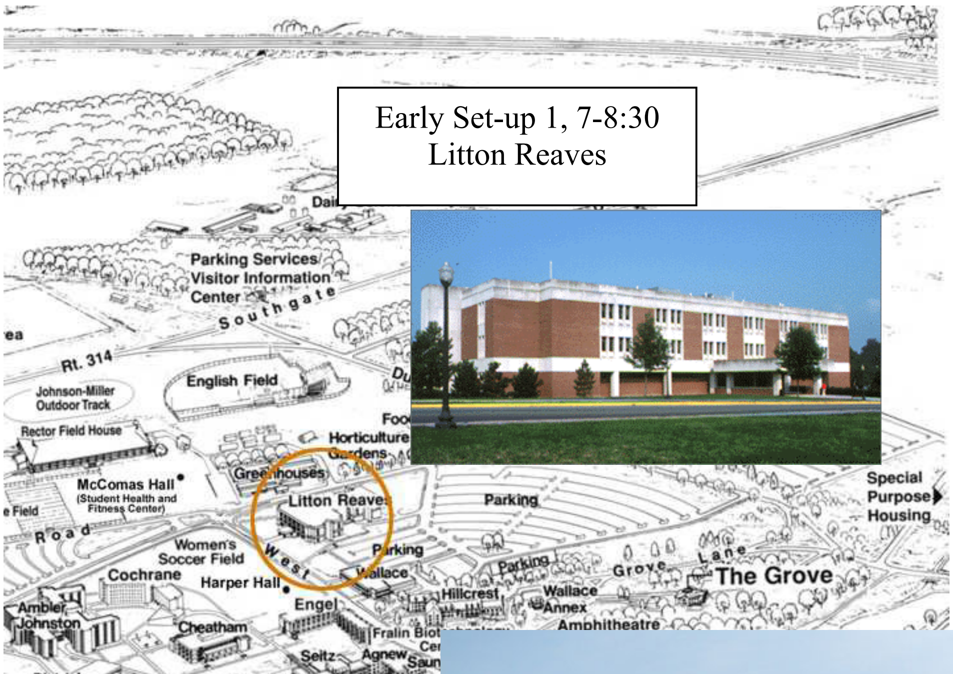
● on Nametag **Leave** to Bowman, after orientation. Check nametag. Exit through 2 center doors. **RA4** and **RA6** look for squares and turn them around.

● if any stay, they will not have a group later on. Send them on.

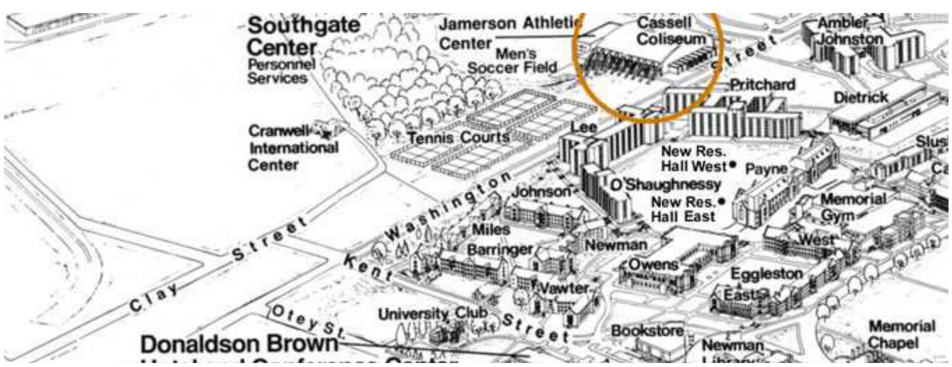


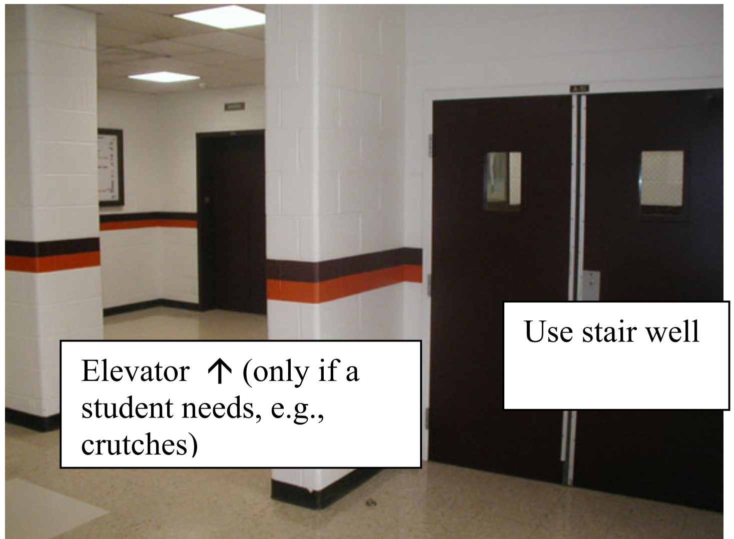
All participants meet here for morning orientation.
■ on Nametag **Stay** in Litton Reaves during AM.
⬣ on Nametag **Leave** to Bowman, after orientation.
(Do not tell participants what the W and M stand for: Let the presenters announce this at the appropriate time (**RA12** and **RA1**).

Early Set-up 1, 7-8:30
Litton Reaves



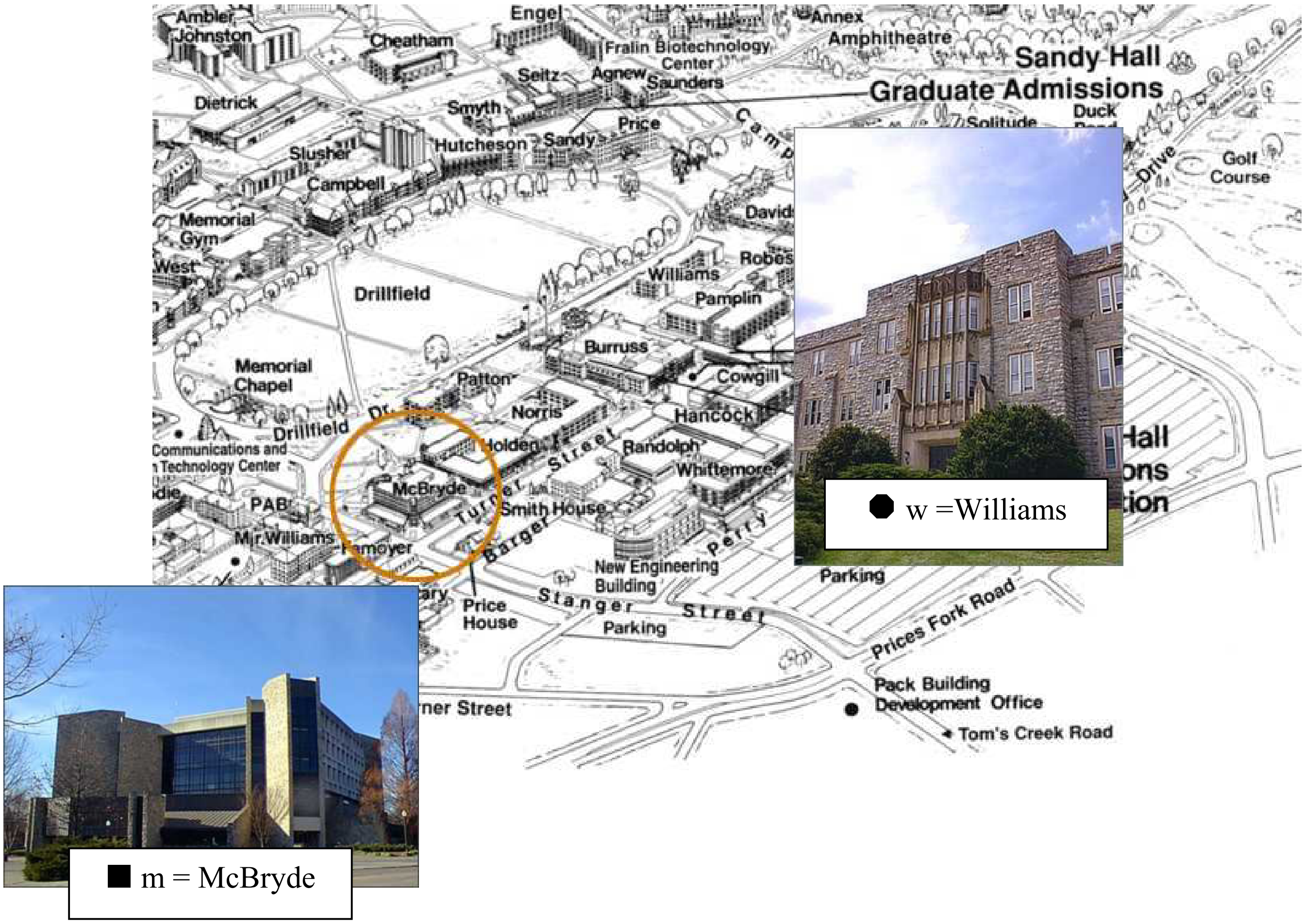
Early Set Up 2, 7:00 to 8:30 Bowman
Room is on the fourth floor of the
Jameson Center, behind Cassell




Use stair well
Elevator ↑ (only if a student needs, e.g., crutches)


Keep students moving

PM locations (late set up, 9-11 am)



Confidential Information

Nametag front for squares (Litton Reaves)

E[c] **Name**

First Name

106J ■ G m232

s4 N286

Nametag Back for squares

hokiebird@vt.edu

PID (VT e-mail)

9031111111

(Hokie Passport) ID Number on VT Student Photo ID

□

106J ■ G m232

This alpha numeric must go on all documents completed by a participant.

PID and student ID number must also be placed on all documents completed by participants.

Group Number (11 through 112)

Member Letter (I, J, K, or L) Must go on any document filled out.

Squares stay in Litton Reaves for morning activities.

Organizational Group Letter (A through G) 18-22 participants per letter.

Building and room number students must be ushered to after lunch. **RA1** or **RA12** will announce this right before we get ready to make building changes.

s4

Nametag front for circles (Bowman)

Circles leave for Bowman for morning activities.

E[c]

First Name

107K ● G w232

Note: Do NOT announce what items on the nametag stand for, until after the director (**RA1** or **RA12** has announced this to participants).

Appendix S: Example Teamwork Exercises

Note. The first part of this appendix is the planning document developed by the teamwork consultant. The researcher met with the teamwork consultant during the planning of the workshop. The word CORE refers to divisions of an organization, which are described in Chapter three: *Organizations for Teamwork Exercises and Control Group Activities*. The second part of the document includes three example teamwork exercises that teams participated in during the teamwork exercises treatment. Photos are *not* of participants. All items in this appendix were reprinted by permission of Tom Heck.

Outline for approximately 2.5 hours

- Introduction
    - My goal (the goal of this session) is to help you operate/perform at your highest potential.
    - About me
        - Graduated from VaTech 18 years ago with an education degree
        - I make my living helping teams function at their highest levels.
- Assemble in CORE – 3 teams
    - Big Question
    - Mrs. Wright
    - Team Spell
        - CORE – 3
        - CORE – 1
            - Debrief
                - Top 3 truths about teamwork that were demonstrated in this activity.
                - Diversity = strength

CORE - 1
- Coat Hanger

CORE - 2 (two groups of 9)
- Funderbirds
- Hole Tarp
    - I.D. top 5 obstacles to a high performing team
    - Debrief
        - How is it just like…not at all like…
        - Pair up with another team, deliver your findings

CORE - 3
- Tennis Ball Madness
    - Create a one syllable Cheer
    - Pass out directions
    - Debrief
        - CORE – 2
        - Win-win, win-lose, lose-lose
            - Our culture promotes what?
            - Yes, you are going to compete in the afternoon. Competition is good.
            - Do you have to compete on your OWN TEAM?

Ready to Go

Bandana Cup Marble
Infinite Loops
- All must solve in 10 min once the first has solved.

Elastic Cord

Touch the Ball (elimination)
Race Car

Random Count Up
Team Story

- Trust - - (Covey) the foundation
    - Car
    - Yurt (up and down)

Wave?

Do Not Do

Mousetrap
Focus Ring
Ain't No Flies
Balloon Triangles (LATEX!!)

Mr. Potato
Infinite Loops
Elastic Cord
Bandana Cup Marble
____
 	
• CORE - 1
    o Appreciative Inquiry
        ▪ Describe a great team experience – what made it great for you?
            • A talks, B listens
            • Switch
 	
--- 	
 	
CORE – 1
    o Brian Biro exercise – point and turn x 2
    o THE key to success: <u>Imagination</u>
        o The key (the lynch pin) is NOT about the best skill set, highest IQ,
        o Einstein - - “Imagination is more important than knowledge.”
        o The team that can identify their experience AND feel it are leagues above all others.
    o Equation
        o Performance = Potential + Imagination
    o Video: Stripes
    o Imagination Session
        o In CORE – 1, fully imagine your success and write it out (phrases you will be saying), describe the experience, get clear
        o Top 3 (Key) “take-aways” from this session
        o Agreements - - top 3
            ▪ Keep it positive
 	
Closing
    o Jim’s finger catch	

Bandana Cup Marble

Teambuilding Game

Group Size 4 to 10 people per bandana
Age Range: Elementary – adult
Intensity: Mental=1, Physical=1
Time: 5 – 15 minutes
Space: Minimal – Medium – Lots
Set Up Time: 60 seconds
Props: One plastic cup, one bandana, one marble per group

Objective

Transport a marble balanced on a cup from one point to another.

Set Up / Preparation

Create groups of about 8 people and supply each group with one bandana, one marble and one plastic cup (the plastic cup should have some kind of lip on the bottom of it). The group surrounds the bandana and holds on to it with both hands along the edges creating a tabletop effective. The cup is now placed up side down on the bandana then the marble is placed on top of / balanced on the cup. The group is now asked to transport the bandana-cup-marble from one point to another.

Rules

1. If the marble falls off the group must start again.
2. Everyone must hold on to the edge of the bandana with both hands.
3. The bandana must be kept tight and flat.
4. The supplied equipment (props) may not be altered.
5. No other supplies may be used.

Debriefing

I once led this activity at a retreat for a group of school system volunteers (adults). There were about 30 people so I had them form into 3 groups in one of the meeting rooms. After everyone was set to go with the activity, I asked them to place their bandana-cup-marble assembly on a small table in an adjacent room SIMULTANEOUSLY. There was only one doorway and to the other room so the teams were forced to wait on each other. The table was small which forced the groups to communicate and create a plan. I had everyone circle up in their small groups and answer the following questions: What metaphorically is the bandana, cup, marble, and table relative to your job in this organization? I gave the groups 15 minutes to create a presentation, which they would be giving to the other groups. The groups loved the activity and loved the discussion as well as the presentations from the other small groups.

Variations

1. Place obstacles in the path of the group such as a tables or chairs. Consider having the group go up a flight of stairs.
2. Use a taller cup and a larger, denser ball (like a baseball) to make this lots harder.
3. Fill a cup of water and balance it on the bandana. If you want to get folks really wet, have them transport the cup by holding the bandana above their heads.

History

I learned this activity from Sam Sikes, author of “Executive Marbles” and “Feeding the Zircon Gorilla”.

Team Build-a-Word

Teambuilding Game

Group Size 20 – 200+
Age Range: Elementary – adult
Intensity: Mental=3, Physical=1
Time: 15-45 minutes
Space Minimal – **Medium** – Lots
Set Up Time: 60 seconds
Props: One 3x5 index card per person

Objective

Create words using letters on index cards.

Set Up / Preparation

First you must create at least one 3x5 index card for each person. Using a black marker, write one letter of the alphabet on each card using BIG block letters. One set of cards = 26 letters (all letters of the alphabet).

If you have less than 26 people playing, give some people two cards. If you have more than 26 playing, have a second set of index cards (26 letters) ready to hand out. If you have a really large group (say ... 200) you'll need lots of sets of the alphabet so everyone can play. Consider printing additional cards for those letters used most often in word creation (example: a, e, i, o, u).

Rules:

1. Each person is supplied with one card. You must stay with your card throughout the activity (no trading cards or handing them off).
2. When I give the signal, form a 3-letter word. Once you've formed your word, stay with your word (group) until the next set of directions. Give the group about 60 seconds to form their words. Ask all non-utilized letters to come to the "lost and found" area (so they can help each other).
3. After the words are formed, take a moment to see what all the words are (let everyone see each other's words). Most likely all the letters won't get used in each round (but look in the variations section below).
4. Round 2: Now form 4-letter words (but not the bad kind of 4-letter word. You know what I'm talking about.) Everyone plays, even the lost and found letters.
5. Round 3: Now form 5 letter words, etc.
6. Six and seven letter words starts to be a little over the top but if you have fanatical group give it a try.

Comments

A wonderful activity to lead with large numbers of people. Usually lots of laughter is involved.

Debriefing

I like to use this activity when discussing inclusion vs. exclusion. Consider giving a vowel to someone who is normally treated as an "outsider". Because vowels are so useful, the owner of the vowel will usually feel included when the group invariably needs their help on a consistent basis when forming words. On the flip side, consider giving a “tough” letter (Z for example) to someone who is popular or with the “in” crowd. It can be enlightening to hear how these two people were treated.

I like to lead this activity at the beginning of a personal mission statement workshop I offer. After we play, I usually ask the group if there are there any wrong letters (out of 26 letters in the alphabet)? The response is usually – no. I continue…If there are no wrong letters, then how is it possible to have a misspelled word? The group response with - - 1) right letter in the wrong place and/or 2) missing letter. I then share with the group my belief that our mission in life is unique, just like the letters of the alphabet. There is no other person on the planet like you. I believe there are many people who are unhappy with their job/life because they are, like the wrong letter in a misspelled word, in the wrong place. We are all unique and it's our job to awaken to our divine purpose. Until we awaken, frustration abounds.

Variations:

1. The group must utilize ALL the letters in the group. Words can be any length. Give the group plenty of time to complete this (5 minutes). Allow the group to use other letters in a crossword fashion.

2. If you're teaching Spanish, ask the group to form Spanish words. If you're teaching Pig Latin have the group form Pig Latin words.

3. Instead of index cards with letters, create cards with math symbols (x, - , <, >, {, }, +, =, etc.) and numbers (1, 2, 3, 4, 5, 6, 7, 8, 9, 0). Supply the group with a number (52) and then have the group work to make the answer (52) as many ways as they can. Example 51 + 1 = 52 (they must make the entire equation), or 40 + 12 = 52.

History

I learned this activity from Karl Rohnke author of "Cowstails and Cobras II"

Hole Tarp

Teambuilding Game

Group Size 8-20
Age Range: Elementary – adult
Intensity: Mental=3, Physical=2
Time: 15-45 minutes
Space: Minimal
Set Up Time: 30 seconds
Props: Hole Tarp (buy or make), 3 tennis balls

Objective

Make the tennis ball travel around the holes without falling through a hole or off the tarp.

Set Up / Preparation

Between 8 and 20 participants surround the tarp spacing themselves out evenly holding on to the tarp with both hands. Supply the group with one tennis ball.

Rules

1. If the ball falls off the tarp or through a hole, the game starts over.
2. Participants must hold onto the tarp with both hands throughout the activity.
3. The tarp must be stretched out so that it remains flat (like a table top).
4. The tarp must be held so that it remains at its maximum size (the tarp may not be "gathered up" around the edges to be made smaller).
5. The group must hold the tarp in the air (i.e. not laid on the ground or on any other surface).
6. If the ball starts to roll off the tarp, participants can use their body like a "bumper" to keep the ball on the tarp (hands may not let go of tarp though).

7. Tarp holes may not be blocked. Should a ball fall through a hole, it may not be knocked back through the hole (example: kicking ball with foot back through the hole).
8. The tarp may not be altered.

What To Expect

Some common reactions for a group are to start off without a plan of action (example: "lets do this hole first, than that hole"). Frustration can set in as the ball rolls through a hole or off the top multiple times. Success is usually achieved when the group decides on which hole to go after and they do so in a calm and deliberate fashion. A very high functioning team can accomplish this activity in 5 minutes or less. An average team takes about 10-20 minutes to complete. A team having difficulty can take as long as 45 minutes.

Debriefing

This activity lends itself well to discussions around achieving success despite the obstacles in our lives. Life long success is rarely achieved through chance – instead, the successful make a plan, continually evaluate, then change the plan as needed. When everyone on the team is committed to the plan success is much more likely.

What strategies did you apply here to experience success and are any of these strategies applicable to real life situations?

How is this activity just like real life? How is it unlike real life?

Variations

1. Provide the group with a time limitation (example: only 10 minutes to complete this activity).
2. Require the group to do the basic activity without verbal communication.

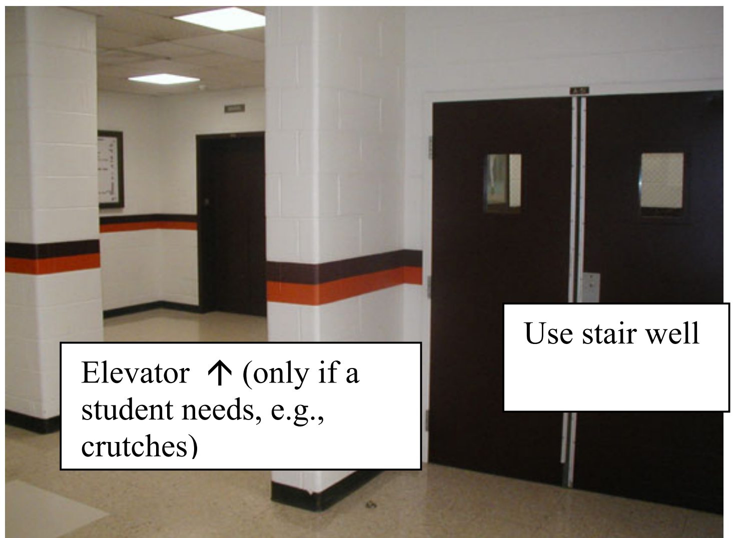
3. To make this easier, cover some of the holes with paper and tape. As the group improves, uncover more holes.
4. Require the group to circle the holes in a specific order.
5. Start the group off with only one ball then have them graduate to completing the same task with 2 then 3 balls simultaneously.
6. Try using different size and types of balls (example: baseball, marble, Nerf ball). The balls will react differently. It's especially interesting when the group must manage different types of balls simultaneously. The different balls could represent different types of challenges.
7. The basic Hole Tarp is created with five 6 inch round holes. Try cutting more holes in the tarp for added difficulty. Consider cutting holes with different diameters (for different "sizes" of challenges).
8. Here is a more involved version: Have the group identify the top 5 things that hold them back in some way then have them write these top 5 on 5 removable stickers (measuring approximately 2" x 3"). Now have the group write their first names on a tennis ball. Then supply the group with the Hole Tarp and ask them to apply the stickers next to the holes. Now ask the group to complete the basic challenge (described above). To debrief this exercise, ask the group to find strategies that promoted success on the tarp (i.e. how to avoid the top 5 pitfalls) and identify which of these strategies can be translated to avoiding the same pitfalls in real life.

History

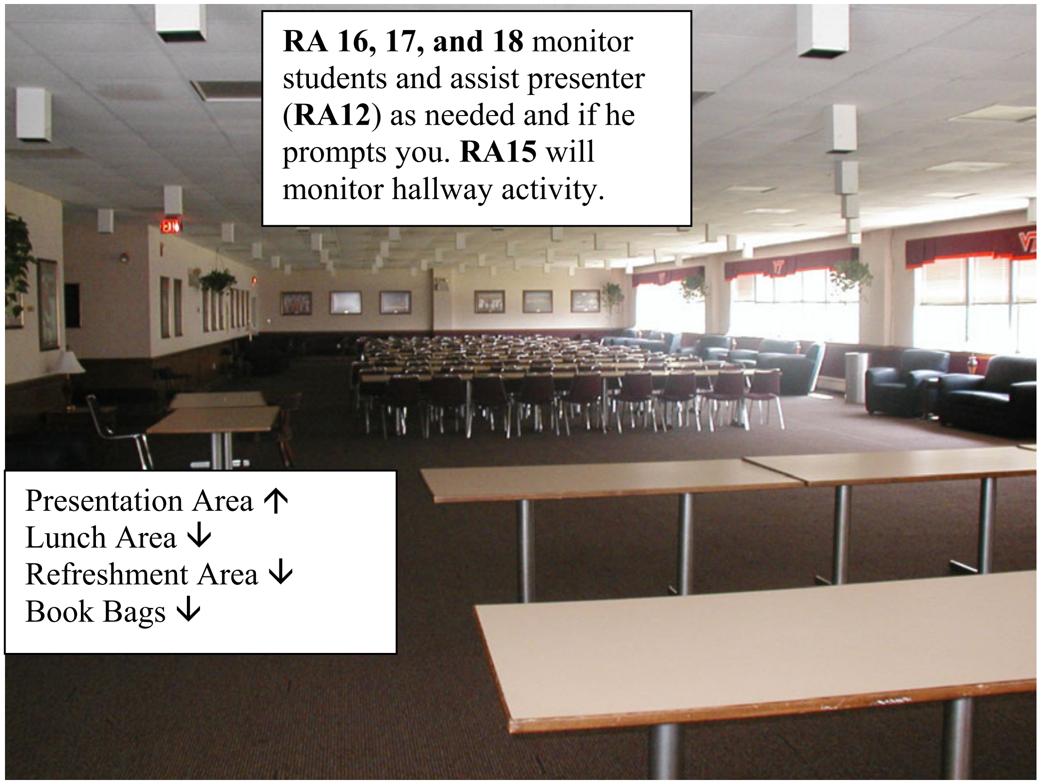
I developed this game in 2001 in an effort to help a group of public school teachers address and find solutions to some challenges facing them. The activity is perfect in it's ability to mimic the real life dilemma of dealing with challenges while working as a team to experience success. Some people allow themselves to use obstacles as a reason for not experiencing success.

Appendix T: Information for Research Assistants to the Teamwork Exercises

CONFIDENTIAL INFORMATION
AM activities in Bowman



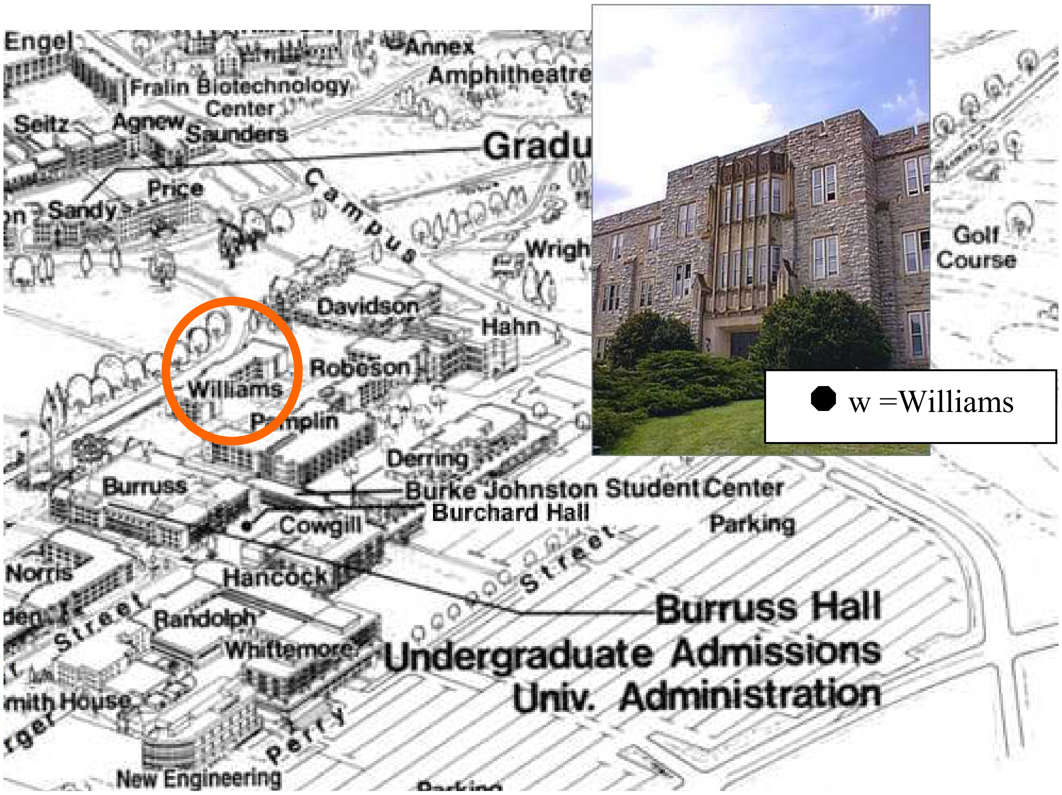
Note. The real names of research assistants have been replaced with RA1, RA2, etc. Roles were covered during the training session.



LUNCH-**RA15** [we must obtain the pizzas from the front of Jameson. We will hold the pizzas on the cart, until five minutes before lunch, then bring them up and set them on 4 different tables (two tables per organization). The pizza will be in 8 stacks of 7 pizzas—one stack for each organization.

RA12—[Before lunch start remind people to use the restroom sometime during lunch] Let participants know that lunch will be short. With about ten minutes left in the lunch period, announce, "If anyone needs a restroom break, go now because when we leave this building, you will need to proceed directly to the classroom in your next building." Do this however it works effectively. After lunch, have teams look at their nametags to identify the rooms they need to report to.

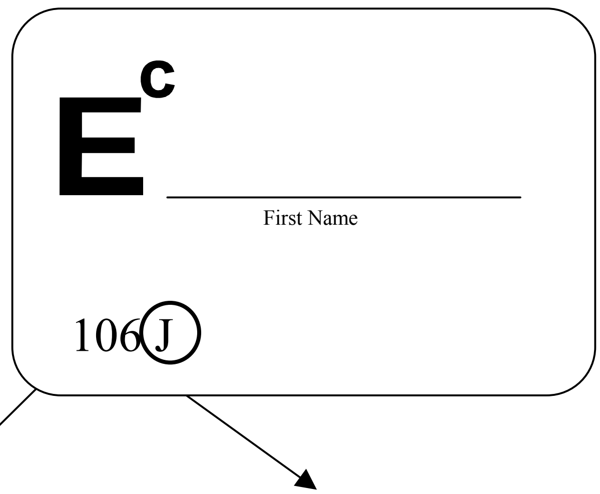
RA15 will lead the participants to the afternoon activities. **RAs 16, 17, and 18** will assist **RA15** in taking the participants to the other building. Refer to the *Orientation and Nametags* for the route to travel.


Engel
Annex
Fralin Biotechnology Center
Seitz
Agnew
Saunders
Price
Sandy
Campus
Golf Course
Davidson
Hahn
Williams
Robeson
Derring
Burruss
Burke Johnston Student Center
Burchard Hall
Parking
Cowgill
Norris
Street
Hancock
Randolph
Whittemore
Burruss Hall
Undergraduate Admissions
Univ. Administration
Perry
New Engineering
w =Williams

Appendix U: Control Group Activities

Problems

Fill in the following accurately:



Group Number: ___________ Member Letter: ___________(I, J, K, or L)

PID: ______________________@vt.edu

Student ID: ____________________________

Note. All puzzles on the next four pages, except numbers 16 and 18 are from the book *The Mammoth Book of Astounding Puzzles Collection* and editorial copyright © Constable & Robinson Publishing 1992, 2001. Appears by permission of Constable & Robinson Ltd., UK and Carroll & Graf Publishers, a Division of Avalon Publishing Group, USA.

1- MY FIRST-MY SECOND

By picking the right letter for each line, you can spell out a word of five letters. What is it?
My first is in FISH but not in SNAIL
My second is in RABBIT but not in KALE
My third is in UP but not in DOWN
My fourth is in TIARA but not in CROWN
My fifth is in TREE you'll plainly see,
The whole is a food for you and me.

2-EYING MARTIAN EYES.

There are Martians with 4 eyes, Martians with 6 eyes, Martians with 8 eyes, and Martians with 12 eyes. You know that there is an equal number of each type of Martian and you also know that the total number of eyes that the Martians have between them is 5,130.

How many Martians of each type have you got?

3-REPLACEMENT

Replace the first letter in each pair of words on either side of the brackets with another letter, which will form two new English words. Then place this letter in the brackets. When you have completed this for all five pairs of words you will find another word reading downwards in the brackets. What is it?

WIND (   ) CAP
AVER (   ) BATCH
MACE (   ) RACK
SATIN (   ) DEMON
TOUR (   ) LAWN

4-GET ONE IN.

Replace each question mark with one of the following digits in order that the calculation is correct.

1 2 2 3 4 4 7 9

(???/??x?)/??=1

5-WORD WORK

Rearrange the letters below to make a ten-lettered word.

GONEISCOMR

<u>6-GET RICH QUICK!</u>

A man cashed a check at the bank, and discovered that the cashier had transposed the pounds for pence and the pence for pounds, thus giving him more money. He went home on the bus and that cost him 42 pence. He then realized that he had exactly three times the amount of the original check.

What was the value of the original check?

<u>7- A LEAKY TANKER</u>

A petrol tanker travels at a speed of 42 mph. It is leaking petrol, however, and the petrol catches fire at the very moment it sets off. The petrol flame chases the tanker at a speed of 41-½ mph.

If the tanker has stopped after 56-¼ miles, when might it explode?

<u>8-HANDICAD</u>

In a 150-yard race, Bobby beats Karen by 22 yards. The race is now run again with Bobby starting 26 yards behind the start line.

Assuming equal performance, who wins the race this time?

<u>9-DOGGONE IT!</u>

Select and re-arrange the letters from the sentence below to find the names of at least three types of dogs.

I CAN STIR A MANAGER'S BLOOD

<u>10-STEAL A LETTER</u>

The same letter, which occurs at least three times in each of the following words, has been removed from them, and the remaining letters mixed up. Can you find the missing letter and unscramble the words?

TMRNC
JHRHM
LICTNF
PRISLP
NTLRCH

11-WORDPLAY

a) What is the longest word you can find that begins with "A", ends with "Y" and has a connection with order?

b) Which refreshment can be made from the letters of the words "WINTER COAT"?

12-CONFUSE ASSIGNATION

A gentleman says to his fair lady, "We will meet three days after the day before tomorrow."

If today is Monday, when will they meet?

13-WORD CHAIN

By changing one letter at a time to create a different word, what is the least number of steps needed to change the word CILL to BAIT?

14-GEOMETRICAL SERIES

This is a series. You will find what comes next from what is given. SPHERE. CIRCLE. LINE. What comes next?

Minutes allowed=5

15-STRANGE SERIES

Give the next number in this series: 22 20 10 8 4 2 ?

16-MANUFACTURING MANIA

A small company must produce 20 units of a product. It requires 20 different operations to make one product. The product only has one part. The operations are organized on a continuous line basis. Each operation requires exactly 6 minutes. How much time in minutes will be required to produce the 20 units?

The same small company must produce 20 units of another product. It requires 20 different operations to make one product. The product only has one part. The operations are organized on a continuous line basis. The 10th and 11th operations require 8 minutes each. All the other operations require exactly 6 minutes each. How much time in minutes will be required to produce the 20 units?

17- WHERE DO I LIVE?

Within the mass of letters there are seven four-letter words. Work out what the words are and place them into the rows, so that a town can be read downwards in one of the columns.

LNHAVAIESTRONEPUIOANNEPKWTRS

Answer Space

18- MANUFACTURING MANIA REVISITED

A small company must produce 20 units of a product. It requires 20 different operations to make one product. The product only has one part. The operations are organized on a continuous line basis. The 8^{th} operation requires 12 minutes. The 10^{th} and 11^{th} operations require 8 minutes each. All the other operations require exactly 6 minutes each. How much time in minutes will be required to produce the 20 units? Assume transportation between operations is zero.

A small company must produce 20 units of a product. It requires 20 different operations to make one product. The product only has one part. The operations are organized on a continuous line basis. The 10^{th} operation requires 22 minutes. However, for the 10th operation there are four identical stations to complete the operation. All the other operations require exactly 6 minutes each. How much time in minutes will be required to produce the 20 units? Assume transportation between operations is zero.

Appendix V: Script for Control Group Activities

CONFIDENTIAL INFORMATION
AM activities in Litton Reaves

Cell phone information for Saturday October 23rd:

RA13: 111-111-1111 (call with research related problems).

RA14, R.N.: 111-111-1111 (call if a participant becomes sick or injured).

Please arrive no later than 8:10 am, in case you have any last minute questions.

Bowman and Litton Reaves Morning Activities are covered in a separate packet.

All research assistants are asked to wear a white shirt, so we are easily identifiable from the participants.

Note. The real names of research assistants have been replaced with RA1, RA2, etc.

[Remember not to discuss these events with anyone who is transitioning to Bowman.]

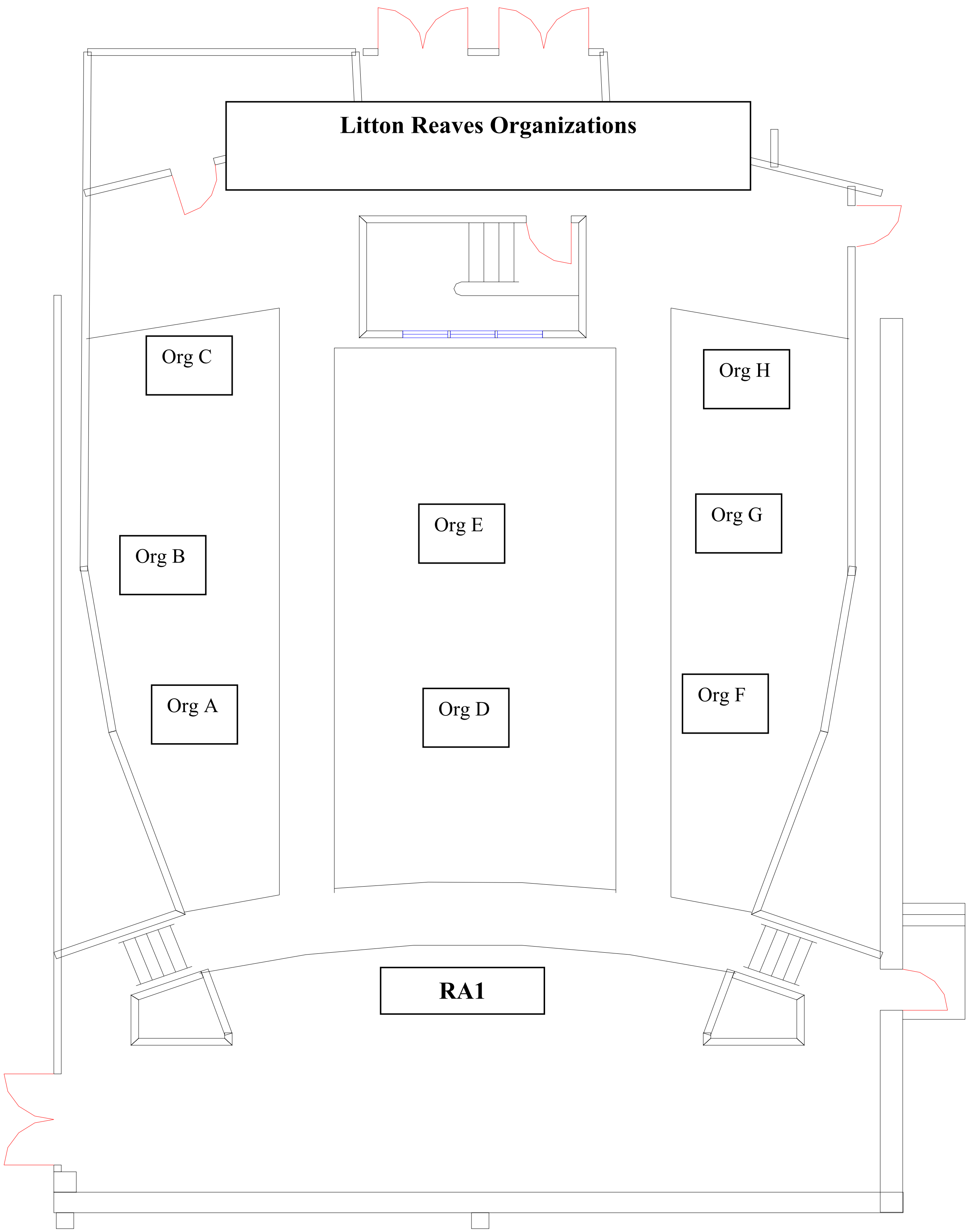
After the ● Nametags leave, **RA1** will send an organization of 18-22 participants to you. (This organization will consist of 4 to 5 small groups: Two 2s, Two 3s, and Two to Three 4's). At that point, hold up your letter so that your organization can find you. Listen for **RA1**'s cues. He will only be on the stage when all the organizations need to be addressed. The big items that need to happen are the following:

- find organization
- worksheet problems
- video/refreshments
- lunch

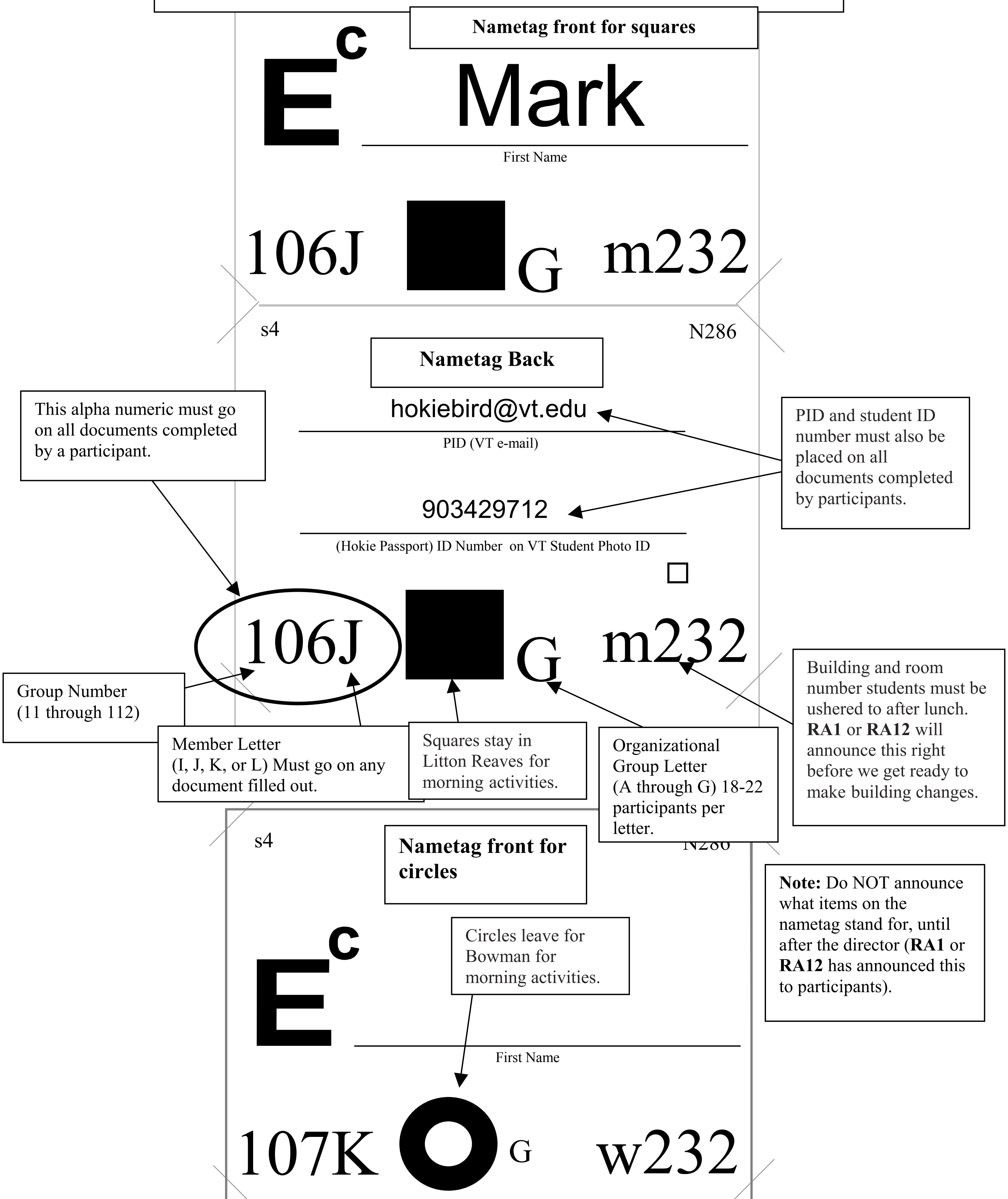
Fast pace usher to McBryde:

1. Make sure each participant finds his or her organization, which consists of his or her small group.
2. Once you have your organizations, make sure everyone has found their small group. Small groups must sit together within an organization.
3. Distribute the worksheet problems.
4. Collect the worksheet problems back, making sure that they have filled out the participant information correctly.
5. Distribute the refreshments during the video. You can get a volunteer or two from your organization to help you carry items.
6. Conduct round robins with the other organizations, so all the participants don't try to go to the restrooms at once.
7. For lunch, send 2 or 3 participants from your organization to stage to get the pizza stack. The pizza will be stacks of sevens boxes, with one stack for each organization.

RA1	Director
RA2	ORGANIZATION A
RA3	ORGANIZATION B
RA4	Primarily monitors outside, but looks in often to see if anyone needs assistance.
RA5	ORGANIZATION C
RA6	Fills in if you need a break. Also, assists **RA1**.
RA7	ORGANIZATION D
RA8	ORGANIZATION E
RA9	ORGANIZATION F
RA10	ORGANIZATION G
RA11	ORGANIZATION H


Litton Reaves Organizations
Org C
Org H
Org E
Org G
Org B
Org A
Org D
Org F
RA1

Confidential Information



MORNING ACTIVITIES IN LITTEN REAVES

- “I want to show you something else about your nametag.” [POINT TO THE LOWER LEFT CORNER OF THE NEW EXAMPLE.] “This is the small group you will remain with throughout the day. Some groups will have 2 people, some will have 3, and some will have 4.”
- “Now look at the letter beside your square. This is your organization. For the morning activities there will be 8 organizations. These organizations are only for the morning activities. In a few minutes you will get with your organization letter, which will make it easier to find the members in your small group. Once with your small group, introduce yourself to the other members in your group.”
- “Ok, now the Research Assistants will hold up a letter. Once you get to your organization, your Research Assistant will make sure you find your small group. Proceed to your organizational letter NOW.” [WAIT UNTIL THEY MOVE TO THEIR PLACES: the research assistant should try to arrange seating so small groups are together, side by side, when possible.]
- “We are going to give you some problems to solve. You may work with your group or as an individual, but everyone must turn in a solution. Do your best even though this does not count for the competition, which will come later today. At the end of 70 minutes, everyone must turn in a solution.” [RESEARCH ASSISTANTS NOW COME TO THE FRONT TO GET THE ASSIGNMENTS AND HAND THEM OUT TO THEIR ORGANIZATION.]
- “Fill out the top part of your packet, following the instructions on the front. Ask your Research Assistant if you don’t understand the instructions. They cannot help you with the problems. Show all your work and arrive at the best solution that you can.” [ONCE THEY HAVE WORKED 30 MINUTES, THE RESEARCH ASSISTANTS CAN TAKE TURNS GIVING RESTROOM BREAKS AND GIVING OUT WATER.]
- [When 65 minutes are up, take up solutions and place them back in the box they were in].

TRANSITION TO NEXT ACTIVITY
“We are going to show an instructional video. The Research Assistants will pass out candy and water if you don’t already have yours. If you need a restroom break, we will go by organization, with Letter A going first. Progress up the letters until everyone who needs a break is back.” [Instruct the Audio Visual person to start the instructional videos.]

LUNCH-----**RA4** [we must obtain the pizzas from the front of Litton Reaves. We will hold pizza deliverers in side hallway until **RA1** goes to the door to admit them. The pizza will be in 8 stacks of 7 pizzas-one stack for each organization.

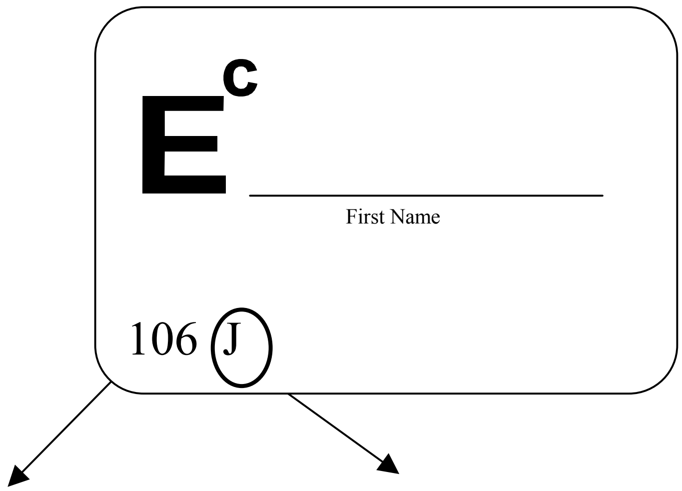
RA1—Before lunch starts, remind people to use the restroom sometime during lunch. Let participants know that lunch will be short. With about ten minutes left in the lunch period, announce, “If anyone needs a restroom break, go now because when we leave this building, you will need to proceed directly to the room in your next building.”

[With 5 minutes left in lunch, have a couple of volunteers from each group bring the boxes back up to the stage.] We will now go to McBryde: Walk quickly to McBryde with your Research Assistant and go directly to your room number within. Look at your nametag and find your room number. It is beside the *m* in the lower left corner. RA7 [RA7 holds up his hand] will lead you to McBryde. Please exit in an orderly way.”

Appendix W: Design Brief (Problem Structure)

Design Brief

Fill in the following accurately:



Group Number: ___________ Member Letter: ___________(I, J, K, or L)

PID: ____________________@vt.edu

Student ID: ___________________________

Directions: You have 20 minutes to individually read over the design brief and write out answers to the questions. You should not talk during this time. After 20 minutes, your room proctor will announce that you can share your ideas with other group members.

Your total score this afternoon is 50% from a computer design and another 50% from a truss model. If your group has one of the highest combined scores, then each member in your group will receive awards. Although the units are different for the two problems, the scores will be standardized so each one is weighted as 50% of your total score.

Engineering Problem 1: *Computer Bridge Design*
You are competing for a design contract to make the most cost effective bridge that can span 24 meters and support a dynamic load of 20 kilotons. You will use computer design software to simulate and test a bridge design. Your goal with the design software is to make the lowest cost bridge that will support a 20-kiloton load. The company accepting bids allows you to submit your current design every thirty minutes. For each 30-minute interval that you have a testable bridge that has improved at least $75 dollars, your group will receive a $30.00 bonus (i.e, $30 dollars will be subtracted from your raw score at a later date). Therefore, if you have four 30 minute increases of greater than $75 dollars, then you will receive (final raw score – 3($30 dollars) = $90 dollar bonus. You are allowed to make any type of bridge you like (deck, through, or combination), as long as it is 24 meters and you don't use templates or examples. That is, you "start from scratch." It may be a good idea to use the high-resolution drawing grid for your design. The following is some information that is provided with the computer bridge software.

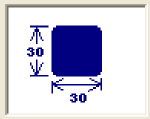
Member Properties Report

Material Properties:

Material	High-Strength Low-Alloy Steel
Yield Stress (Fy)	345000 kN per sq. meter
Modulus of Elasticity (E)	2.00E+08 kN per sq. meter
Mass Density	7850 kg per cubic meter

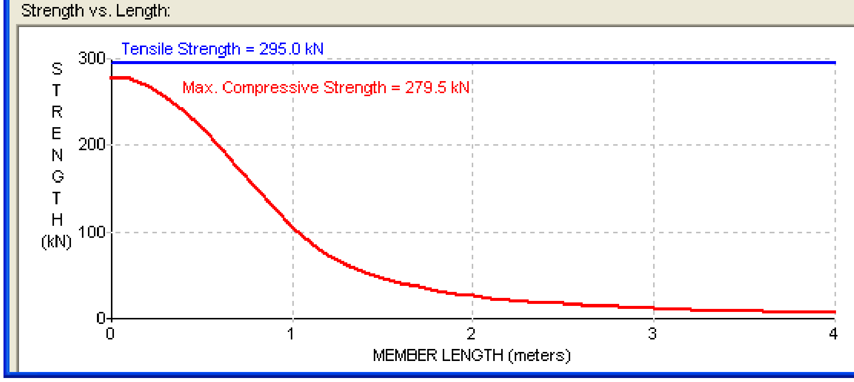
Cross-Section Properties:

Cross-Section Type	Solid Bar
Cross-Section Size	30 x 30 (mm)
Area	.0009 sq. meters
Moment of Inertia	6.75E-08 meters^4



Cost per Meter: $3.39

Strength vs. Length:



Hint: To view the engineering properties of a different member, you don't have to close this window. Just change the Material, Cross-Section, or Size on the Main Toolbar.

Close

Cost Calculations Report (Design Iteration #2)

Type of Cost	Product	Cost Calculation	Cost
Material Cost	Carbon Steel Bars	(10673.0 kg) x ($0.42 per kg) =	$4,482.66
	Carbon Steel Tubes	(154.2 kg) x ($0.63 per kg) =	$97.12
	High Strength Steel Bars	(0.0 kg) x ($0.48 per kg) =	$0.00
	High Strength Steel Tubes	(0.0 kg) x ($0.72 per kg) =	$0.00
	Quenched & Tempered Steel Bars	(0.0 kg) x ($0.70 per kg) =	$0.00
	Quenched & Tempered Steel Tubes	(0.0 kg) x ($1.06 per kg) =	$0.00
Connection Cost		(12 Joints) x ($25.00 per Joint) =	$300.00
Product Cost	16 - 120 x 120 Carbon Steel Bars	($100.00 per Product) =	$100.00
	1 - 80 x 80 Carbon Steel Bar	($100.00 per Product) =	$100.00
	2 - 140 x 140 Carbon Steel Bars	($100.00 per Product) =	$100.00
	1 - 120 x 120 x 6 Carbon Steel Tube	($100.00 per Product) =	$100.00
	1 - 55 x 55 x 2 Carbon Steel Tube	($100.00 per Product) =	$100.00
Total Cost			$5,379.78

Close

Load Test Results Report (Design Iteration #130)

#	Member Size	Section	Matl.	Length (m)	Compr. Force (kN)	Compr. Strength (kN)	Status	Tension Force (kN)	Tension Strength (kN)	Status
1	60 x 60	Bar	CS	4.0	0.0	105.5	OK	810.6	855.0	OK
2	60 x 60	Bar	CS	4.0	0.0	105.5	OK	839.0	855.0	OK
3	60 x 60	Bar	CS	6.2	14.8	44.3	OK	313.7	855.0	OK
4	90 x 90 x 4	Tube	CS	6.2	65.1	69.7	OK	263.4	326.8	OK
5	60 x 60	Bar	CS	5.3	52.7	60.0	OK	249.7	855.0	OK
6	60 x 60	Bar	CS	5.3	28.4	60.0	OK	299.1	855.0	OK
7	60 x 60	Bar	CS	4.0	0.0	105.5	OK	735.8	855.0	OK
8	60 x 60	Bar	CS	4.0	0.0	105.5	OK	622.3	855.0	OK
9	60 x 60	Bar	CS	4.0	0.0	105.5	OK	725.9	855.0	OK
10	60 x 60	Bar	CS	4.0	0.0	105.5	OK	584.1	855.0	OK
11	90 x 90 x 4	Tube	CS	4.4	58.1	134.2	OK	273.2	326.8	OK
12	90 x 90 x 4	Tube	CS	4.4	73.1	134.2	OK	254.2	326.8	OK
13	160 x 160 x 8	Tube	CS	3.4	930.3	938.0	OK	0.0	1155.2	OK
14	160 x 160 x 8	Tube	CS	3.5	908.4	928.5	OK	0.0	1155.2	OK
15	160 x 160 x 8	Tube	CS	3.5	852.6	928.5	OK	0.0	1155.2	OK
16	160 x 160 x 8	Tube	CS	3.4	873.2	938.0	OK	0.0	1155.2	OK
17	40 x 40	Bar	CS	3.1	0.0	35.8	OK	265.6	380.0	OK
18	40 x 40	Bar	CS	3.1	0.0	35.8	OK	283.1	380.0	OK
19	160 x 160 x 8	Tube	CS	3.6	909.3	913.6	OK	0.0	1155.2	OK
20	160 x 160 x 8	Tube	CS	3.6	887.1	913.6	OK	0.0	1155.2	OK
21	40 x 40	Bar	CS	5.1	0.0	13.0	OK	273.2	380.0	OK
22	60 x 60	Bar	CS	5.1	27.8	65.9	OK	245.1	855.0	OK
23	160 x 160 x 8	Tube	CS	3.3	936.0	947.7	OK	0.0	1155.2	OK
24	160 x 160 x 8	Tube	CS	3.3	936.0	947.7	OK	0.0	1155.2	OK
25	40 x 40	Bar	CS	5.3	1.9	12.1	OK	0.0	380.0	OK

Close

Engineering Problem 2: *Truss Model*

You are an engineer working for the Red Cross. The Red Cross needs efficient temporary trusses that can be brought in by helicopter to help people on the east coast during floods. Your goal is to make an efficient truss. For example, a truss that has a mass of 50 grams and supports a load of 10,000 grams (10 kg) just before failure would have an efficiency factor of 200 [10,000 g ÷ 50 g = 200]. Your supervisor wants an efficient truss, so that the Red Cross units can lift more trusses with one helicopter. When the trusses arrive, their function is to support the load of a crane and the items it needs to lift out of the ravine. In order for it not to interfere with the crane, the truss must be a deck truss (the truss is below the roadbed). In order to test your design, your supervisor wants you to construct a truss model. Your supervisor wants you to use the following materials for your truss, because they are readily available in your region.

Qty	Stock Items	Mass
12	3 mm x 24.5 cm card stock strips	
12	4 mm x 24.5 cm card stock strips	
12	5 mm x 24.5 cm card stock strips	
12	6 mm x 24.5 cm card stock strips	
20	7 x 7 x mm x 22 cm square tubes	1.9 g
20	9 x 9 x mm x 22 cm square tubes	
50	45 x 30 mm gusset plates	

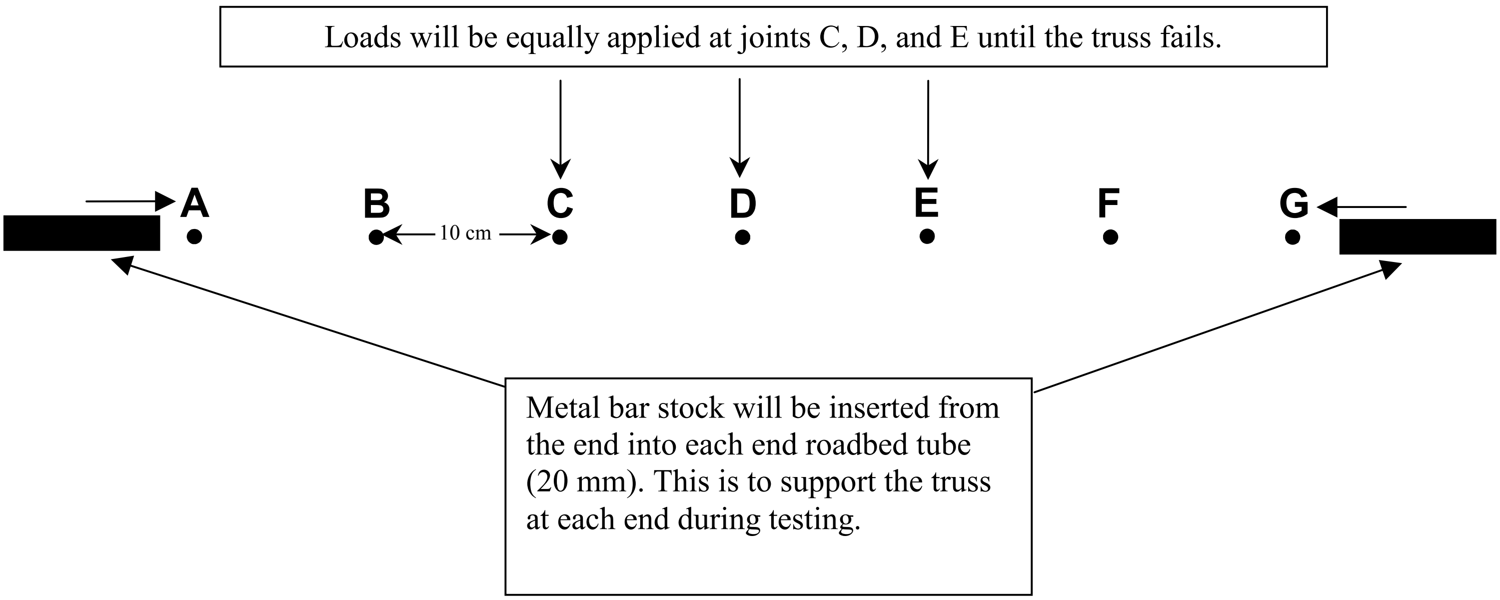
All of the above members are made of one type of material: 80 lb., uncoated cover stock paper, which is .012 inches thick (.305 mm).

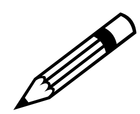
One of your coworkers made this table, which consists of a series of tests. Each individual member is tested until failure. Members below are made of the same card stock material as the ones above.

T = tension and C = compression

Test #	Cross Section (CM) (single bars)	Length (cm)	Trial 1	Trial 2	Trial 3	Trial 4	Mean	Weight of Bucket and sand	Tensile/Compressive Strength (Newtons)	
T1	3.0	20	879.6	822.9	780.3	652.6	783.8594	7.69	21.38	
T2	3.5	20	851.3	865.4	794.5	837.1	837.0625	8.21	22.83	
T3	4.0	20	1021.5	936.4	993.1	993.1	986.0313	9.67	26.89	
T4	5.0	20	1319.4	1276.9	1333.6	1135.0	1266.234	12.42	34.53	
T5	5.5	20	1418.8	1418.8	1305.3	1461.3	1401.016	13.74	38.21	
T6	6.5	20	1631.6	1645.8	1702.5	1688.3	1667.031	16.35	45.46	
T7	7.0	20	1844.4	1730.9	1986.3	1787.6	1837.281	18.02	50.11	
T8	8.0	20	2213.3	2156.5	2099.8	2156.5	2156.5	21.16	58.81	
C1	6.0	15	1645.75	1816	1475.5		1645.75	16.14	44.88	
C2	*8.0*	15	*2014.63*	*1901.13*	*1957.88*		*1957.875*	*19.21*	*53.39*	
C3	*10.0*	15	*2610.5*	*2667.25*	*2043*		*2440.25*	*23.94*	*66.55*	
C4	6.0	10	2043	2525.38	1816		2128.125	20.88	58.04	
C5	*8.0*	10	*1589*	*2525.38*	*1589*		*1901.125*	*18.65*	*51.85*	
C6	*10.0*	10	*2582.13*	*1929.5*	*2270*		*2260.542*	*22.18*	*61.65*	
C7	6.0	5	1730.88	2411.88	1702.5		1948.417	19.11	53.14	
C8	*8.0*	5	*2497*	*2156.5*	*2099.75*		*2251.083*	*22.08*	*61.39*	
C9	*10.0*	5	*2752.38*	*2979.38*	*2411.88*		*2714.542*	*26.63*	*74.03*	

The truss must support the lifting cranes at joint C, D, and E, as it straddles a ravine, and must span 60 cm. It must use one type of square tube or the other, because the tester will not accommodate both at the same time. A variety of doubled bars may be used. In addition, it must have **seven** joints at the roadbed, which are spaced every 10 cm. Additional joints can be added to the roadbed, which must be made entirely of tubes. Your supervisor wants you to submit a deck truss that will be tested in the following manner:





Individual Design Brief Questions: Take the rest of your twenty minutes to write out answers to the following questions:

How is the computer bridge score calculated?

List all of the items that you can vary in the computer bridge design.

What are the factors that you think impact the cost of the computer bridge?

Are you able to detect any patterns in the data? How would you explain these relationships to a friend?

How is the truss model tested? What factors impact this score?

Is there a meaningful way to put all of the relationships together?

What math and science tools can you apply to the problem?

Do you have any initial ideas? How would you test these ideas?

What are suggestions you have for your group to insure ALL ideas and their relationships to other ideas are explored fully?

What additional information do you need to gather in formulating solutions to this problem?

What knowledge do you bring to this situation, and how can you use that to determine what you need to know to solve the problem?

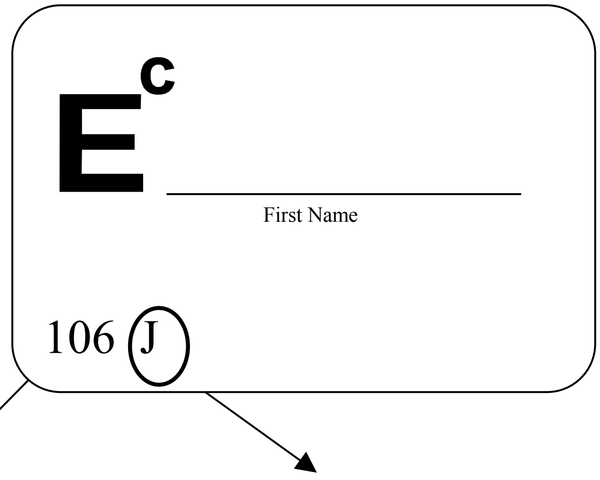
How can you make sure that everyone's unique knowledge of the situation is shared?

Design Sketches

Appendix X: Design Brief (Control Group)

Design Brief

Fill in the following accurately:



Group Number: ___________   Member Letter: ___________(I, J, K, or L)

PID: ____________________@vt.edu

Student ID: __________________________

Directions: You have 30 minutes to read through the design brief and formulate solutions, before we transition to the next activity.

Your total score this afternoon is 50% from a computer design and another 50% from a truss model. If your group has one of the highest combined scores, then each member in your group will receive awards. Although the units are different for the two problems, the scores will be standardized so each one is weighted as 50% of your total score.

Engineering Problem 1: *Computer Bridge Design*
You are competing for a design contract to make the most cost-effective bridge that can span 24 meters and support a dynamic load of 20 kilotons. You will use computer design software to simulate and test a bridge design. Your goal with the design software is to make the lowest cost bridge that will support a 20-kiloton load. The company accepting bids allows you to submit your current design every thirty minutes. For each 30-minute interval that you have a testable bridge that has improved at least $75 dollars, your group will receive a $30.00 bonus (i.e, $30 dollars will be subtracted from your raw score at a later date). Therefore, if you have four 30 minute increases of greater than $75 dollars, then you will receive (final raw score – 3($30 dollars) = $90 dollar bonus. You are allowed to make any type of bridge you like (deck, through, or combination), as long as it is 24 meters and you don't use templates or examples. That is, you "start from scratch." It may be a good idea to use the high-resolution drawing grid for your design. The following is some information that is provided with the computer bridge software.

Member Properties Report

Material Properties:

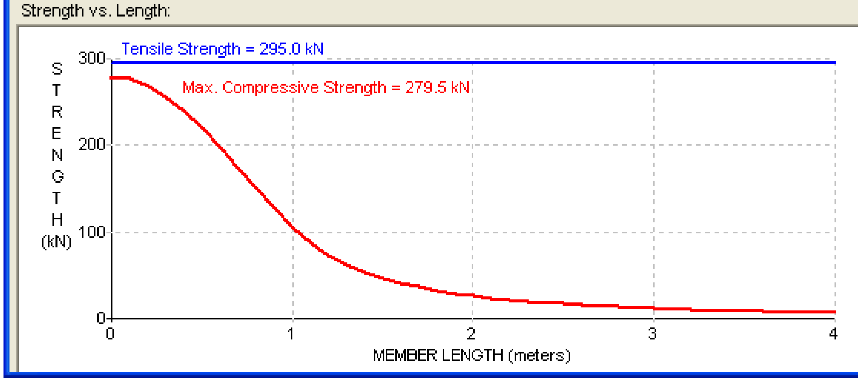
Material	High-Strength Low-Alloy Steel
Yield Stress (Fy)	345000 kN per sq. meter
Modulus of Elasticity (E)	2.00E+08 kN per sq. meter
Mass Density	7850 kg per cubic meter

Cross-Section Properties:

Cross-Section Type	Solid Bar
Cross-Section Size	30 x 30 (mm)
Area	.0009 sq. meters
Moment of Inertia	6.75E-08 meters^4

Cost per Meter: $3.39

Strength vs. Length:



Hint: To view the engineering properties of a different member, you don't have to close this window. Just change the Material, Cross-Section, or Size on the Main Toolbar.

Close

Cost Calculations Report (Design Iteration #2)

Type of Cost	Product	Cost Calculation	Cost
Material Cost	Carbon Steel Bars	(10673.0 kg) x ($0.42 per kg) =	$4,482.66
	Carbon Steel Tubes	(154.2 kg) x ($0.63 per kg) =	$97.12
	High Strength Steel Bars	(0.0 kg) x ($0.48 per kg) =	$0.00
	High Strength Steel Tubes	(0.0 kg) x ($0.72 per kg) =	$0.00
	Quenched & Tempered Steel Bars	(0.0 kg) x ($0.70 per kg) =	$0.00
	Quenched & Tempered Steel Tubes	(0.0 kg) x ($1.06 per kg) =	$0.00
Connection Cost		(12 Joints) x ($25.00 per Joint) =	$300.00
Product Cost	16 - 120 x 120 Carbon Steel Bars	($100.00 per Product) =	$100.00
	1 - 80 x 80 Carbon Steel Bar	($100.00 per Product) =	$100.00
	2 - 140 x 140 Carbon Steel Bars	($100.00 per Product) =	$100.00
	1 - 120 x 120 x 6 Carbon Steel Tube	($100.00 per Product) =	$100.00
	1 - 55 x 55 x 2 Carbon Steel Tube	($100.00 per Product) =	$100.00
Total Cost			$5,379.78

Close

Load Test Results Report (Design Iteration #130)

#	Member Size	Section	Matl.	Length (m)	Compr. Force (kN)	Compr. Strength (kN)	Status	Tension Force (kN)	Tension Strength (kN)	Status
1	60 x 60	Bar	CS	4.0	0.0	105.5	OK	810.6	855.0	OK
2	60 x 60	Bar	CS	4.0	0.0	105.5	OK	839.0	855.0	OK
3	60 x 60	Bar	CS	6.2	14.8	44.3	OK	313.7	855.0	OK
4	90 x 90 x 4	Tube	CS	6.2	65.1	69.7	OK	263.4	326.8	OK
5	60 x 60	Bar	CS	5.3	52.7	60.0	OK	249.7	855.0	OK
6	60 x 60	Bar	CS	5.3	28.4	60.0	OK	299.1	855.0	OK
7	60 x 60	Bar	CS	4.0	0.0	105.5	OK	735.8	855.0	OK
8	60 x 60	Bar	CS	4.0	0.0	105.5	OK	622.3	855.0	OK
9	60 x 60	Bar	CS	4.0	0.0	105.5	OK	725.9	855.0	OK
10	60 x 60	Bar	CS	4.0	0.0	105.5	OK	584.1	855.0	OK
11	90 x 90 x 4	Tube	CS	4.4	58.1	134.2	OK	273.2	326.8	OK
12	90 x 90 x 4	Tube	CS	4.4	73.1	134.2	OK	254.2	326.8	OK
13	160 x 160 x 8	Tube	CS	3.4	930.3	938.0	OK	0.0	1155.2	OK
14	160 x 160 x 8	Tube	CS	3.5	908.4	928.5	OK	0.0	1155.2	OK
15	160 x 160 x 8	Tube	CS	3.5	852.6	928.5	OK	0.0	1155.2	OK
16	160 x 160 x 8	Tube	CS	3.4	873.2	938.0	OK	0.0	1155.2	OK
17	40 x 40	Bar	CS	3.1	0.0	35.8	OK	265.6	380.0	OK
18	40 x 40	Bar	CS	3.1	0.0	35.8	OK	283.1	380.0	OK
19	160 x 160 x 8	Tube	CS	3.6	909.3	913.6	OK	0.0	1155.2	OK
20	160 x 160 x 8	Tube	CS	3.6	887.1	913.6	OK	0.0	1155.2	OK
21	40 x 40	Bar	CS	5.1	0.0	13.0	OK	273.2	380.0	OK
22	60 x 60	Bar	CS	5.1	27.8	65.9	OK	245.1	855.0	OK
23	160 x 160 x 8	Tube	CS	3.3	936.0	947.7	OK	0.0	1155.2	OK
24	160 x 160 x 8	Tube	CS	3.3	936.0	947.7	OK	0.0	1155.2	OK
25	40 x 40	Bar	CS	5.3	1.9	12.1	OK	0.0	380.0	OK

Close

Engineering Problem 2: *Truss Model*
You are an engineer working for the Red Cross. The Red Cross needs efficient temporary trusses that can be brought in by helicopter to help people on the east coast during floods. Your goal is to make an efficient truss. For example, a truss that has a mass of 50 grams and supports a load of 10,000 grams (10 kg) just before failure would have an efficiency factor of 200 [10,000 g ÷ 50 g = 200]. Your supervisor wants an efficient truss, so that the Red Cross units can lift more trusses with one helicopter. When the trusses arrive, their function is to support the load of a crane and the items it needs to lift out of the ravine. In order for it not to interfere with the crane, the truss must be a deck truss (the truss is below the roadbed). In order to test your design, your supervisor wants you to construct a truss model. Your supervisor wants you to use the following materials for your truss, because they are readily available in your region.

Qty	Stock Items	Mass
12	3 mm x 24.5 cm card stock strips	
12	4 mm x 24.5 cm card stock strips	
12	5 mm x 24.5 cm card stock strips	
12	6 mm x 24.5 cm card stock strips	
20	7 x 7 x mm x 22 cm square tubes	1.9 g
20	9 x 9 x mm x 22 cm square tubes	
50	45 x 30 mm gusset plates	

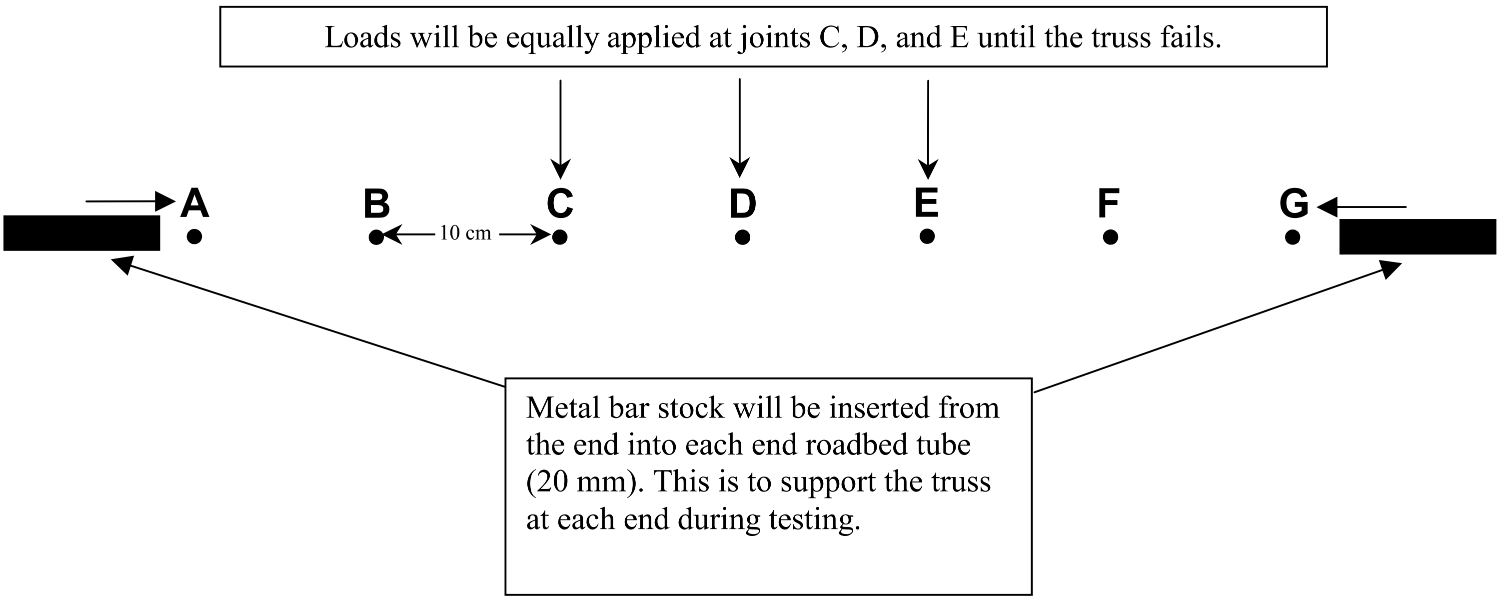
All of the above members are made of one type of material: 80 lb., uncoated cover stock paper, which is .012 inches thick (.305 mm).

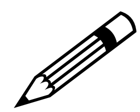
One of your coworkers made this table, which consists of a series of tests. Each individual member is tested until failure. Members below are made of the same card stock material as the ones above.

T = tension and C = compression

Test #	Cross Section (CM) (single bars)	Length (cm)	Trial 1	Trial 2	Trial 3	Trial 4	Mean	Weight of Bucket and sand	Tensile/Compressive Strength (Newtons)	
T1	3.0	20	879.6	822.9	780.3	652.6	783.8594	7.69	21.38	
T2	3.5	20	851.3	865.4	794.5	837.1	837.0625	8.21	22.83	
T3	4.0	20	1021.5	936.4	993.1	993.1	986.0313	9.67	26.89	
T4	5.0	20	1319.4	1276.9	1333.6	1135.0	1266.234	12.42	34.53	
T5	5.5	20	1418.8	1418.8	1305.3	1461.3	1401.016	13.74	38.21	
T6	6.5	20	1631.6	1645.8	1702.5	1688.3	1667.031	16.35	45.46	
T7	7.0	20	1844.4	1730.9	1986.3	1787.6	1837.281	18.02	50.11	
T8	8.0	20	2213.3	2156.5	2099.8	2156.5	2156.5	21.16	58.81	
C1	6.0	15	1645.75	1816	1475.5		1645.75	16.14	44.88	
C2	8.0	15	2014.63	1901.13	1957.88		1957.875	19.21	53.39	
C3	10.0	15	2610.5	2667.25	2043		2440.25	23.94	66.55	
C4	6.0	10	2043	2525.38	1816		2128.125	20.88	58.04	
C5	8.0	10	1589	2525.38	1589		1901.125	18.65	51.85	
C6	10.0	10	2582.13	1929.5	2270		2260.542	22.18	61.65	
C7	6.0	5	1730.88	2411.88	1702.5		1948.417	19.11	53.14	
C8	8.0	5	2497	2156.5	2099.75		2251.083	22.08	61.39	
C9	10.0	5	2752.38	2979.38	2411.88		2714.542	26.63	74.03	

The truss must support the lifting cranes at joint C, D, and E, as it straddles a ravine, and must span 60 cm. It must use one type of square tube or the other, because the tester will not accommodate both at the same time. A variety of doubled bars may be used. In addition, it must have **seven** joints at the roadbed, which are spaced every 10 cm. Additional joints can be added to the roadbed, which must be made entirely of tubes. Your supervisor wants you to submit a deck truss that will be tested in the following manner:



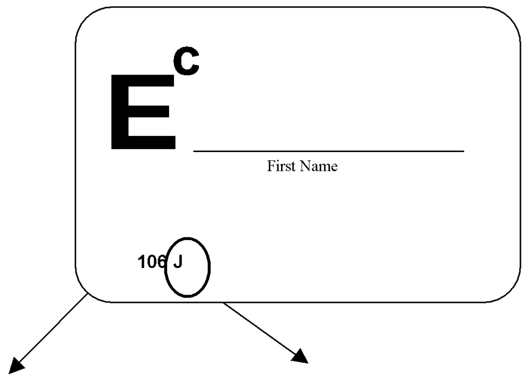


Design Sketches

Appendix Y: Exit Survey

Exit Survey

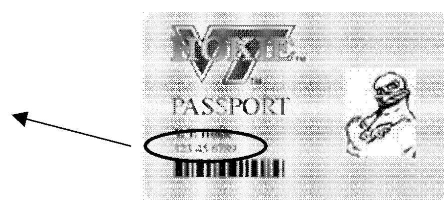
Fill in the following accurately:



Group Number: ___________ Member Letter: ___________(I, J, K, or L)

PID: ____________________@vt.edu

Student ID: ___________________________



What is the last name of your ENGE 1024 Instructor? ______________________________

Gender: ☐ Male ☐ Female

Birth Date: / / (e.g., 02/25/85)

Academic Level: ☐ Freshmen ☐ Sophomore ☐ Junior ☐ Senior

1. On average, how many hours do you spend playing computer games ***per week***?

☐ None ☐ 0-2 ☐ 2-4 ☐ 4-6 ☐ 8-10 ☐ 10-12 ☐ 12-14 ☐ 16+

2. The computer simulation software you used today is *West Point Bridge Builder Version4* (V4). Each version is a different engineering problem. Check the version(s) of this software that you had used before today (check all that apply).

☐ None ☐ V3 ☐ V4 ☐ 2002 ☐ 2003 ☐ 2004

3. Not including today, what is the ***total*** number of hours that you have used all the different versions combined?

☐ None ☐ 0-2 ☐ 2-4 ☐ 4-6 ☐ 8-10 ☐ 10-12 ☐ 12-14 ☐ 16+

4. Not including today, how many ***total*** hours have you used *West Point Bridge Builder Version4.*

☐ None ☐ 0-2 ☐ 2-4 ☐ 4-6 ☐ 8-10 ☐ 10-12 ☐ 12-14 ☐ 16+

5. Have you ever constructed a model bridge or truss and then had it tested until failure (i.e., it breaks)?

☐ Yes ☐ No

6. If yes, what type of material was the bridge or truss made out of?

☐ Balsa or other wood Other Material: ___________________________________

7. Had you ever constructed a bridge or truss model, like the one you made today. That is, were there strips of papers for bars and paper tubes, similar to the ones used today?

☐ Yes ☐ No

8. What did you learn from the ***morning activities?*** What did you find meaningful about them? Please write a few sentences.

9. What did you learn from the ***afternoon activities***? What did you find meaningful about them? Please write a few sentences.

Please *circle* the most accurate response as you consider working in groups.
There are no "right" or "wrong" answers. Do not leave any questions blank.

	Survey 1 (Teamwork Orientation Scale) R = reverse coded	Strongly Disagree	Disagree	Not sure tend to to Disagree	Neither Agree nor Disagree	Not sure tend to Agree	Agree	Strongly Agree
1	What I typically get out of group projects is not worth the effort I've put in.	1	2	3	4	5	6	7
2	I like explaining new things to people.	1	2	3	4	5	6	7
3	Having to work in a group really detracts from my ability to learn new things. (R)	1	2	3	4	5	6	7
4	All else being equal, groups are more productive than the same people would be working alone.	1	2	3	4	5	6	7
5	I believe that group work really unleashes the motivation and power of people.	1	2	3	4	5	6	7
6	I'm more comfortable working by myself than with others. (R)	1	2	3	4	5	6	7
7	I always work hard to make sure my group is the most productive it can be.	1	2	3	4	5	6	7
8	If given a choice, I'd choose to work in a group rather than by myself.	1	2	3	4	5	6	7
9	Working in groups is frustrating because there are too many different opinions on how to do something. (R)	1	2	3	4	5	6	7
10	I generally prefer to work alone than with others. (R)	1	2	3	4	5	6	7
11	I really enjoy working in groups.	1	2	3	4	5	6	7
12	I just end up getting confused working in groups. (R)	1	2	3	4	5	6	7
13	I find other people often have interesting contributions that I might not have thought of myself.	1	2	3	4	5	6	7
14	I dread working in groups. (R)	1	2	3	4	5	6	7
15	Unless I'm confident that members in my group will carry their weight, I tend to be leery of group situations. (R)	1	2	3	4	5	6	7
16	It is easier for me to learn new information by working closely with group members than by myself.	1	2	3	4	5	6	7
17	I find that it takes too long to get anything accomplished when working in groups. (R)	1	2	3	4	5	6	7
18	I like working in groups.	1	2	3	4	5	6	7
19	I think that many people simply "coast" and fail to carry their weight in group projects. (R)	1	2	3	4	5	6	7
20	I enjoy sharing ideas and learning new perspectives during group projects. (R)	1	2	3	4	5	6	7
21	I usually get more out of a project by working alone, rather than with others. (R)	1	2	3	4	5	6	7

Mathieu, J. E., & Marks, M. (1998). *Developing a measure of team orientation: Scale construction, reliability and validity.* Unpublished Manuscript. Pennsylvania State University. Reprinted with permission of the authors.

Note. Team was replaced with the word *group* in order to keep the purposes of the study concealed from participants. (Rs) and title were added after the research study; these were not on the participant version. Original document was converted to an image and reduced in size.

Appendix Z: Truss Testing System

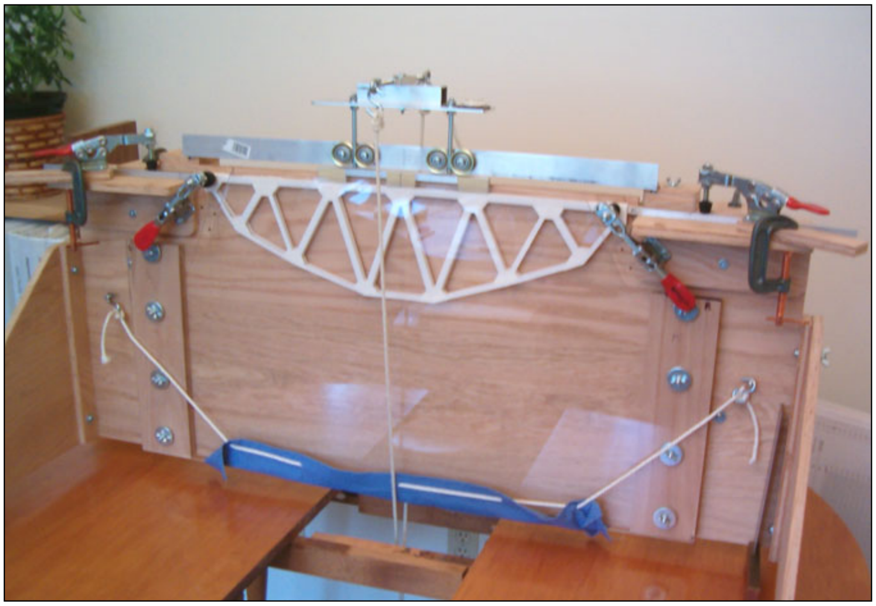


Figure Z1. *Truss tester for testing trusses until failure.*
Note. All trusses were tested until failure with the same procedures.

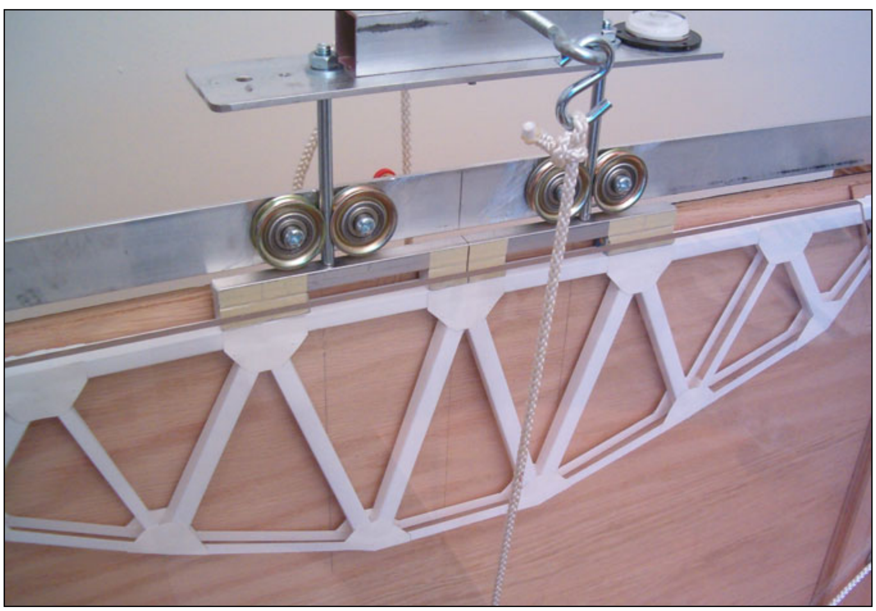


Figure Z2. *Load was transferred to truss through bar stock at joints C, D, and E.*
Note. The load was applied two-thirds the distance out from the middle joint, so that each of the three middle joints had the same load. The bar stock on top of the trusses was aligned with the center of each truss, which was positioned in the center of the truss tester.

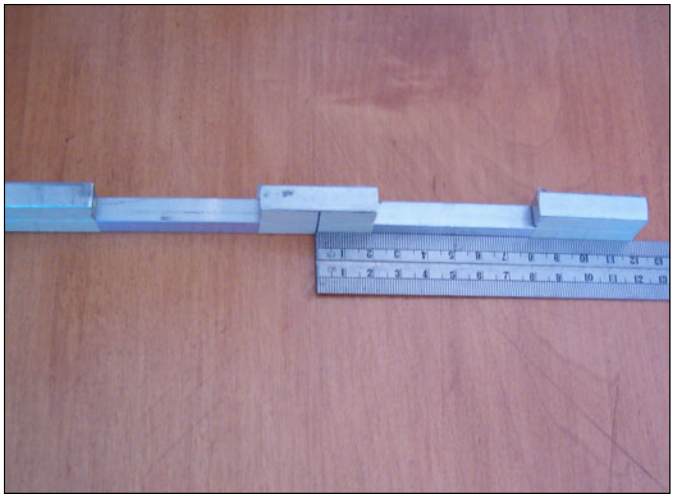


Figure Z3. *Bar stock to transfer the load to three joints.*

Note. Aluminum bar stock was placed on top of the truss, which included three shorter lengths so that the load was applied to the three middle joints.

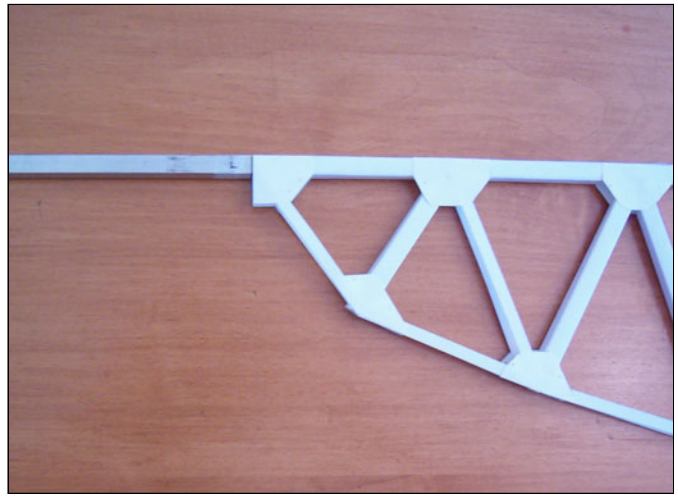


Figure Z4. *Bar stock was placed in each end of the truss.*

Note. Bar stock was inserted 20 mm into each end of the roadbed tubes.

Figure Z5. *Bucket for holding water to apply the load.*

Note. A bucket was suspended with rope underneath the truss tester.

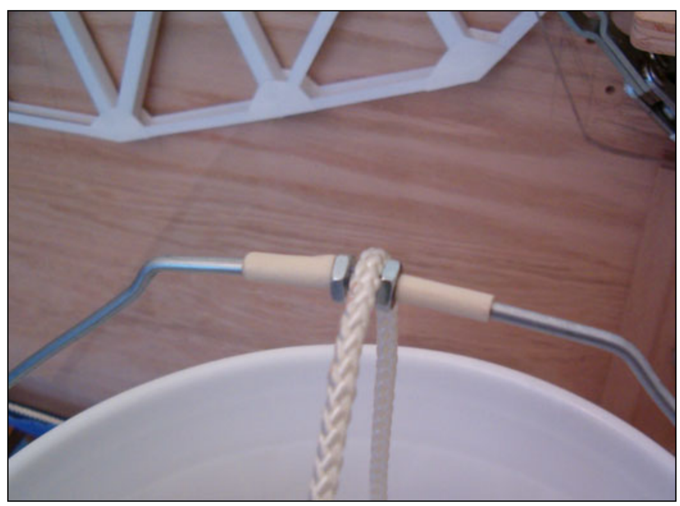


Figure Z6. *Bucket was hung from its balance point.*

Note. The balance point for the handle of the bucket was found and spacers maintained this point during testing.

Figure Z7. *Adjustable feet so truss tester can be leveled.*

Note. The tester had four adjustable rubber feet, so it could be leveled.

Figure Z8. *Checking for level of the truss tester.*

Note. Before trusses were tested, the tester was checked for level.

Figure Z9. *Plexiglass was spaced out for each size truss.*

Note. Plexiglass kept trusses from bowing out during testing. The trusses had some space between the Plexiglass and the back of the truss tester. This allowed equal spacing of the two truss thicknesses (7.25 mm and 9.25 mm).

Figure Z10. *Track was made parallel to the truss.*

Note. The track was made adjustable, so it could be adjusted for the two truss thicknesses (7.25 mm and 9.25 mm).

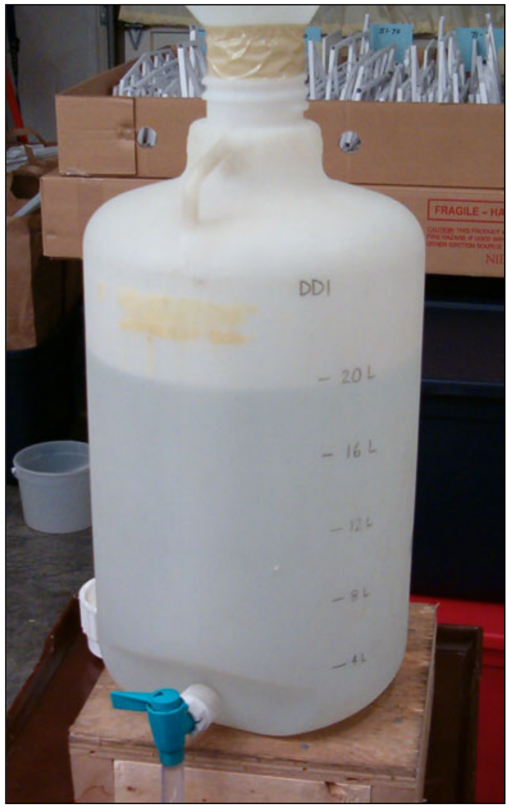


Figure Z11. *Tank for dispensing water.*

Note. Before each truss was tested, a tank was filled with 20 liters of water.

Figure Z12. *A notch was placed on the water valve.*

Note. A marker was placed on the nozzle of the water tank, so that the flow of water was the same for each truss.

Figure Z13. *The tube was at a slight incline before the bucket.*

Note. The water entered the bucket at a slight grade, so that the water would stop flowing as soon as the water valve was shut.

Figure Z14. *Scale platform for measuring mass.*

Note. Before the first truss was tested, the scale was calibrated with weights commonly found in physics classrooms.

Figure Z15. *Photos were made for each mass at which the truss failed.*

Note. A card was placed above the scale readout to insure that the correct measurement was recorded.

Figure Z16. *The mass of each truss was measured with two scales.*

Note. First, all the masses were recorded by one research assistant with both scales. After this, a second research assistant recorded the truss masses. The four mass measurements for each truss were analyzed for accuracy.

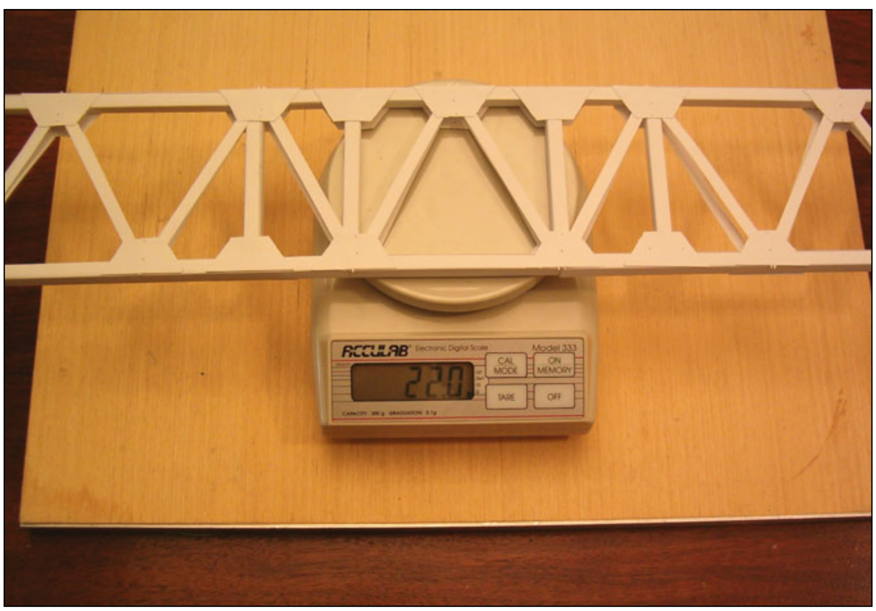


Figure Z17. *Trusses were lined up with the center joint on the scales.*

Note. Tare was reset before taking the mass of each truss.

Appendix AA: Rooms for the Research Study

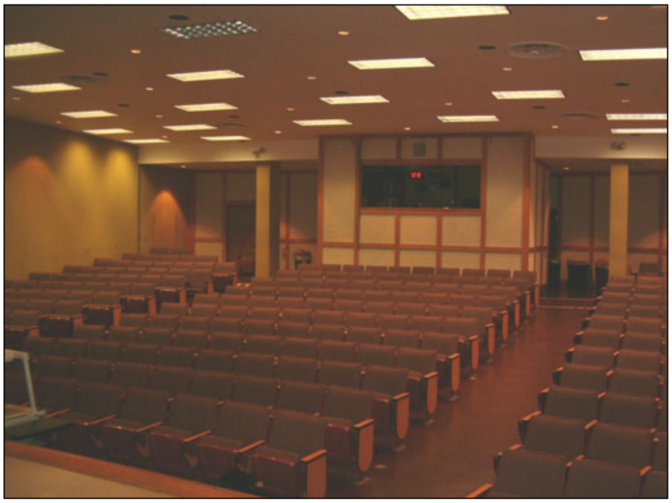


Figure AA1. *Theater room used for the morning orientation.*

Note. During the approximately 20-minute orientation, all participants were in the theater style room.

Figure AA2. *Seating for the control group activities.*

Note. The control group for the teamwork exercises remained in the theater style room for the control group activities, which were paper and pencil puzzles and two videos. During this time period, all participants were with their teammates.

Figure AA3. *Room for the teamwork exercises.*

Note. The chairs and tables were cleared from the floor.

Figure AA4. *Classroom arrangement for a team of two.*

Note. The desks arranged in this room are for team sizes of two.

Figure AA5. *Working space for a team of four.*

Note. This arrangement is for a team of four. The 2 x 4 foot sheet of plywood is provided for the truss construction area.

Figure AA6. *Classroom arrangement for teams of three.*

Note. This is a classroom the day after the study, before the trusses had been removed.

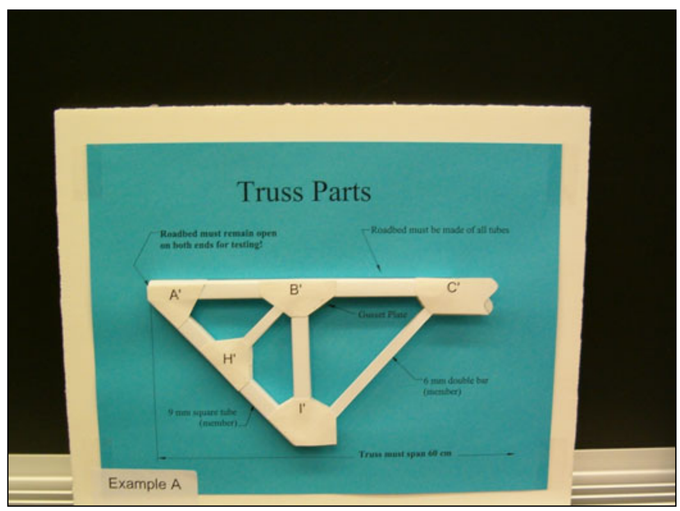


Figure AA7. *Truss construction example on the blackboard.*

Note. After room proctors passed around the truss construction examples, they were placed on the chalk trays of blackboards.

Appendix BB: Request for Academic Space

Department:	School of Education
Event:	Workshop with Engineering Freshman (Department of Engineering Education)
Department Contact:	Dr. Susan Magliaro (School of Education)
Person Responsible:	Mark Springston, maspring@vt.edu (Please contact with questions)
	231 Fairfax Rd.
	Blacksburg, VA 24060
	961-3044

1. ***Academic Classrooms with theater style seating***

Date: Saturday, October 23^{rd} from 9:00 am to 1:00 pm
Request: (one classroom)

Preference	Building	Room #
1^{st} choice	Litton Reaves	1670
2^{nd} choice	Smyth	208
3^{rd} choice	McBryde	100

And

Date: Sunday, October 24^{th} from 1:00 pm to 3:00 pm
Request: (one classroom)

Preference	Building	Room #
1^{st} choice	Litton Reaves	1670
2^{nd} choice	McBryde	100
3^{rd} choice	Smyth	208

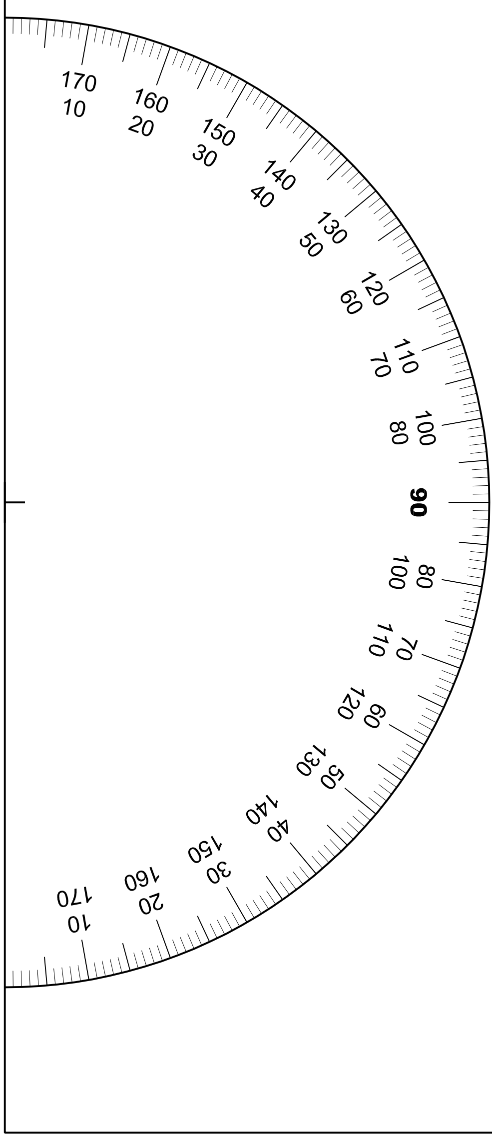
2. ***Academic Classrooms with movable student desks (see example below)***

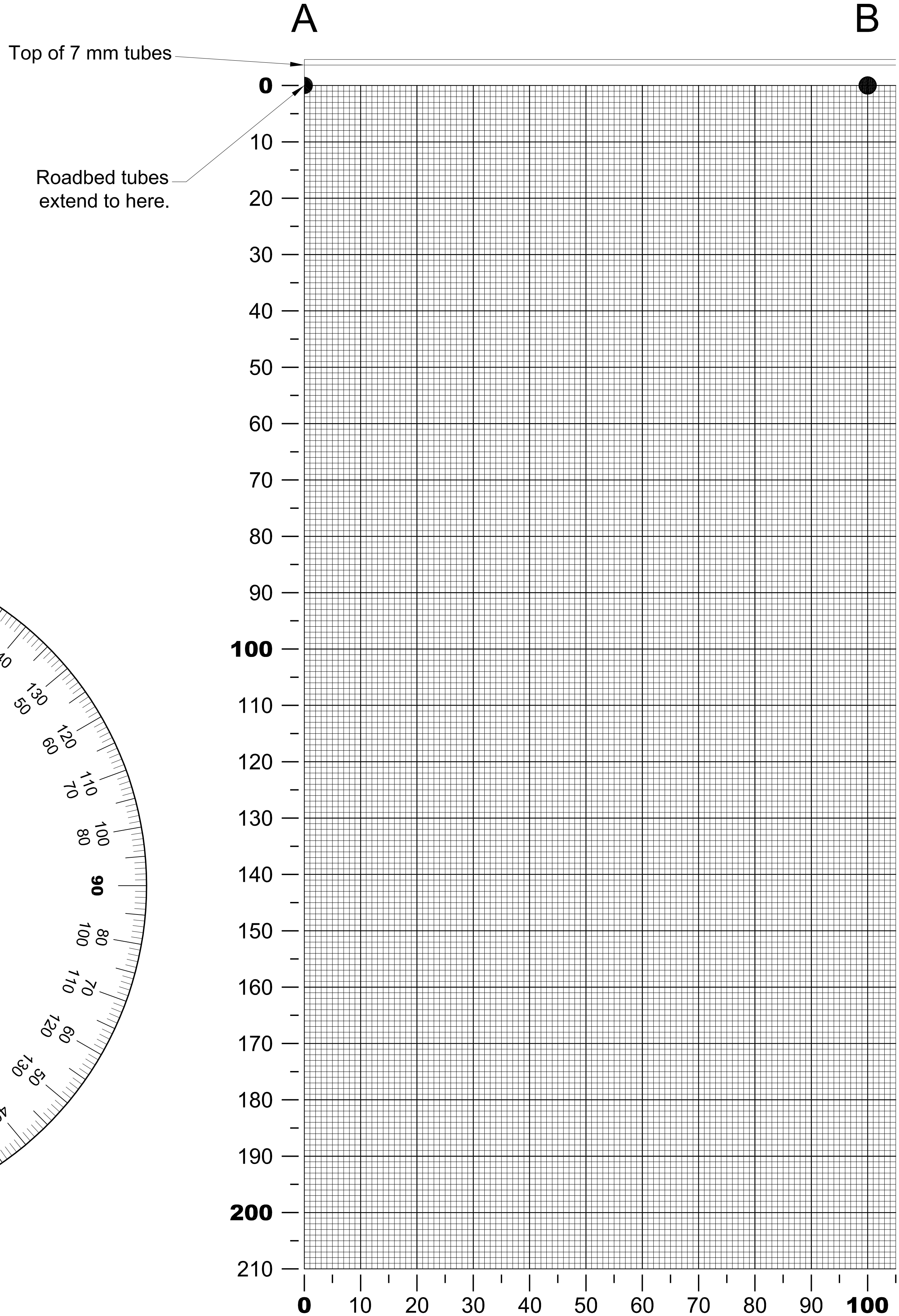
Date: Saturday, October 23^{rd} from 12:00 pm to 6:00 pm
Request: (six classrooms in one location: ten classrooms in another location)

	1^{st} choice		2^{nd} choice		3^{rd} choice	
	Building	**Rm. #**	**Building**	**Rm #**	**Building**	**Rm #**
Location 1	Williams	120	Hutcheson	204	McBryde	302
	Williams	134	Hutcheson	207	McBryde	304
	Williams	209	Hutcheson	209	McBryde	308
	Williams	220	Hutcheson	310	McBryde	316
	Williams	320	Smyth	232	McBryde	318
	Williams	324	Smyth	331	McBryde	322
Location 2	McBryde	202	McBryde	202	McBryde	202
	McBryde	204	McBryde	204	McBryde	204
	McBryde	210	McBryde	210	McBryde	210
	McBryde	212	McBryde	212	McBryde	212
	McBryde	216	McBryde	216	McBryde	216
	McBryde	218	McBryde	218	McBryde	218
	McBryde	230	McBryde	230	McBryde	230
	McBryde	232	McBryde	232	McBryde	232
	McBryde	238	McBryde	238	McBryde	238
	McBryde	240	McBryde	240	McBryde	240

Figure BB1. *Photo included with room request.*

Appendix CC: Partial Plot of Engineering Workspace for Truss Construction





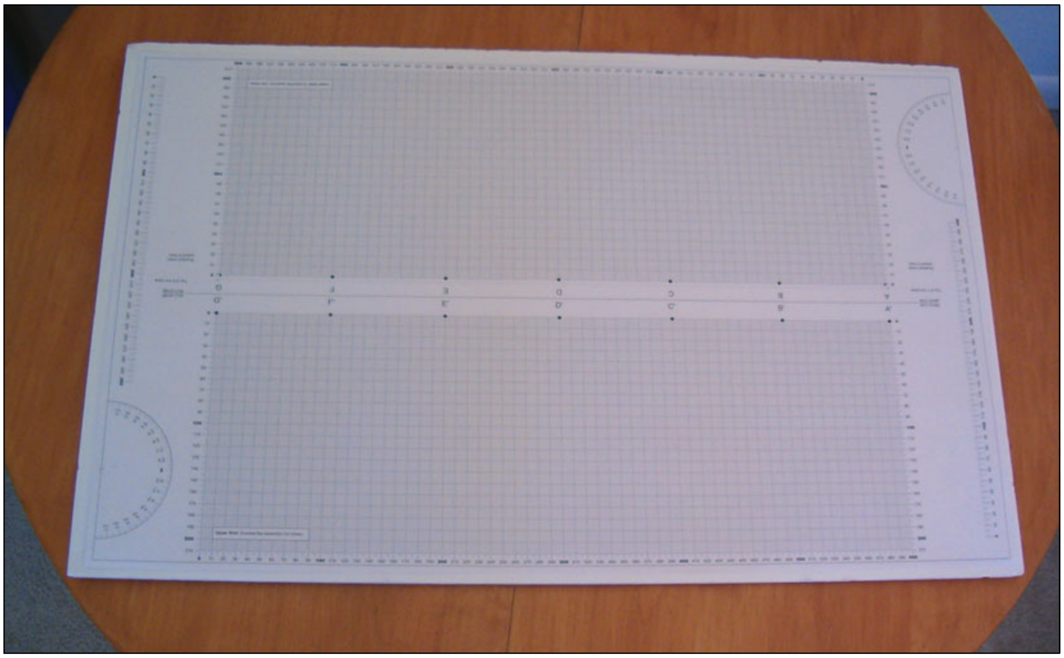


Figure CC1. *Engineering workspace for truss construction.*

Note. The plot on the previous page is approximately 1/8th of the total engineering workspace; the above photo is the full engineering workspace. The workspace consisted of a 3/16 x 20 x 32 inch piece of foam core board. A layout grid was taped on top of the foam core board. The layout grid was professionally printed on 80-pound paper at 2,400 dots per inch. The mm grids were ultra thin due to the "computer to plate" technology used during the printing process.

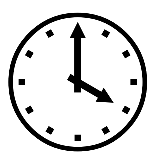
Appendix DD: Truss Construction Instructions

Constructing Your Truss

It is important that you understand the following steps to construct your design.

Warning!!! If you do NOT follow and understand these instructions, you may not have time to finish the truss.

These instructions include deck truss construction techniques, but also how to make your truss in a time efficient way.



Make sure you note the items that can save you time.

Note: All illustrations in here are for **construction** purposes only. You **design** your truss in the way you think it will be most efficient.

You must follow all design constraints (e.g., your truss must span 60 cm).

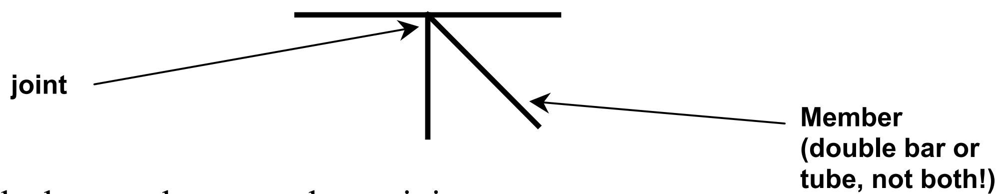
Terminology for Truss Construction

Truss – one side of a bridge.

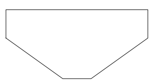
Deck Truss – when the truss system is below the roadbed.

Member – either a double-bar or tube that goes from one joint to another.

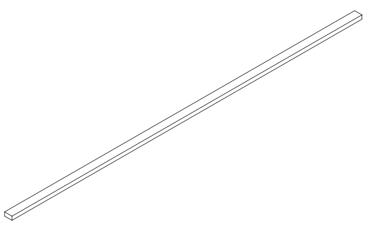
Joint – the location where members are connected.



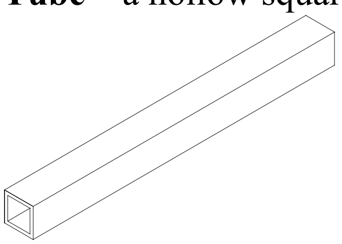
Gusset Plate – holds the members together at joints.



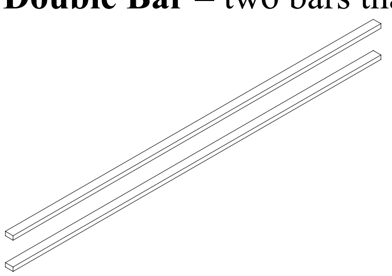
Bar – a solid or single strip of paper (3, 4, 5, or 6 mm in width).



Tube – a hollow square member (7 mm square or 9 mm square).



Double Bar – two bars that are the same size (e.g, 6 mm), which go on opposite sides of a tube.

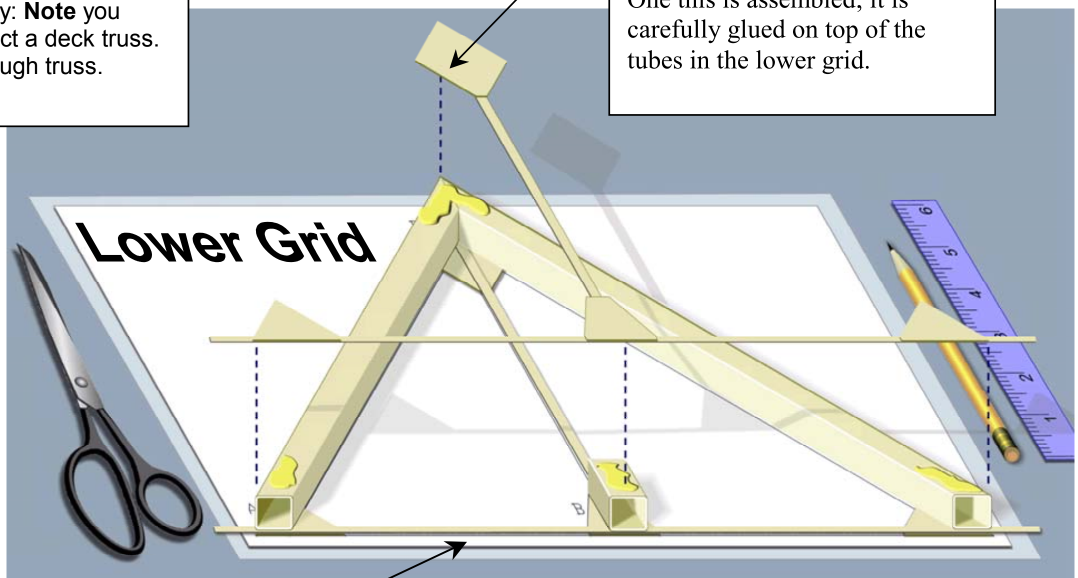


Gusset-Bar Assembly – a set of single bars and gusset plates. You need two to make your truss. Construct one each in the upper and lower grid.

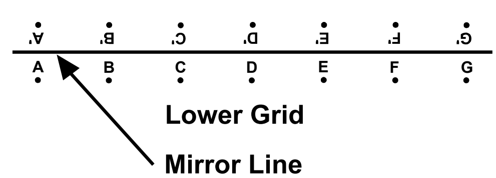
Gusset-Bar Assembly
(from Upper Grid, see your grid paper) **Note:** no tubes.

One this is assembled; it is carefully glued on top of the tubes in the lower grid.

Example Only: **Note** you must construct a deck truss. This is a through truss.



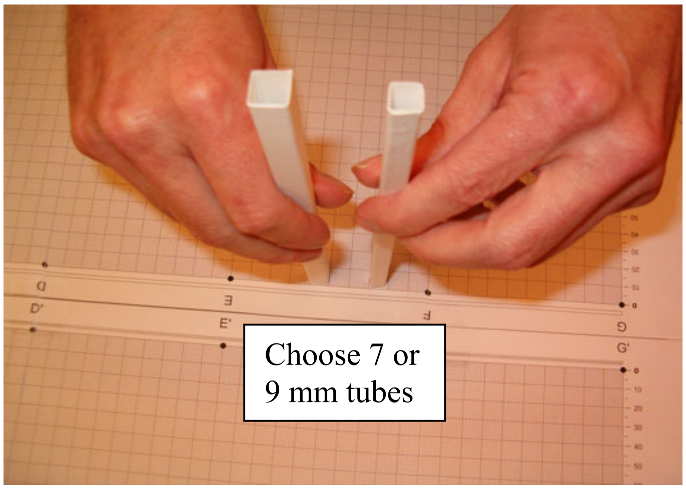
Gusset-Bar Assembly
(Constructed in Lower Grid, see your grid paper)
Tubes are glued on top of this assembly.



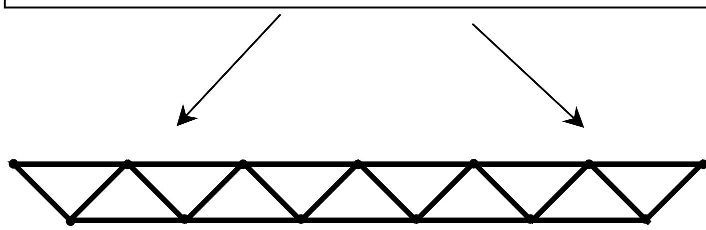
The truss or one side of a bridge can be thought of as **two gusset-bar assemblies** with **tube members** in between. The upper grid assembly folds over the mirror line on top of the lower grid, once tubes have been placed in the lower grid. If you do not understand the above, ask the room proctor to see the construction example again.

Truss Model Construction Steps (make sure you follow these steps to insure success).

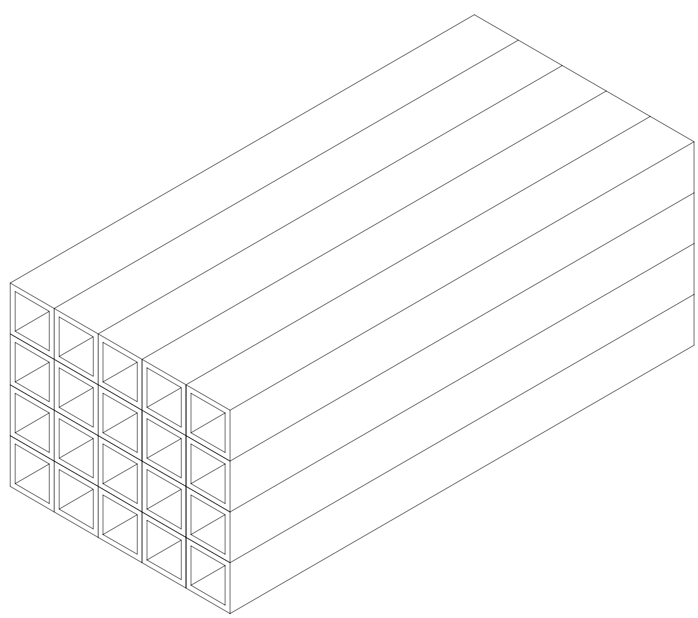
1. **Choose roadbed tube size:** The roadbed must be made entirely of 7.25 square tubes or 9.25 square tubes.



The roadbed must be made entirely of tubes. It will take 3 pieces of cut tube stock to span the required 60 cm.

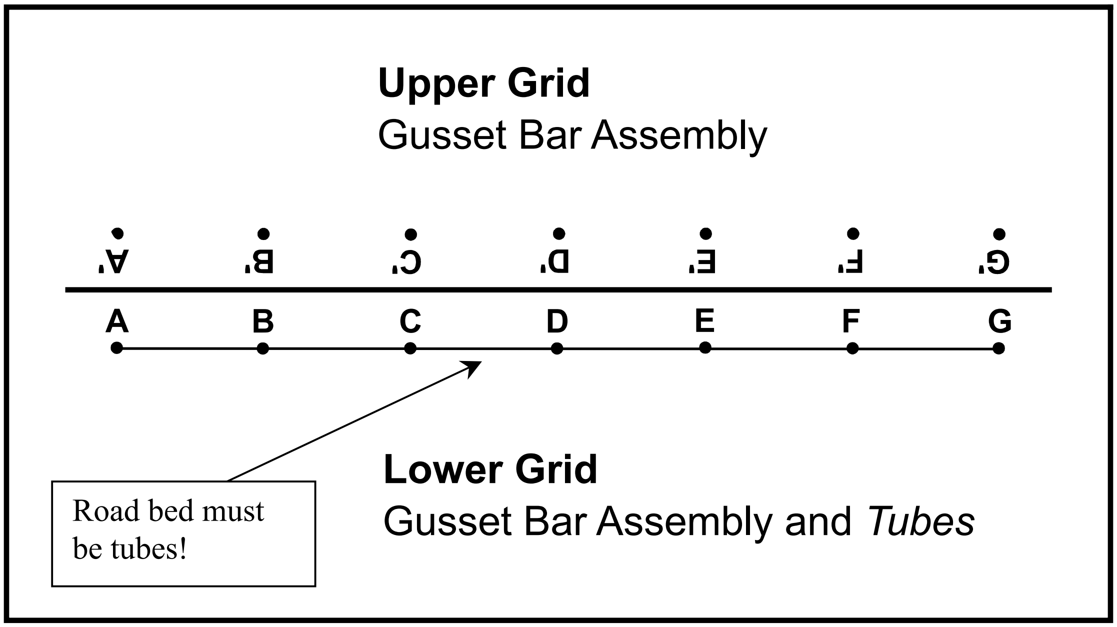


Give the unused set of tubes back to your room proctor.

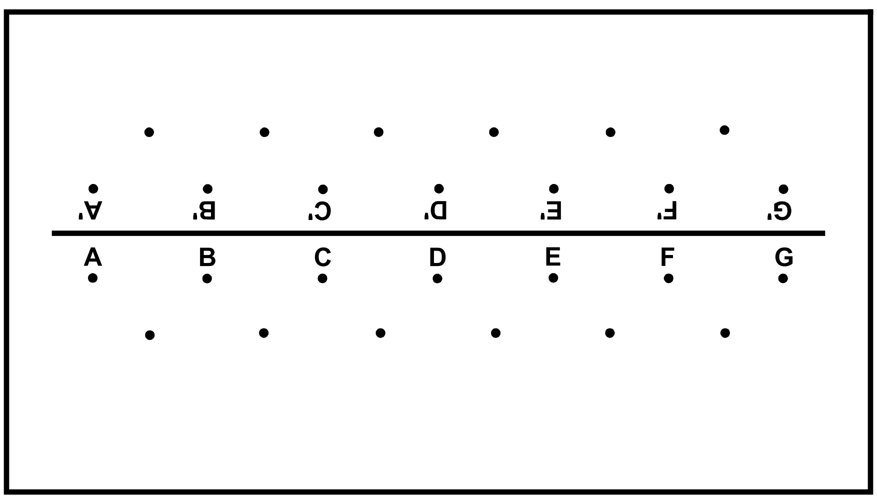


Once you decide on a tube size (7 or 9 mm), turn the other set back in to your instructor.

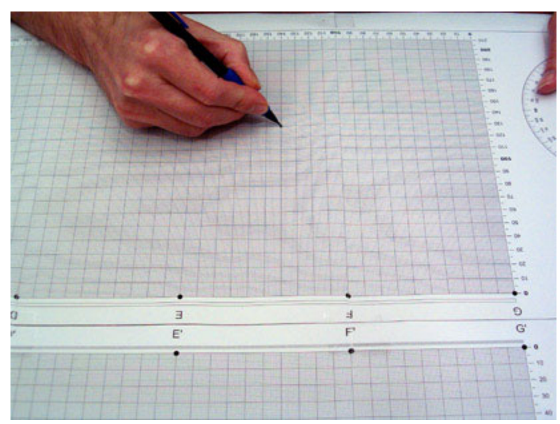
2. **Truss Design:** Mark all joint locations and connect them with lines. Make a mirror image of this on the other half of the graph paper. Label all joints with letters. Since A through G and A′ through G′ are already marked, start with H through H′ serially progressing. **You must have joints at A through G.** You are allowed to add joints to the roadbed (e.g, between A and B).



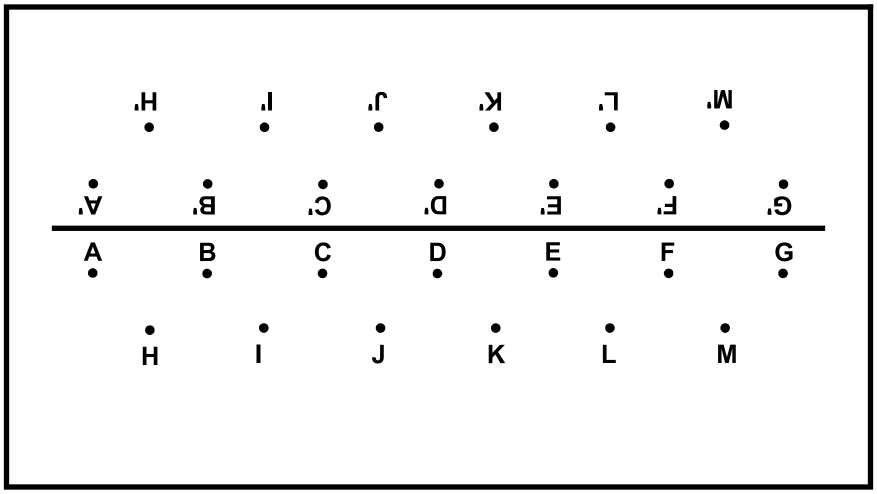
The roadbed, consisting of members AB, BC, CD, DE, EF, and FG, must be tubes!!!!!

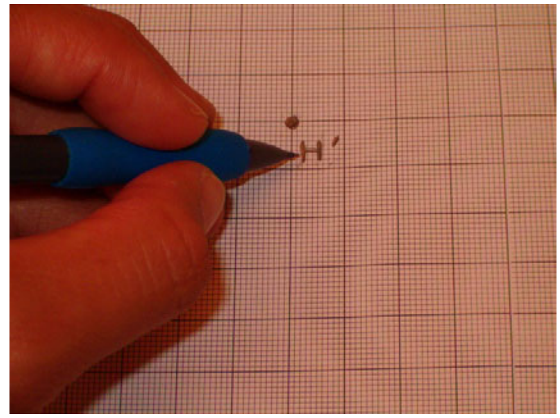


Choose joint locations. Make sure you create a mirror image in the top half of the grid. **This is just an example**. Design your truss on the grid area in a way you think will result in the most efficient truss. You can have as many triangles or connecting squares as you like.

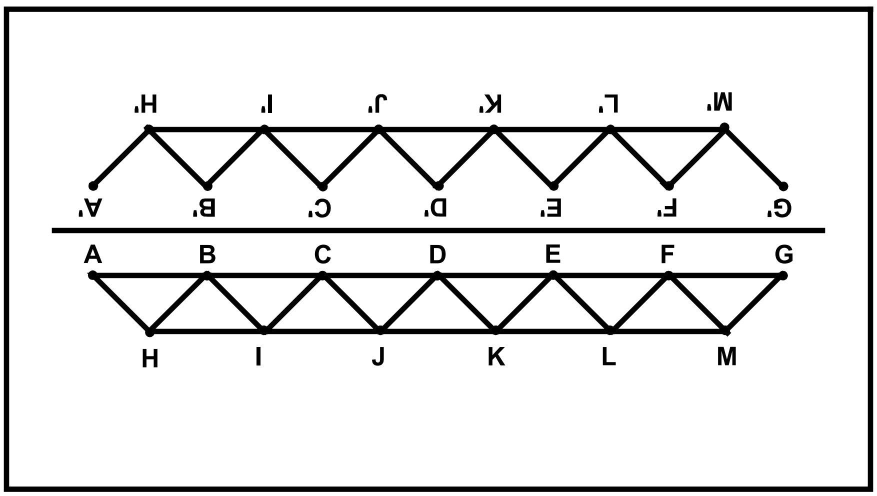


Mark joint locations in upper and lower grid.

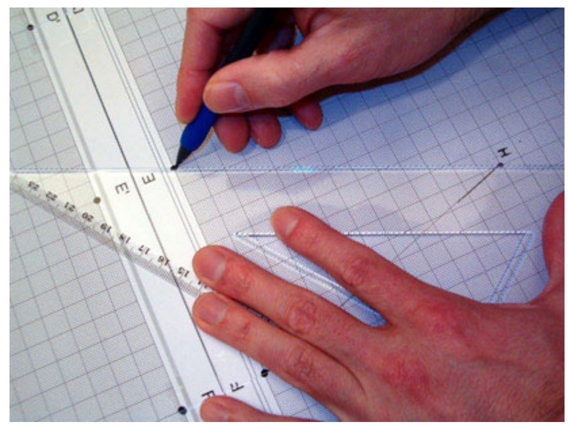




Label all joints: This will help you not get confused later on.

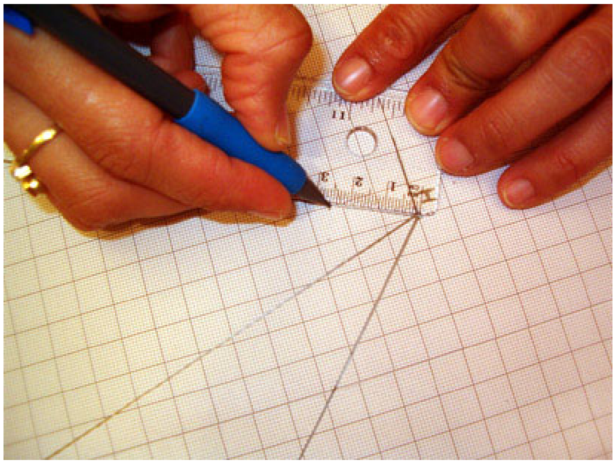


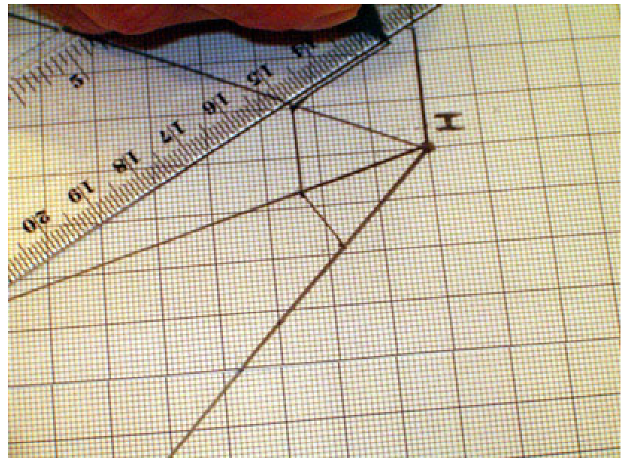
Draw Member Lines



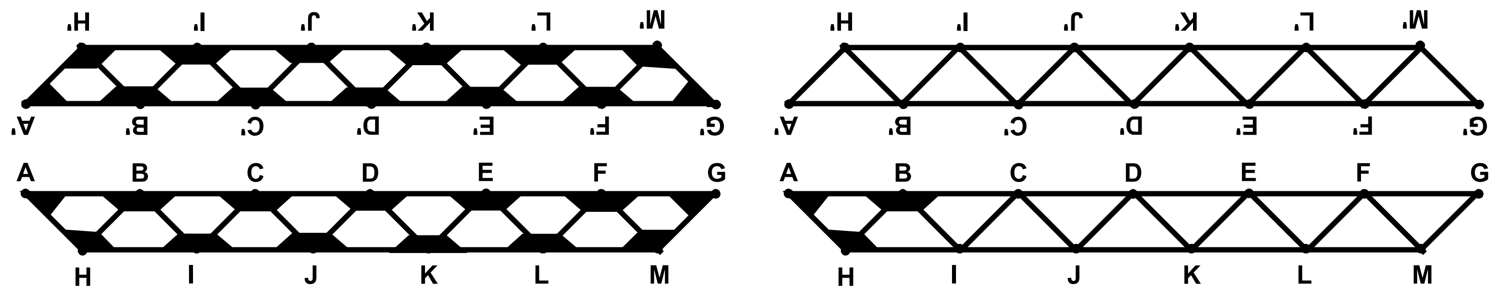
Use a straight edge to indicate where members will be placed.

3. **Gusset Plate Design:** Measure along each member line from the joint location at least 18 mm, marking a point. Then, connect each point with a line for all gusset plates. **Important: Do this only for unique joints!!! For the gussets at the end of the truss, you must measure more than the 18 mm.**


Measure and mark point

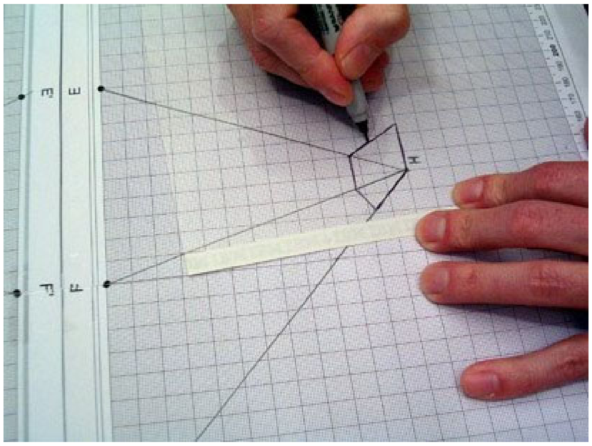

Connect points to make gusset plate design

Depending on the symmetry in your design, you will have more or less unique joints. How many unique joints are in this truss design? **Are you able to see that it only has three?**

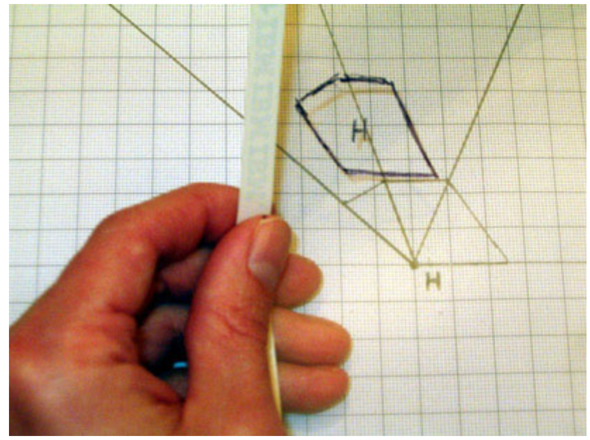


Note: You only need templates for one side of the truss. In addition, if your truss design is symmetrical, this reduces the unique number needed by half. If it is horizontally and vertically symmetrical, this reduces it to one quarter.

4. **Gusset Plate Template:** Lay the transparency paper (clear plastic) on top of each gusset plate, marking over the gusset plate shape with the marker. Label each gusset plate template with the letter of the joint. Note: You only need templates for one side of the truss. In addition, if your truss design is symmetrical, this reduces the number needed by half. If it is horizontally and vertically symmetrical, this reduces it to one quarter.



Use the marker and transparency paper to make Gusset plate templates.

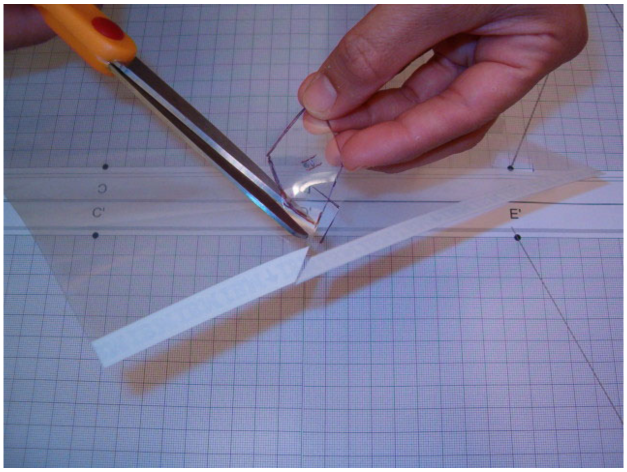


Example gusset plate template.

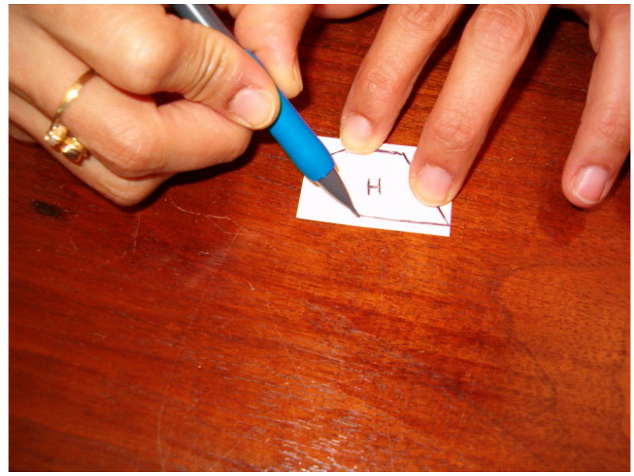
Schedule of gusset plates needed

Identical Gusset Plates	**Qty**
A, G, A', G'	4

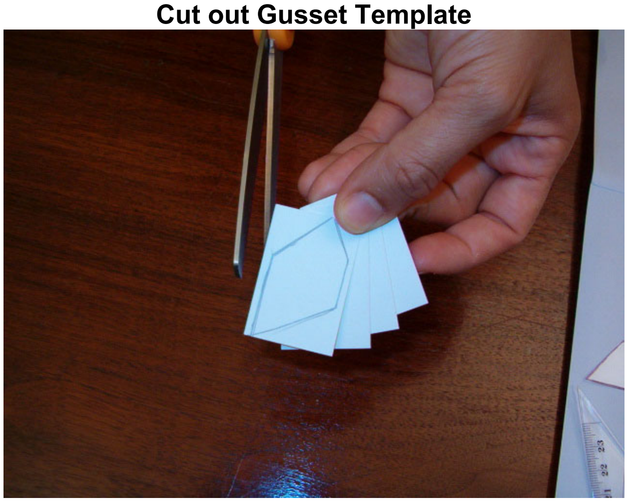
5. **Cut Out All Gusset Plates:** Calculate how many gusset plates are necessary. For example, joint A will need 2 gusset plates, and (if your truss bridge is vertically symmetrical) joint F will be identical. Therefore, stack four tabs on top of each other and cut them out. It is not suggested to gang more than 4 sheets at once. You must hold them securely when cutting, or each plate will not be identical.



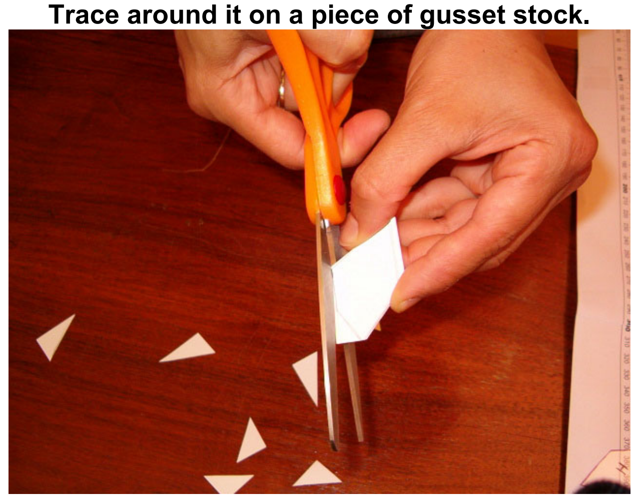
Cut out Gusset Template



Trace around it on a piece of gusset stock.



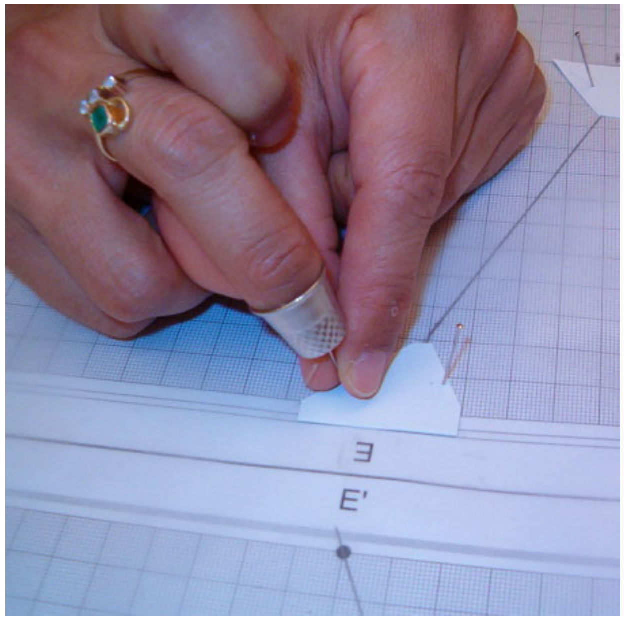
Once you determine how many you need of that gusset design, lay the lined gusset stock on top of several pieces. This will allow you to make several at one time. This is sometimes referred to as "gang cutting."



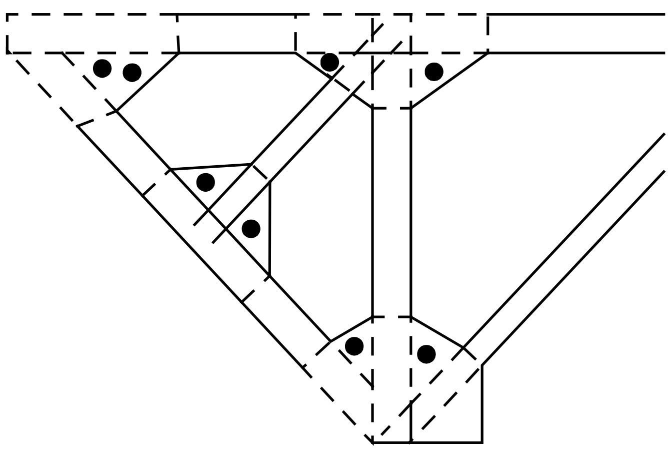
Hold firmly while cutting out. Do not stack more than four on top of each other at once.

Warning: it is time to place the wax paper on top of your truss design.

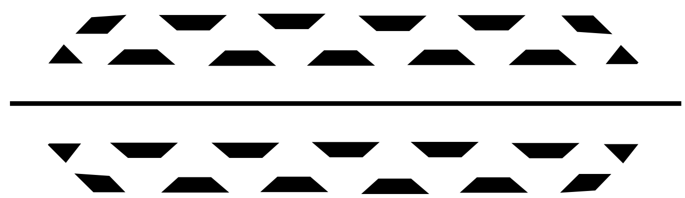
6. **Pin All Gusset Plates:** Each gusset plate must have two holding pins. Make sure holding pins will not interfere with where your strips (bars) or tubes need to be glued. Use a thimble, if it is uncomfortable when you are trying to push the pin into the foam core board. **Have you placed wax paper on top of your grid? Use the masking tape.**



Thimble, if it is uncomfortable for your fingers.

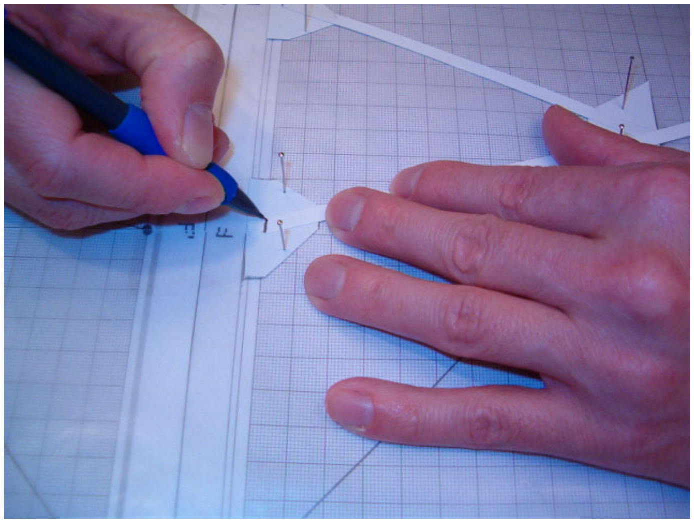


Make sure you pin the gusset plates, so they will not be in the way of the members you have planned.

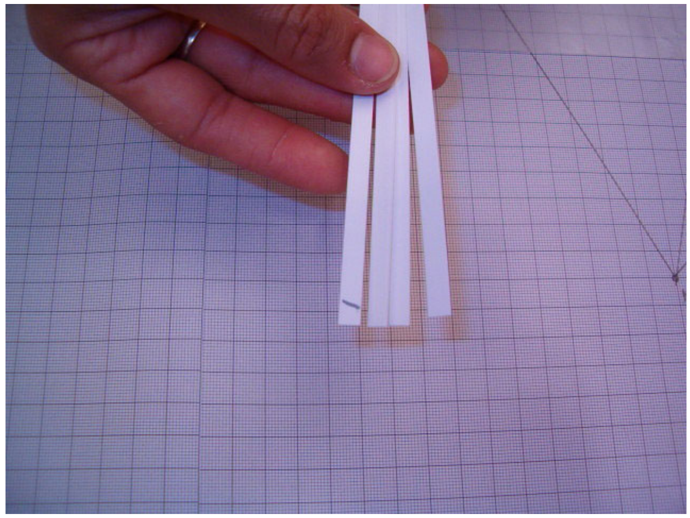


An example of what all gusset plates might look like when pinned to the upper and lower grid.

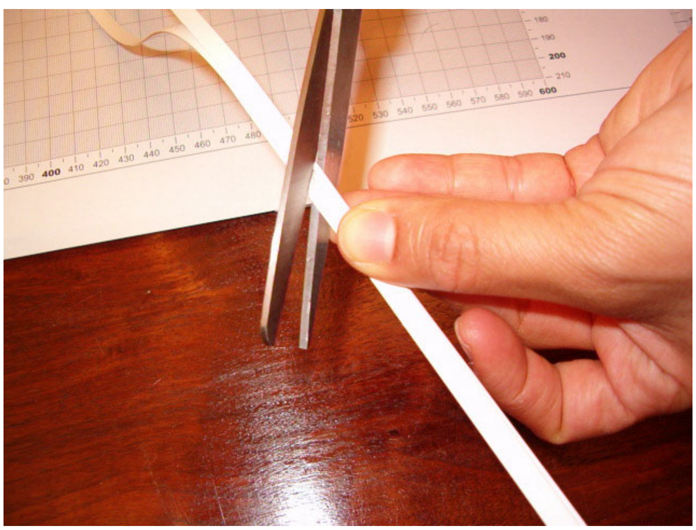
7. **Cut All Bars:** Measure length of bars needed and then mark a cut line. How many identical bars do you have? Stack bars on top of each other like you did with the gusset plates. Make sure you cut angles so there is no overlap.



Line off (mark) bars, then …



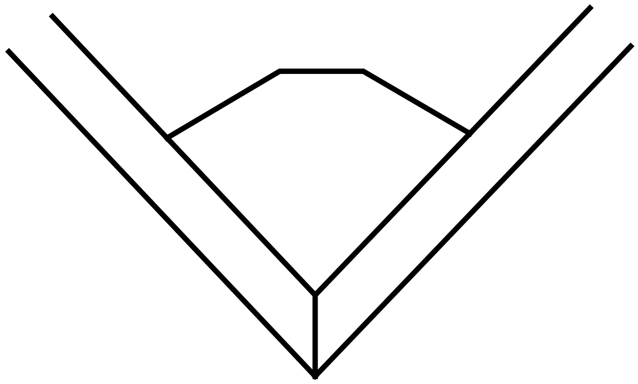
Stack identical bars on top of each other.



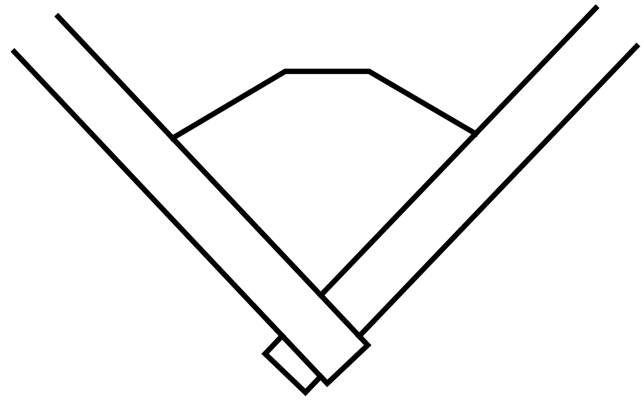
Cut identical bars at the same time.

Schedule of bars needed

Identical bars	Qty

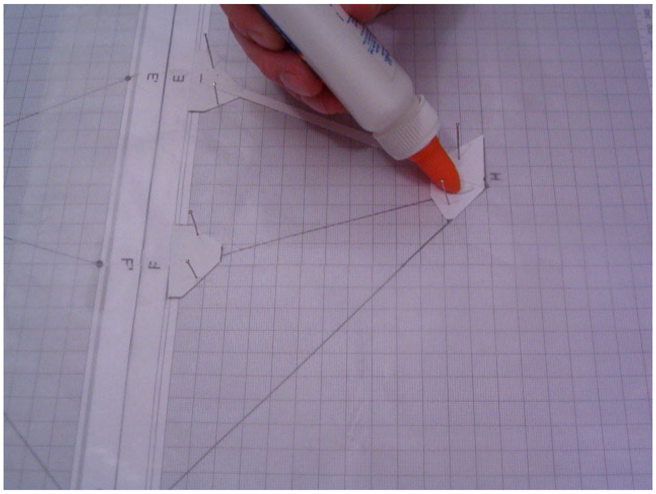


Bars should be cut so they meet like this.

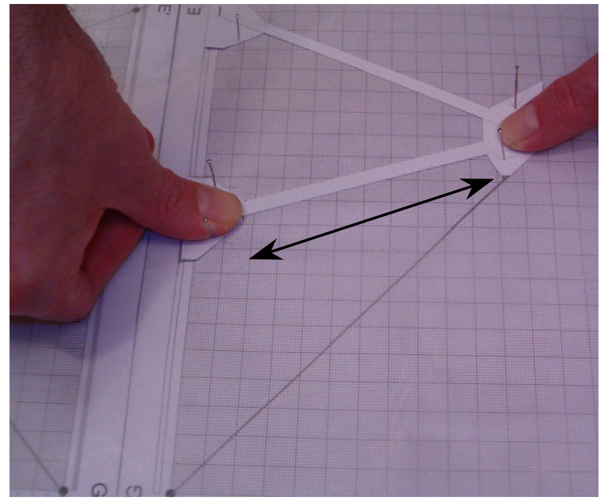


Do **not** overlap bars.

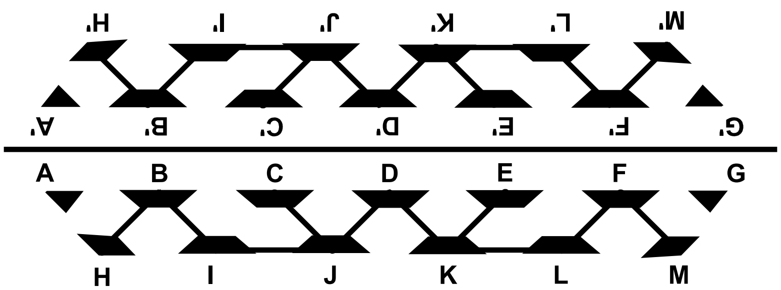
8. **Glue All Bars:** Glue the bars to the gusset plates on both sides of the mirror line. Make sure that you pull snug before the glue sets.



Apply a thin layer of glue where each bar will attach to the gusset plates. Do not use too much glue.
Construction Tip: Only open your glue nozzle just a little.

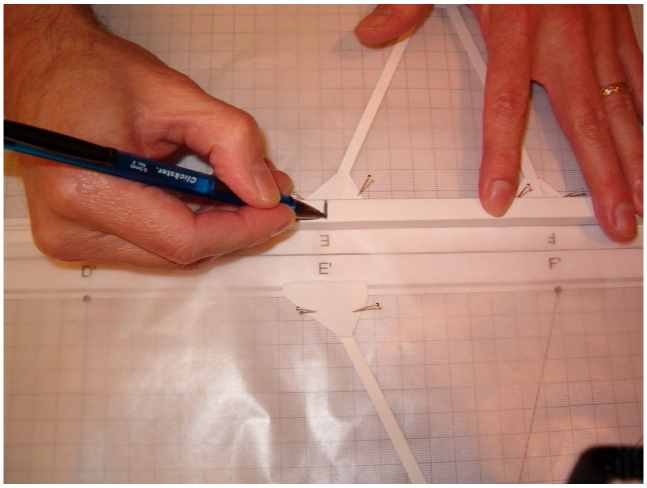


Pull out “slack” in the bar, before you press down.

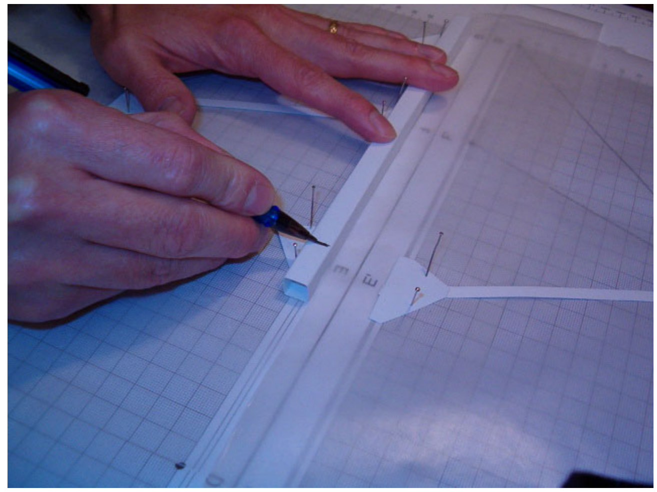


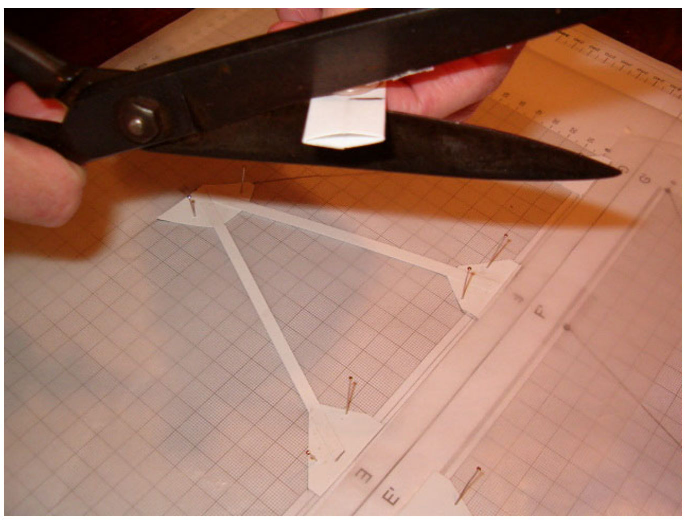
This is purely an example of what your grid area might look like at this point.

9. **Line and Cut All Tubes:** Tubes must be carefully flattened to cut. Carefully make the tube square again. You only need tubes on the lower grid.

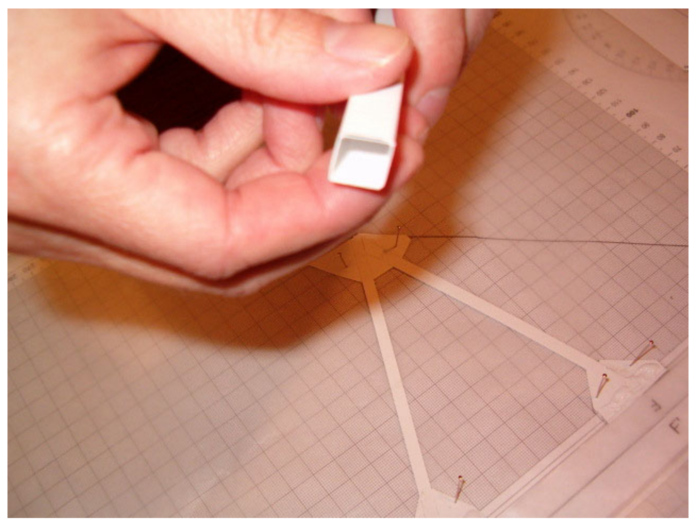


Mark tube. The roadbed will need three tubes to span the 60 centimeters.



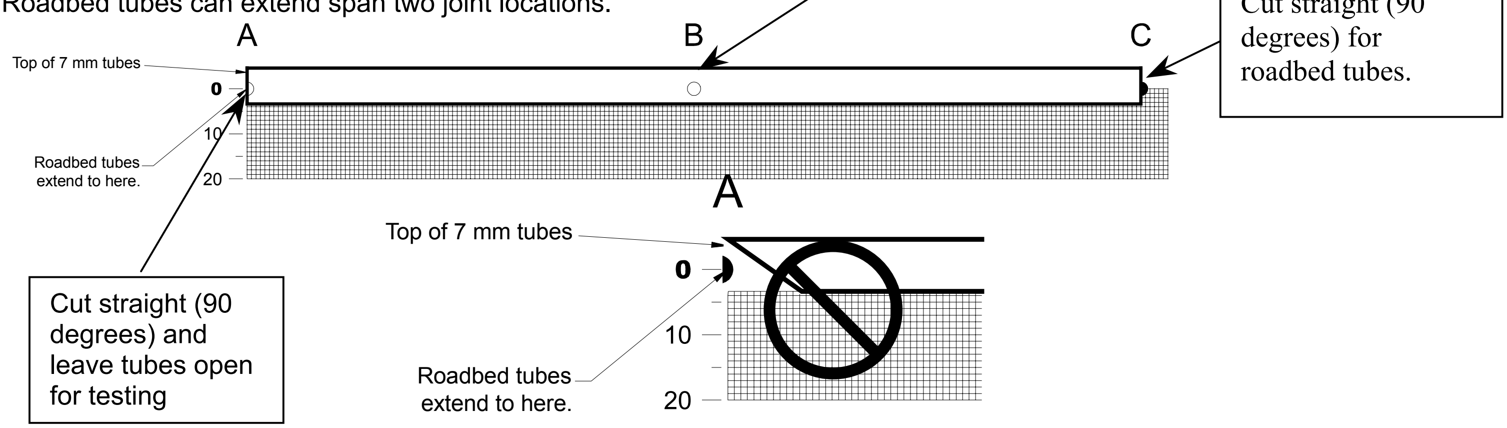


Carefully press the tube flat to cut.
Note: Once you cut one tube, you can use it as a template to line off other identical tubes.

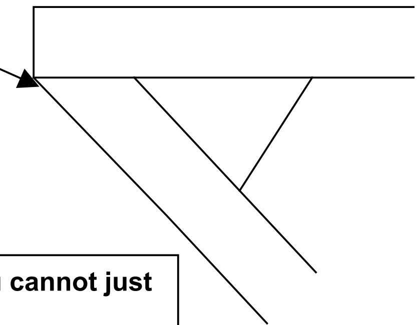


Square the tube back up after cutting.

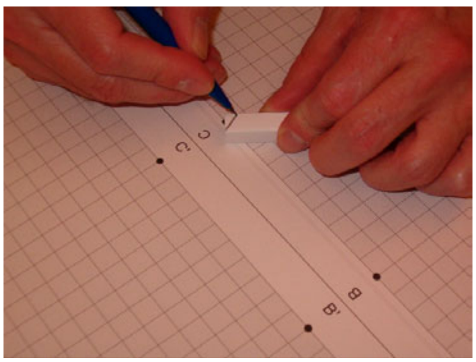
Roadbed tubes can extend span two joint locations.



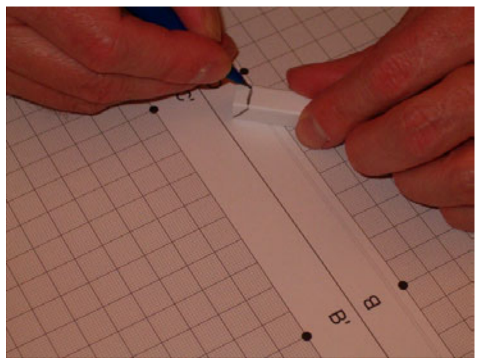
This member meets the roadbed tube at an angle. Note that the end of the roadbed tube is open.



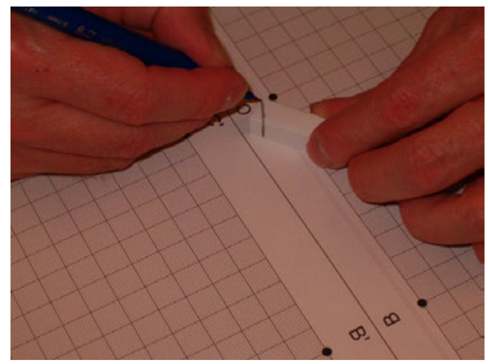
If you need to cut an angle on the end of a tube, you cannot just fold the tube over and cut the angle.
Line off the angle on opposite sides, then make three cuts as illustrated below.



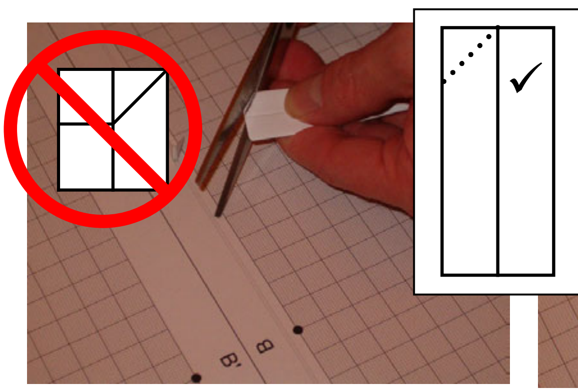
1. Draw a line for the inclined angle.



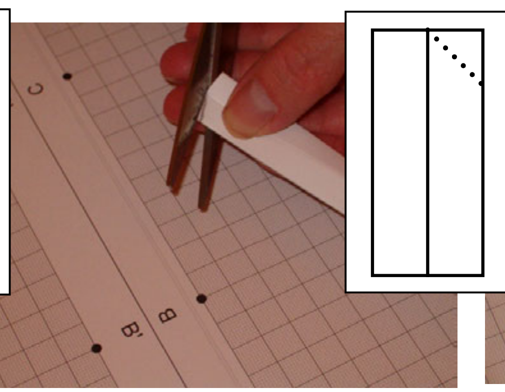
2. Rotate tube away from you 90° and draw a line straight across.



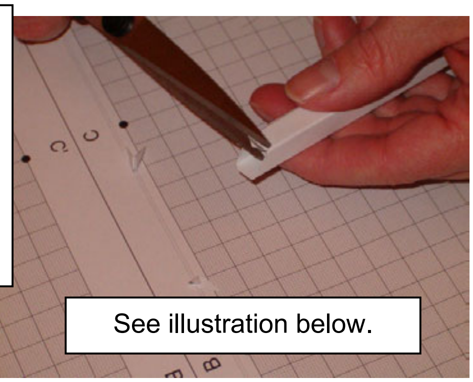
3. Rotate 90° again and draw to opposite corner.



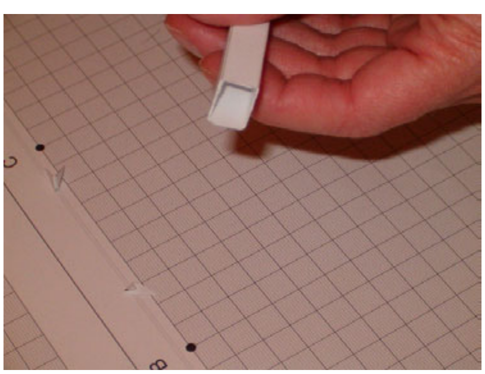
4. Cut the angle toward the crease of the tube.



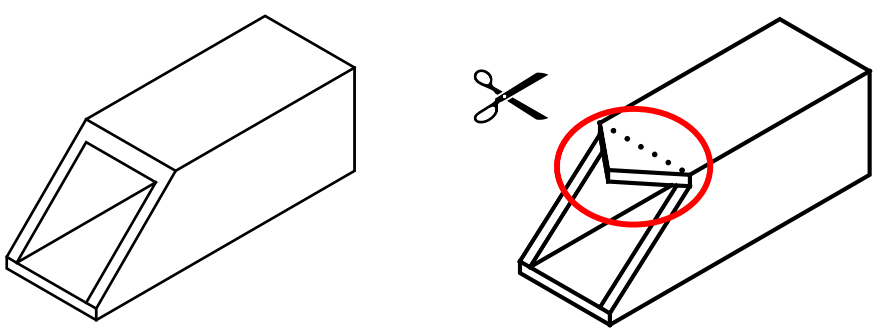
5. Open tube and fold the other way. Cut this angle.



6. Snip out the excess.

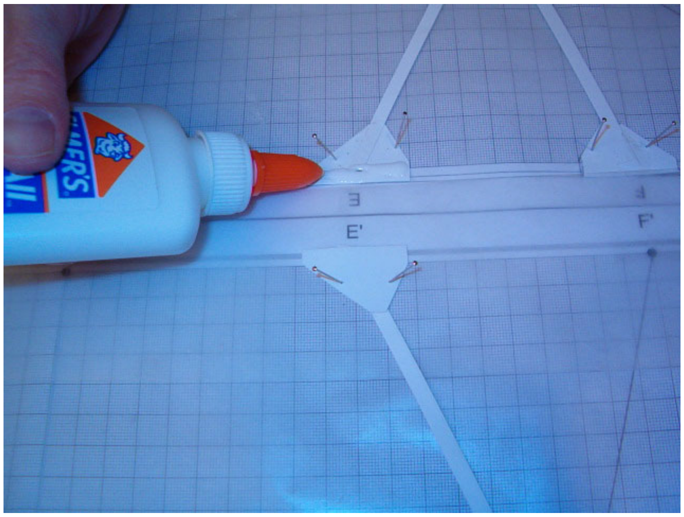


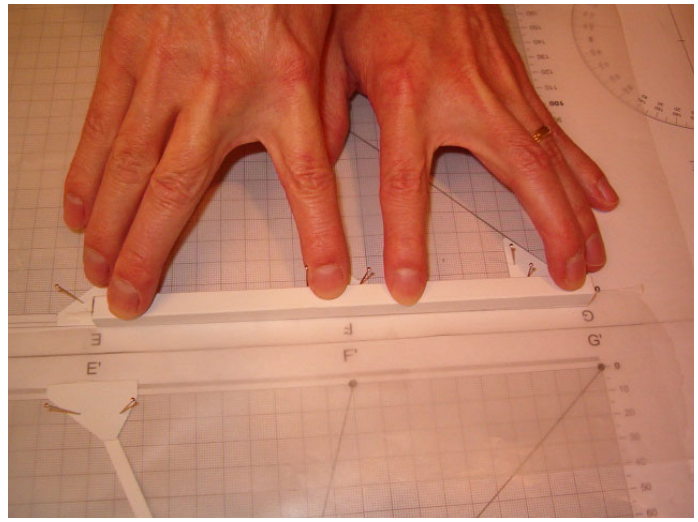
7. Finished product.



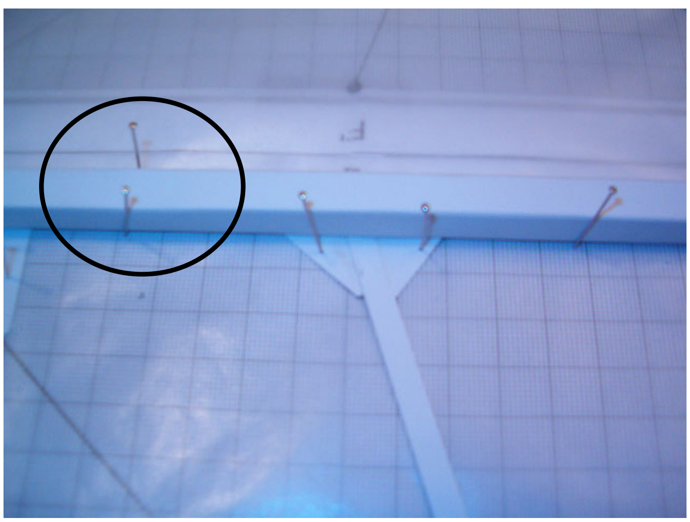
8. Illustration of finished product.

10. **Glue All tubes:** Glue all tubes on bottom grid.



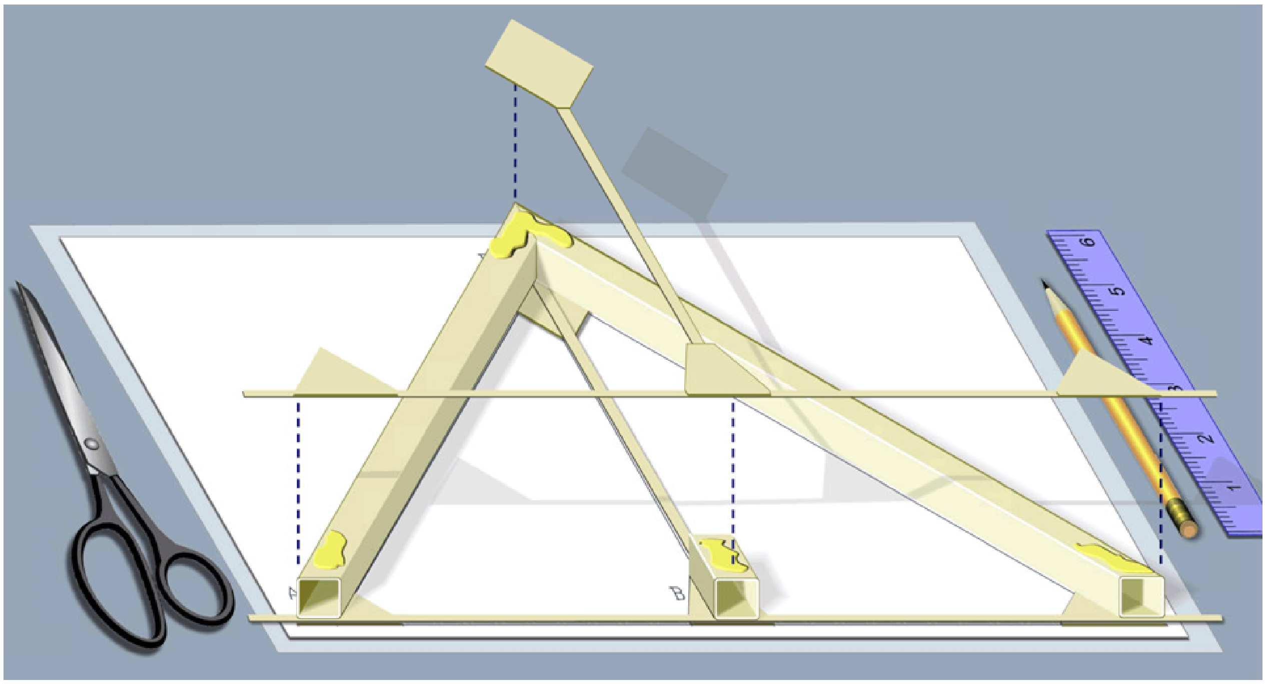


Apply light pressure down on the tube at the gusset plate locations for at least 30 seconds. Member is repositionable for the first few seconds.

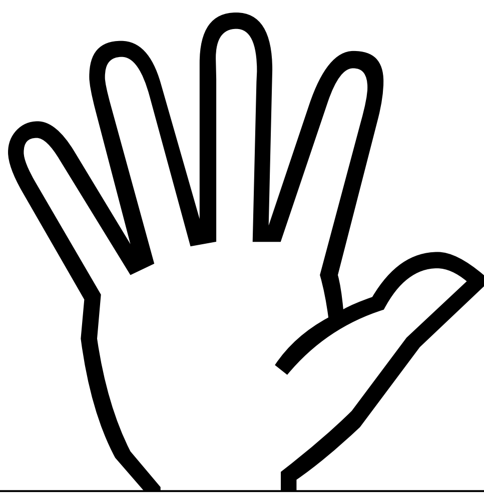


Use pin to square up tube for the next step.

11. **Assemble Sides:** Remove all holding pins. Carefully peel up the top gusset-bar assembly. Glue the assembly from the top grid on top of the bottom grid (i.e., the one with tubes). Do this one section at a time, making sure the bars do not become overly slack. Work from the vertical centerline of the truss out (⇔). The **concept** is illustrated below.



12. **Double check glue joints:** Make sure you all gusset plates have been glued. It is easy to overlook one.



Raise your hand so the room proctor can check off what time 🕓 your group finished. Leave your truss on the wax paper, so the room proctor can note your group number.

Appendix EE: Truss Model Construction Examples

Figure EE1. *Examples presented to teams to help with truss construction.*

Note. Each room had the above set of three examples, which were made from a template so that they appeared identical. The examples were mounted to foam core board.

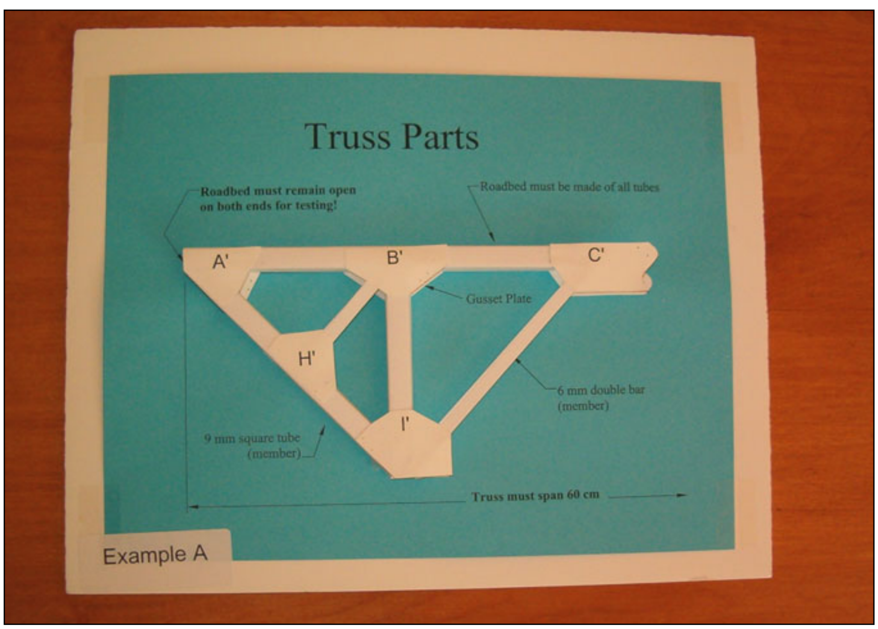


Figure EE2. *Example of truss parts.*

Note. Only a section of the truss was presented to teams, so that they would not simply copy the design.

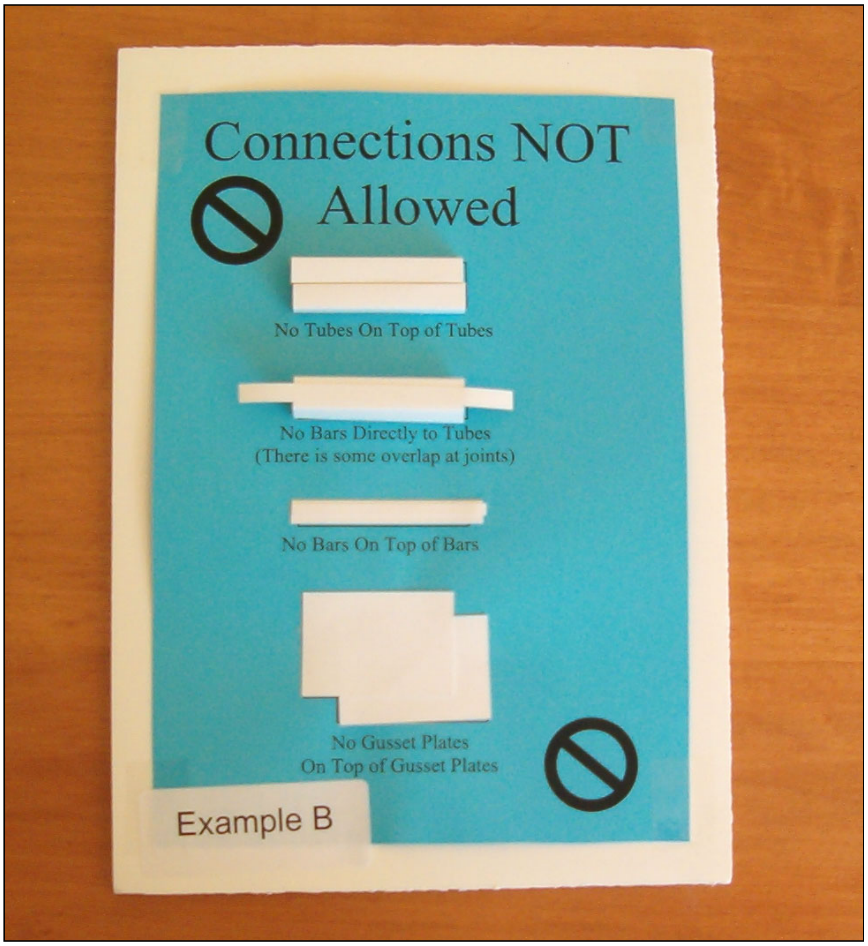


Figure EE3. *Example model of truss connections not allowed.*

Note. The objective for teams was for them to build a truss, rather than trying to laminate or stack members.

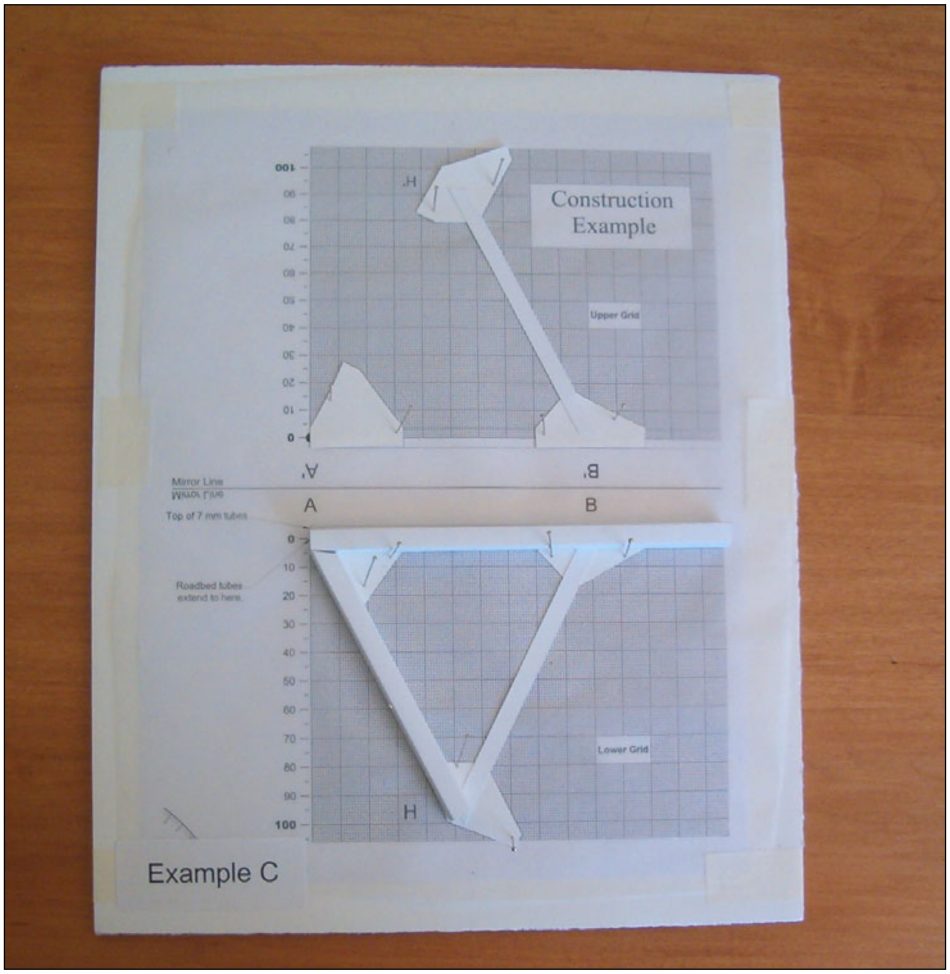


Figure EE4. *Example model of a section of a truss under construction.*

Note. Participants in the pilot study commented that examples would help them better understand the construction steps. Therefore, the above example was developed. Once again, only a portion of the truss is revealed, so teams are forced to develop their own design ideas. The above example is covered with wax paper and has stickpins inserted, just like suggested in the truss construction instructions.

Appendix FF: Truss Construction Tools and Materials

Table FF1
Truss Bin Inventory Placed Inside the Truss Construction Bin

Truss Construction Bin Inventory

Materials		
Qty	**Item**	**Function**
12	3 mm x 24.5 cm card stock strips	Double bar members
12	4 mm x 24.5 cm card stock strips	Double bar members
12	5 mm x 24.5 cm card stock strips	Double bar members
12	6 mm x 24.5 cm card stock strips	Double bar members
20	7 x 7 x mm x 22 cm square tubes	Tube members
20	9 x 9 x mm x 22 cm square tubes	Tube members
50	45 x 30 mm gusset plates	Connect members at joints
1	Glue	Make connections permanent

Construction Tools		
Qty	**Item**	**Function**
2	Scissors	"Gang Cut" members and gussets
1	Geometry set	Lay out of design
1	Overhead transparency	Gusset plate templates
1	Fine marker	Outline gusset plates onto the transparency
2	Rolls of Wax Paper	Prevent truss members from adhering to the drawing grid
1	Roll of Masking Tape	Hold down wax paper
100	Stick pins	Hold gusset plates during construction
2	Thimbles	Drive pins into foam core board

Figure FF1. *Each team received a bin with all materials and tools to construct a truss.*

Note. Construction bins remained closed until the T_2 computer bridge score.

Figure FF2. *Tube stock for hollow truss members.*

Note. Teams had to choose between either 7.25 mm or 9.25 mm tubes.

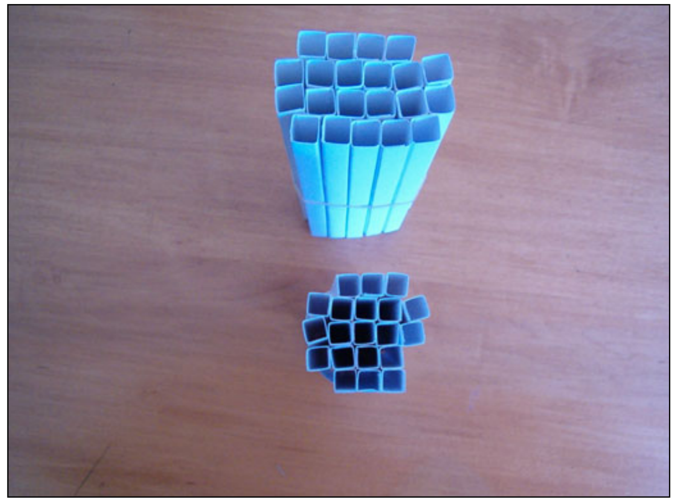


Figure FF3. *The ends of tube stock.*

Note. Tubes were machine scored so that they were consistent in size. Tubes were assembled with metal bar stock and a form.

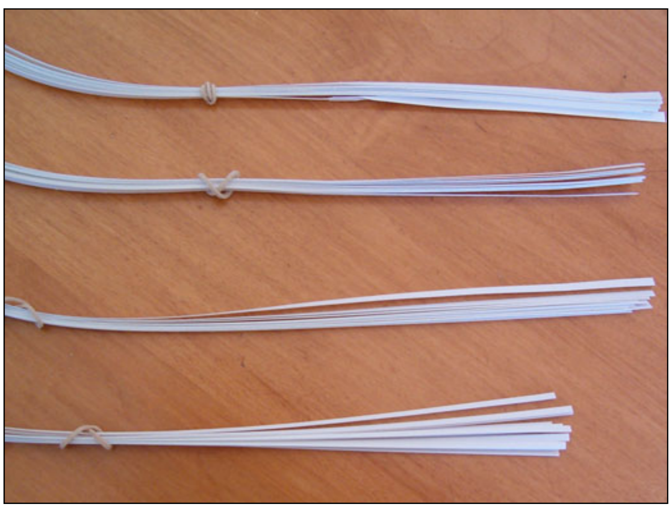


Figure FF4. *Bar stock for solid truss members.*

Note. Teams could mix and match from four different size bars.

Figure FF5. *Additional truss construction tools and materials.*

Note. The bag contains gusset plate stock, stickpins, and two thimbles for driving stickpins. During the pilot study, the researcher discovered that teams might not use the thimbles; however, they were included in case it was uncomfortable for anyone to drive the stickpins with just their hands.

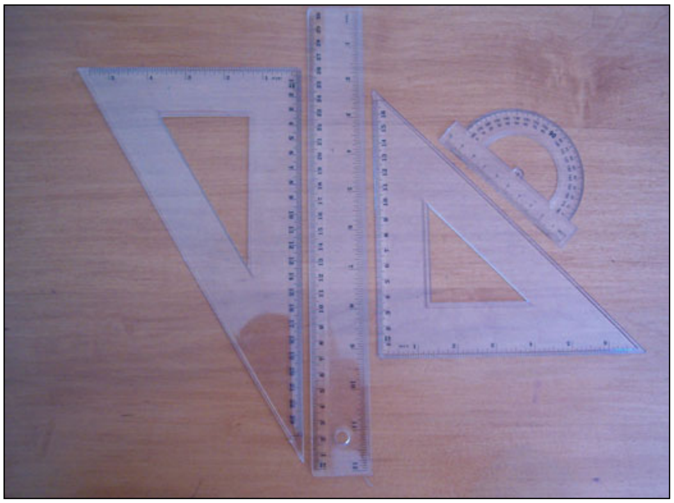


Figure FF6. *Four piece geometry set for designing the truss.*

Note. Regardless of team size, the four-piece geometry set provided at least one layout/measurement tool per team member.

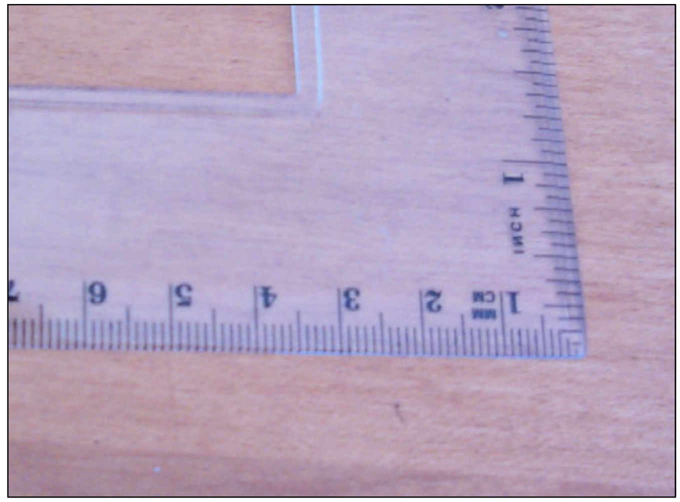


Figure FF7. *Geometry set included both metric and English units of measurement.*

Note. The two triangles and rule had both fractional inch and millimeter/centimeter graduations; the 180-degree protractor had millimeter/centimeter graduations.

Figure FF8. *Miscellaneous tools for truss construction.*

Note. After teams created a design on the layout grid, the wax paper was placed on top to prevent the truss from gluing to the grid. The inkjet overhead transparency was used to make gusset plate templates. Teams could trace over gusset plates they had designed on the layout grid. Inkjet overhead transparency has one rough side so that the fine point marker will not smear.