

Collaborative Study and Paired Test Taking in Collegiate Level Linear Programming

Instruction

by

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(ABSTRACT)

The purpose of this investigation was to examine the effects of collaborative learning strategies on formulating solutions to linear programming word problems that were designed to incorporate problem-solving skills. Forty-six students majoring in business at a small southwest college in Virginia participated in the study. After an instruction session, a study period, and a question and answer discussion, participants completed the test instrument based upon random assignment to three treatment groups. These included individual study with individual test taking (control), paired study with individual test taking, and paired study with paired test taking. All participants returned in 17 days to complete a posttest individually having received no further instruction in linear programming theory.

The following null hypothesis was examined: No differences in treatment means measuring problem-solving abilities would be found based on students' test and posttest scores using two treatment groups of collaborative study, with collaborative or individual test taking, and a control group of individual study with individual test taking. After satisfying the assumptions of no difference in ability in the treatment groups, establishing significant influence of ability on test score and

posttest score variables, and establishing homogeneity of regression, an analysis of covariance (ANCOVA) was used to test the null hypothesis. The null hypothesis was rejected. Treatment had a significant effect on the variance for the test score variable, $F = 3.92, p < .05$, and for the posttest score variable, $F = 4.44, p < .05$. Newman-Keuls post hoc test showed significant differences in the adjusted means of the test score variable between the individual study with individual test taking group (72.22) and the paired study with paired test taking group (87.86). For the posttest score variable, the Newman-Keuls post hoc test revealed significant differences between the adjusted means of the individual study with individual test taking group (36.25) and the paired study with individual test taking group (59.20), and between the adjusted means of the individual study with individual test taking group (36.25) and the paired study with paired test taking group (55.77). Implications of findings and recommendations for further research were discussed.

DEDICATION

This dissertation is dedicated to my family who have provided me with untiring support. My husband, Gary, and two children, Stuart and Brynn, found a level of patience and understanding for which I will always be grateful. And to my wonderful parents, Robert and Bernadine Stephens, who gave me the confidence to reach my goals by always insisting that I could accomplish anything. To all of you, I extend my love and gratitude.

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TABLE OF CONTENTS

	Page
Chapter I: Introduction	1
Background	1
Purpose of Study	7
Statement of the Problem and Hypothesis	8
Significance of Study	9
Definitions	11
Delimitations	12
Summary	13
Chapter II: Literature Review	15
Introduction	15
Academic Profile of Business Majors	15
Cognitive Psychology and Operational Criteria for Problem Solving . . .	19
Group Decision Making	22
Methodological Problems	23
Issues in Group Decision Making	25
Process Gain versus Process Loss	25
Ability	27
Role of Discussion	28
Homogeneity versus Heterogeneity of Personality	29

Cooperative and Collaborative Learning	31
Cooperative Learning	32
Collaborative Learning	38
Differences in Cooperative and Collaborative Learning	42
Summary	45
Chapter III: Methodology	47
Participants	48
Instructional Treatment	49
Test Instrument	52
Test Administration	54
Posttest Administration	55
Pilot Study	56
Data Analysis	57
Summary	57
Chapter IV: Results	59
Demographics	59
Second Grader and Test/Posttest Scores	59
Comments on Recorded Collaborative Study and Test Taking	61
Data Analysis	63
No Significance in Ability Means for Treatment Groups	64
Significance of Ability Covariate	64

Homogeneity of Regression	69
Significance of Treatment	69
Summary	75
Chapter V: Summary, Implications, Recommendations, and Conclusion .	77
Summary	77
Implications of Findings	79
Test Score Variable Results	80
Differences between the Individual Study with Individual Test Taking and Paired Study with Paired Test Taking	80
Differences between the Individual Study with Individual Test Taking and Paired Study with Individual Test Taking	82
Differences between the paired study with individual test taking and paired study with paired test taking	82
Posttest Score Variable Results	83
Differences between the Individual Study with Individual Test Taking and Paired Study with Paired Test Taking	83
Differences between the Individual Study with Individual Test Taking and Paired Study with Individual Test Taking	85
Differences between the paired study with individual test taking and paired study with paired test taking	85
General Issues Associated with Collaborative Strategies	87

Recommendations for Further Research	88
Ethnicity and Gender	89
Enhanced Learning for Drill and Practice Items	89
Effect upon Problem Solving in Other Disciplines	90
Other Treatments	91
Perceptions of Students	93
Conclusion	93
References	98
Appendix A: Types of Knowledge in Test and Posttest Conforming to Problem Solving Criteria	104
Appendix B: Model Formulation Instructions	107
Appendix C: Linear Programming Study Problems	117
Appendix D: Instrument for Test	124
Appendix E: Criteria to Evaluate Performance on Test Instrument	129
Appendix F: Grades Assigned and Reconciled by Researcher and Second Grader	131
Appendix G: Recorded Times for Completing Test	134
Appendix H: Instrument for Posttest	137
Appendix I: Pledge	142
Appendix J: Recorded Times for Completion of Posttest	144
Appendix K: Criteria to Evaluate Performance on Posttest Instrument	147

Vita

149

LIST OF TABLES

	Page
Table 1: Differences in Cooperative and Collaborative Learning	43
Table 2: Demographic Composition of Treatment Groups	60
Table 3: Analysis of Variance for Ability (Covariate) and Treatment Levels . .	65
Table 4: Analysis of Covariance for Test.	66
Table 5: Analysis of Covariance for Posttest	67
Table 6: Number of Participants, Range of Scores, and Unadjusted and Adjusted Means for the Test and Posttest Scores	68
Table 7: Analysis of Covariance for Testing the Homogeneity of Regression for the Three Levels of Treatment for the Test.	70
Table 8: Analysis of Covariance for Testing the Homogeneity of Regression for the Three Levels of Treatment Groups for the Posttest	71
Table 9: Differences in Means of the Treatment Groups and Results of Newman-Keuls Post Hoc Test for the Test	73
Table 10: Differences in Means of the Treatment Groups and Results of Newman-Keuls Post Hoc Test for the Posttest	74

CHAPTER I

Introduction

A merely well-informed man is the most useless bore on God's earth. . . . Education with inert ideas is not only useless: it is, above all things, harmful. . . . But if education is not useful, what is it? Is it a talent, to be hidden away in a napkin? . . . theoretical ideas should always find important applications within the pupil's curriculum (Whitehead, 1929, p. 3).

Background

Many businesses share this view of education and think that theoretical ideas are not always applied in the curriculum of four-year colleges and universities. A study conducted by the Business Higher Education Forum (1997) likened the chasm between business and higher education as two continents, both experiencing considerable movement. Some of these disturbances resemble violent earthquakes invalidating old rules while leaving no new structure to take their place. Uncertainty is enhanced as new rules evolve only slowly and painfully (Reich, 1991; Thurow, 1996). Primary and secondary educational leaders are well underway with school reform to address workforce needs in the changing environment (Center for Applied Technology and Career Exploration, 1997; Lankard, 1995; National Skill Standards Board, n.d.; Reddy, 1997). However, leading educators and businesspeople agree that institutions of higher education have been slow to respond to corporate needs. An extensive study, conducted by Gardiner (1994) for the Association for Study of Higher Education, found that "crucial skills...are poorly developed in many college and university students" (p. 1). Young, the director of the Potomac Knowledge Way project, makes the point more bluntly, "...everyone is at the hand-wringing stage: The only way we're going

to get enough people fast enough is if business takes charge” (“Changing Nature,” 1997, p. 4). However, others (Business Higher, 1997; Reich, 1990; Useem, 1989) have found that colleges and universities are preparing their graduates for the work world, at least or perhaps, better than in the past. Having stated this, employers, employees, and educators find their current efforts inadequate, given rapid and abrupt work environment changes. They cited such curricular problems as content brokering, boring lectures, standardized tests, little group work, compartmentalized disciplines, weak courses and teachers, rote memorization for learning, and unproductive “busy work” among others (Business Higher, 1997; Gardiner, 1994; Green & Seymour, 1991; Lankard, 1994).

Baccalaureate degrees have continued to be highly coveted and many graduates reported that additional education added value to their personal and professional lives. Surveyed alumni, including graduates from expensive private institutions, (Business Higher, 1997) reported that the benefits of their undergraduate education outweighed the costs and provided them with superior opportunities that helped prepare them for the workplace. “However, most of them also suggested that their education would have been more useful if their colleges had done a better job teaching skills needed in the work world” (Business Higher, p. 31). Graduates from four-year colleges and universities continue to enjoy higher income levels than other educational groups and have not seen the overall decline in their standard of living (“American Workers,” 1997; Reich, 1991; Thurow, 1996). In addition, economic development, workforce preparation, human capital (measured by the percent of the population with a college degree), and income

growth of city residents have been tightly intertwined with postsecondary education, including an increase of 2.8% in productivity for each year of additional education (“High Stakes, High Skills,” 1997).

Although a four-year college degree is an important credential in one’s job portfolio, it no longer guarantees a “good” job. Organizational infrastructures have become flatter and workers at all levels continue to be held increasingly accountable for what they know how to do. “Degrees are less important than competencies...Today’s Web masters, for example, didn’t learn their craft in any degreed program; they’re largely self-taught” (“High Stakes, High Skills,” p. 4). As evidence of this trend, the share of the postsecondary market garnered by four-year institutions is shrinking while community college share is flat, and the share for proprietary schools awarding certificates is increasing (“Who’s Training Technical Workers,” 1997). Companies want performers with a strong knowledge base. Esther Lam, vice president of human resource at Intel Containers International Corporation, emphasized:

We are not interested in hiring technicians, people who have managed to cram enough facts in their head to pass an accounting or management exam. The degree...doesn’t impress me. It is the skills that they have acquired that are key to this company. We look for people who can think on their feet...We want people that dig in with a team spirit (Green & Seymour, 1991, p. 17).

The continued vitality of the American economy depends upon college graduates, among others, possessing competencies and skills that will provide a seamless transition into the world of work. A review of the literature exposes numerous recommendations of what these workplace competencies should include. A long, but incomplete, list could contain critical thinking, problem solving

without supervision, technical skills, collaboration, worker autonomy, verbal and written communication, creativity, interpersonal skills with the ability to work in diverse teams, and flexibility (American Workers and Economic Change, 1996; Bridges, 1994; Gardiner, 1994; National Skill Standards Board, 1994; Useem, 1989; "High Stakes, High Skills," 1997; Wall, 1998). Regardless of the source, problem solving and collaboration/teamwork, the focus of this study, were considered necessary to be successful in the workplace.

The skill of problem solving has become so important that some companies place higher significance on it than on having knowledge of their industry (Green & Seymour, 1991). As job descriptions blur and specific sets of work quickly enter and exit the work place, the ability to understand the relationship between situational variables in order to facilitate creative solutions is crucial. Workers in the 21st century will be required to analyze and integrate data into knowledge. Mathematical algorithms and scientific principles remain important tools in problem solvers' arsenals and the ability to use them pivotal to their success. Reich (1991) wrote of symbolic analysts,

[they] solve [and] identify problems by manipulating the symbols. They simplify reality into abstract images that can be rearranged, juggled, experimented with, communicated to other specialists, and then, eventually, transformed back into reality. The manipulations are done with analytic tools...(p. 178).

In an attempt to select employees with complex problem-solving skills and strong analytic abilities, an increasing number of companies use the "analytic interview." It is not unusual to hear about a job candidate being placed in a room with some eclectic material and instructed to "do something

with it.” In order for college graduates to make a successful transition to the world of work, they must be “able to take data from several different sources and combine them into new and interesting combinations” (Bridges, 1994, p. 86).

Reich (1991) equates collaboration with teamwork and communicating abstract ideas to others. While other countries have successfully implemented self-managed teams, much work remains to be done in many American organizations. Businesses and nonprofit companies continue to spend millions of dollars in an attempt to inculcate the advantages of collaboration and teamwork. However, concepts of rugged individualism and authoritarian management styles interfere with progress in this arena.

At Southwest Airlines collaboration is indistinguishable from leadership where “leadership is practiced through collaborative relationships” (Frieberg & Frieberg, 1996). This partnership binds workers at all levels, not just to be effective problem solvers, but to reach higher levels of motivation and development. All individuals become an integral part of the organization and peer learning is enhanced. For the Matsushita Electric Industrial Company (Panasonic), collaboration and teamwork have become ingrained into its corporate culture. Speaking to U.S. business leaders in 1979, Konosuke Matsushita, chairman of Panasonic, outlined the differences between Japanese and American management.

For us [in Japan], the core of management is...pulling together the intellectual resources of all employees....Because we [in Japan] have examined [better than our U. S. counterparts] the scope of the new... challenges....Only by drawing on the combined brainpower of all its

employees can a firm face up to the turbulence and constraints of today's environment (Green & Seymour, 1991, p. 63).

Nevertheless, "the ability to function together as a single unit is essential" (Green & Seymour, 1991, p. 70) if American companies are to be competitive in the rapidly changing global economy.

Many leading educators and businesspeople believe that spanning the chasm and making the academic connections are essential components for successful transition from college to a high-performance work environment. Echoed throughout the literature was the need for college graduates to be better prepared to work and solve problems collaboratively in self-managed teams. Currently, the majority of students sit quietly in lecture-based courses, completing course requirements individually, memorizing facts and statistics to be regurgitated on a standard test being taught by professors whose educational experiences have been very similar to this scenario (Business Higher, 1997; Boyett & Boyett, 1995; Green & Seymour, 1991; Reich, 1991). This chasm will only be narrowed by altering the curriculum; however, few are proposing radical changes. The task force on high performance work and workers suggested that "corporate needs can be satisfied by making relatively modest curricular adjustments" (Business Higher, 1997, p. 23). This reference noted, for example, that although individual competition has been strongly encouraged on college campuses, it is antagonistic to the collaborative abilities and teamwork needed in the corporate world. Hoerner (1995) has been critical of the no help, no sharing of knowledge approach that occurs in classrooms of higher education and recommended several methods for upgrading curriculum to make it more relevant

to the world of work. He wrote, "The key rests with the way in which we teach or present what is expected to be achieved" (Hoerner, 1995, p.14).

Changes in the curriculum at four-year colleges range from using state-of-the-art technology to assigning collaborative work in teams to performing on-site analysis. These modifications must become more pervasive in order for

American colleges and universities [to become] a major resource for preparing the nation to meet the challenges of the future. However, if they do not respond to the changing needs of the business world, corporate leaders explained that they will be forced to rely on their own educational systems to train employees (Business Higher, 1997, p. 49).

On a positive note, the literature did not reveal deep-seated conflicts between the development of abilities needed by businesses and what colleges and universities teach. However, overall changes in the curriculum are needed to improve problem solving, critical thinking, collaboration, and the communication of abstract ideas as they will be applied in the work world ("Changing Nature," 1997; Reich, 1991). At the heart of getting work completed in the 21st century, especially as job descriptions become increasingly blurred, will be self-managed teams dependent on problem solvers for "constant collaboration among team members" (Bridges, 1994, p. 40).

Purpose of Study

The purpose of this study was to examine collaborative study and alternative testing methods in an effort to discover instructional techniques that may increase learning and prepare graduates of four-year colleges for the work world. This included learning discipline-specific theories (linear programming), learning to apply abstract concepts to solve word problems, and learning to work as a

collective unit. Great interest exists in exploring strategies that maintain academic rigor while increasing student engagement, intellectual acuity, and mastery of content. Many of these strategies have the potential for negative consequences and can impair performance if not used properly. This study investigated the effects of collaborative study and paired test taking while controlling for ability as measured by Scholastic Aptitude Test scores and high school grade point averages.

Statement of the Problem and Hypothesis

Many business leaders and managers have been concerned that graduates from four-year colleges and universities do not have the necessary abilities, such as problem solving and teamwork skills, to make a successful transition to the work world. Curricular problems such as content brokering, boring lectures, standardized tests, little group work, compartmentalized disciplines, weak courses and teachers, rote memorization for learning, and unproductive ‘busy work’ have been cited as areas where changes are needed (Business Higher, 1997; Gardiner, 1994; Green & Seymour, 1991, Lankard, 1994). To implement successful curricular changes empirical research needs to be conducted to determine the positive impact, as well as the caveats, of incorporating nontraditional teaching techniques into college courses. Of particular interest to the researcher was the effect of collaboration on problem-solving abilities. The ability to work collaboratively to solve problems is a vital attribute in the work world.

This experimental study was conducted to examine the influence of collaborative study and paired test taking on problem-solving development and group-to-individual transfer within a discipline-specific domain while controlling for ability. By applying their collective knowledge, students should acquire a more thorough understanding of the concepts and domain-specific content, increasing individual mastery of the desired competencies. The target population was business students at a four-year, liberal arts college. Linear programming theory was selected as the domain because it is a required core course in the business curriculum and presents a formidable challenge for many business majors. The following null hypothesis was tested: No differences in treatment means measuring problem-solving abilities would be found based on students' test and posttest scores using two treatment groups of collaborative study, with collaborative or individual test taking, and a control group of individual study with individual test taking.

Significance of the Study

In the college classroom, collaborative learning continues to be the exception, while lecture, individual study, and individual test taking persist as the norm. This entrenched educational paradigm is preserved by faculty and college administrators who continue to "do business as usual." As discussed previously, the passive learning model has not been successful for preparing some groups of students, including many majoring in business, with needed competencies to be competitive in the global marketplace. Experimentation and innovation in higher

education supported by empirical research are needed to develop educationally sound approaches to learning.

As an instructional strategy, collaborative learning and paired test taking have the potential to provide students, faculty, and administrators with a mechanism for developing essential competencies including enhanced problem-solving abilities and learning to work in teams composed of diverse members. However few empirical studies, especially at the collegiate level, have been conducted to establish the most effective ways of using collaborative learning in the classroom. This investigation examined paired study and paired test taking and the effect of collaboration on group-to-individual transfer. This study will contribute to an accumulating body of knowledge of collaborative learning. It has specific implications for the following areas:

1. Indicating effectiveness of collaborative learning and paired test taking for students who frequently encounter difficulty in problem solving with traditional instructional methods.
2. Understanding the impact of group-to-individual transfer for collaborative paired groups to determine if students both increase their understanding of the content and their ability to solve problems.
3. Indicating value of collaborative learning and paired test taking for students of varying ability levels. This information will help instructors determine whether to use collaborative learning and paired test taking.

4. Exploring the level of responsibility that students can assume for their learning and the level of authority that instructors can allot to students studying collaboratively and taking tests in pairs.
5. Using outcomes as a basis for establishing instructional policy related to collaborative study and paired test taking.
6. Aiding in establishing professional development programs that will assist prospective and practicing teachers in the implementation of collaborative study and paired test taking.
7. Providing guidelines for curriculum design as educational institutions at all levels are searching for instructional strategies that encourage students to be actively involved in learning.

Definitions

Many of the words and phrases used in this study have multiple meanings and some are being used for the first time. To clarify the meanings of these words and phrases and provide a common basis of understanding, definitions as they applied to this study are provided below:

1. **Collaborative learning:** Two or more students mutually engaged in mastering a particular set of concepts to achieve a common goal in an unstructured learning environment (Bruffee, 1994; Gokhale, 1995; Rau & Heyl, 1990; Schrage, 1990). It frequently requires that learners participate in oral discussion.
2. **Individualized study:** Students receive no assistance from a peer or instructor during the study sessions when solving linear programming word problems.

3. **Individualized test taking:** Each student in the control group will complete a criterion-referenced test with no human or other resource assistance.
4. **Paired or collaborative study:** Two students collaborating during a study session.
5. **Paired test taking:** Two students collaborating on taking a criterion-referenced test where one grade is assigned to both students.
6. **Problem solving:** Students analyzing word problems, formulating them into mathematical models, and understanding their comparison relationships (Snow & Lohman, 1989; Mayer, 1983; Trabasso, 1977). For this study, linear programming theory was used to formulate mathematical models from word problems.

Delimitations

The participants in the pilot, treatment, and control groups were selected as a convenience sample. They were students taking required classes in the business curriculum at a liberal arts college in southwest Virginia. Their participation was on a volunteer basis, and they received bonus points for completing the requirements of the study. Thus, the generalizability of the results was limited. Although the participants were not randomly selected, they were randomly assigned to the treatment and control groups. Further, the lack of being able to conduct the study within an actual classroom resulted in a simulated environment. Laboratory environments seldom capture dynamics of actual situations.

Another delimitation of this study was that very little has been formally undertaken with collaborative paired study and paired test taking, especially at the four-year college level. The study, therefore, was exploratory and attempted to add knowledge to the area of collaborative study and achievement testing by identifying some of the salient characteristics of this instructional technique. Collaborative learning has been a recent arrival to higher education and the theoretical base has not been established. To confound further the application of collaboration, some researchers have discussed it as simply mutual engagement for a common cause (Gokhale, 1995), while others have interwoven it with epistemology and the meaning of knowledge (Brufee, 1995; Romer & Whipple, 1991). Gamson (1994), one of the first proponents of collaborative learning, wrote that there has been no “theoretical basis for understanding how and why [the effects] occur. It is time for us to explore some promising theoretical approaches that might help make sense of the effects of collaboration” (p. 6). As sound research accumulates, theoretical approaches can be explored to explain and provide additional insights into the effects of collaborative learning. Given the other delimitations of the study, this lack of an established theoretical framework has suggested that the results of this study must be interpreted with caution.

Summary

American businesses must compete in the world marketplace and having poorly prepared college graduates as managers and decision makers can only lead to a disadvantaged position for those businesses. As Whitehead (1929) suggested in the opening quote to this chapter, inert ideas or those ideas that

cannot be applied are not only useless, they are harmful. Instructional innovation and experimentation are needed in higher education to develop pedagogies that will help baccalaureate degree students majoring in business acquire essential workplace skills. Collaborative study and paired test taking may offer a strategy to increase learning, augment problem-solving skills, facilitate successful teamwork, and prepare for the work world.

Little research on the effects of collaboration on learning, problem solving, and facilitating teamwork has been undertaken at the collegiate level. Thus, this investigation studied the outcomes of individual study with individual test taking, paired study with individual test taking, and paired study with paired test taking for students majoring in business at a four-year college. Its results should contribute to the accumulating body of knowledge on the effects of collaboration in general as well as for students continuing their postsecondary education at a baccalaureate institution.

CHAPTER II

Review of Literature

School achievement is no longer to be understood as simply the accretion of facts and content specific skills. Certainly, bits and amorphous masses of information are internalized, and specific habits of thought and action are acquired. But educational learning is not just cumulative in the old associationistic sense; a significant part of the learner's task is continually to assemble, reassemble, structure, and tune the cumulating body of knowledge into functional systems for use in thought, and in further learning (Snow, 1980, p. 43).

Introduction

This study focused on collaborative learning in a collaborative study and paired test taking environment involving problem-solving abilities. The literature review examined the academic profile of business majors at four-year colleges, cognitive psychology and measurement of problem-solving abilities, group decision making, and cooperative and collaborative learning.

Academic Profile of Business Majors

At a time when education in general is being closely scrutinized, the academic preparation of students majoring in business at four-year colleges has been increasingly questioned. In a study commissioned by the American Assembly of Collegiate Schools of Business, Green (1992) asserted "business draws a smaller proportion of academically talented students than other majors" (p. 41). A report by the American Assembly of Collegiate Schools of Business (1992) stated

As a group, business students have lower high school grades than students planning to major in the liberal arts and engineering; they are also more likely than their peers in almost all fields . . . to anticipate needing remedial work in English during

their college years...During high school, business majors spent less time on homework and more time “partying” than students planning to major in other fields (p. 3).

Additionally, Green’s (1992) research indicated that 25% of business majors needed remediation in math, only 8.2% did extra reading or classroom work, and only 40% used the computer frequently (even though this is an essential competency for business majors). No research surfaced concerning the narrowing of the academic gap between business graduates and graduates with other majors. However, business majors scored consistently lower than other majors on the Graduate Record Examination, Graduate Management Admissions Test, and Law Scholastic Aptitude Test (Graduate Management Programs, 1995; Law School Admission Council, 1995), which are taken near or after graduation. This situation has been problematic since the number of undergraduate management degrees has more than doubled between the years of 1971 and 1990, business is the most popular undergraduate major, and one-fourth of all bachelor’s degrees are awarded in business and management. Thus, significant numbers of four-year college graduates present an academic profile that poses challenges to academic institutions and perhaps to the workplace.

Although the reasons business majors are not stronger academically are unclear, Green (1992) offered some additional insights: 38% of freshmen business majors indicated that they were first generation college attendees and 43% ranked their intellectual self-confidence below all other students, except for students studying education. “These ‘new students’ to higher education often face unique challenges in their quest for a degree: conflicting obligations, false

expectations, and lack of preparation or support are among the factors that may hinder their success” (Hsiao, 1992, p. 1). The social origins of many of these first-generation students include minorities, women, and those from blue-collar backgrounds. Green (1992) reported that enrollment of minorities in business programs is over 20% and that women have been entering the major in record numbers. As Hsiao (1992) wrote about first-generation students, “they...face a daunting array of challenges in their pursuit of a postsecondary education” (p. 3). Perhaps this partially explains why business majors rank second on the percent of students dropping out of college (Green, 1992).

The perceptions of employers have been that business graduates frequently need additional education or training in academic and workplace skills before they are able to be significant contributors to the organization (Business Higher, 1997; Green, 1992; Green & Seymour, 1991; Porter & McKibbin, 1988). Green and Seymour linked data from Porter and McKibbin (1988) and Useem (1989) to produce a comparison of employers’ perceptions of the strengths and weakness of college graduates—business majors compared to liberal arts majors. It is important to note that although these studies were completed independently and cannot be directly compared, their findings provided a sense of what employers think are the attributes that the different majors bring to the workplace. Both of these studies were based upon surveys with Likert scales where employers rated each attribute. The Porter and McKibbin study (1988) investigated employers’ ratings of the perceived major strengths of business graduates while the Useem study (1989) examined employers’ ratings of the

above average qualities of liberal arts graduates. A few comparisons should illustrate the differences. The highest rating for the business majors was that 38% of employers thought that their motivation to work was a major strength. However, only 19% of employers thought that analytic skills were a major strength for business majors as compared to 43% of employers that found analytic skills to be an above average quality for liberal arts majors. The gap was wider for communication skills, 14% and 85% respectively, and leadership skills, 7% and 51% respectively. Green (1992) admitted, "the surveys are not identical. But, in general terms, the juxtaposition of the Porter-McKibbin and Useem data should send a chilling message to business school deans and faculty" (p. 91). Thus, the data suggested that business students who graduate from a four-year college may not have the abilities to become the problem solvers and decision makers demanded by the competitive global marketplace in the 21st century.

The data suggest that students majoring in business have an academic profile similar to at-risk students who do not usually respond positively to the traditional lecture, passive acquisition of content, and standard individual test taking after cramming the night before. These are the courses where the professor functions as a content broker and little else as J. L. Hoerner (personal communication, April, 1996), a prominent school-to-work advocate, has noted. As a result, at-risk students frequently do not acquire the basic academic competencies needed in the workplace.

Cognitive Psychology and Operational Criteria for Problem Solving

Because measurement, and specifically collaborative (paired) test taking to measure problem-solving abilities, was central to this study, cognitive psychology and testing for educational purposes were reviewed. Historically, tests have served two broad purposes: to measure aptitude and to measure achievement. Since aptitude is not the concern of this investigation, it was omitted from the discussion. The literature review, thus, focused on measuring achievement in a problem-solving context.

For this study, the impact of collaborative learning on the learner's understanding of linear programming knowledge and its application (i.e., problem solving) was examined through the use of a measurement instrument developed by the researcher. A review of the literature provided the theoretical base for developing the instrument to ensure that the appropriate problem-solving constructs were measured, to provide a basis for reproducing the study, and to provide operational criteria that allowed the study to move forward in a logical manner.

Although the literature addressed the influence of studying and working in groups and pairs on performance as measured by individual test scores (Gokhale, 1995; Johnson & Johnson, 1991; Rau & Heyl, 1990; Yager, Johnson, & Johnson, 1985), no studies were uncovered that had paired groups completing a traditional, in-class test. Measurement of cognitive psychological constructs is still emerging especially as they relate to achievement testing. In an extensive literature review, Snow and Lohman (1989) acknowledge that cognitive

psychology is not a well-defined discipline and researchers investigate quite disparate problems. However, cognitive processes incorporate “attention, perception and memory, thinking, reasoning and problem solving, and the acquisition, organization, and use of knowledge” (p. 264). Problem solving based upon mathematical abilities, an essential part of this study, has received considerable attention from those investigating educational measurement in cognitive psychology.

Although difficulties determining and measuring problem solving exist, the work of Mayer (1985), Sadler (1983), Snow and Lohman (1989), and Trabasso (1977) were synthesized to establish criteria for such assessment. These criteria were developed to ensure that the measurement instruments used in this study conformed to well-defined problem-solving criteria. Since evaluating the performance of college students on linear programming problem-solving tests for achievement was an essential component in this study, establishing operational criteria was essential for the reasons outlined by Sadler (1983).

Once criteria are identified, they serve to (1) provide a rationale for the current judgment so that others may understand the reasons, (2) foreshadow future valuations, making them more, but not absolutely predictable, and (3) invite others to judge similarly. (p. 66)

The first five criteria were based on Mayer’s (1985) work with problem solving and word problems and the last one on Trabasso’s (1977) investigation of problem solving and encoding of relational facts. Both emphasize the role that organized knowledge plays in problem solving. After completing their extensive literature review, Snow and Lohman (1989) acknowledged that even general problem-solving capabilities were impacted by the particular knowledge domains.

The criteria given below include examples of how they are applicable for modeling linear programming word problems. As stated earlier, linear programming word problems were used for this study because they are part of a required course in the business curriculum at most four-year colleges and universities.

1. linguistic knowledge such as meaning of words in a business oriented context
2. factual knowledge such as units of resources available, resource use, and profit per unit
3. schema knowledge for mathematical problem types such a minimization of cost or maximization of profit
4. strategic knowledge such as resolving what decisions to make and determining the use of scarce resources
5. algorithmic knowledge of how to perform an operation such as applying linear programming principles to business problems by identifying decision variables, developing the objective function, and determining the system constraints
6. abstract knowledge such as comparison relationship between variables, resources, and products to be produced

Word problems have presented students with a high level of difficulty that increased when comparison relations were incorporated into them. “Word problems are difficult because they require coordination of several different types of mathematical, linguistic, and world knowledge” (Snow & Lohman, 1989, p. 305). In addition, several researchers (Mayer, 1985; Snow & Lohman, 1989; Trabasso, 1977) acknowledged that students of all ages have difficulty representing relational mathematical expressions. Adding abstract knowledge to Mayer’s types of knowledge needed for problem solving disallowed rote memorization of the premises as adequate to demonstrate problem-solving abilities. Since mathematical knowledge has been necessarily abstract, it “depends for its development on the individual’s ability to understand and manipulate increasingly

abstract concepts” (Snow & Lohman, 1989, p. 305) and these include comparison relationships. Therefore, if instruments have these knowledge criteria incorporated into word problems, they should measure the ability of the test takers to employ problem-solving skills. Examples were included in Appendix A showing how each type of knowledge for problem solving was incorporated into the test and posttest instruments.

Measurement in cognitive psychology continues to emerge and instructional theories of testing remain incomplete. Nevertheless, the available literature provided important criteria for developing achievement instruments to measure problem solving. Since the test and posttest instruments for this study provided the data for assessing the impact of collaborative learning on problem-solving abilities as defined by paired test taking, it was essential that they were constructed based upon well-defined criteria.

Group Decision Making

Contrary to popular belief, group decision making is not always the optimal method for solving a problem or increasing performance, and is multifaceted and quite complex. Societies have used groups to make important decisions throughout the centuries. In modern times, small groups decide the guilt or innocence of individuals, who is included or ostracized, what bills are referred to Congress, etc. However, the issue of whether groups outperform individuals in various decision making situations has not been resolved, even though many researchers suggest that they do. Studies reproduced with similar problems, such as the Painter-Inspector Problem, Thumbs Problem, and NASA Moon

Problem have produced conflicting results (Hoffman & Maier, 1961; Salazar, 1995; Waugh, 1996). One of the reasons may be the lack of control the researchers exercised over the many and complex variables--methodological problems. Before discussing these issues involved with group decision making, these methodological considerations should be examined to put the findings of the literature review and this study in perspective.

Methodological Problems

One of the problems with studies on group decision making and performance was the selection of samples. Some were convenience samples consisting of students in psychology classes at major universities (Goldman, 1965; Hoffman & Maier, 1961), some tried to control for confounding variables through random assignment (Yager, Johnson, & Johnson, 1985), and in others students chose their own groups (Gokhale, 1995; Webb, Ender, & Lewis, 1995). The lack of rigor in selecting participants for their studies may have compromised their findings.

The role of ability was investigated with psychology students at University of Missouri at Kansas City (Goldman, 1965). However, ability levels were chosen in an arbitrary manner as students were divided into high, moderate, and low ability based upon scores received on the Wonderlic Intelligence Test. Yet, ability levels in these classes were not representative of the population at large. Students who had been identified as low ability at a major university were significantly above the ability level of low ability individuals found in the population. Based upon this

standardized test score, students were divided equally into the various groups, without consideration to criteria that would constitute a particular ability level.

Age was another variable that did not seem to receive more than casual consideration. Sometimes ages were stated (Webb, Ender, & Lewis, 1986) and in others they were more general such as college-age students (Goldman, 1965; Hoffman & Maier, 1961) or second-grade students (Yager, Johnson, & Johnson, 1985). Based upon cognitive abilities, as shown with the work of Piaget (1959), age can make a substantial difference in the performance of certain tasks. Webb, Ender, and Lewis (1986) conducted a study with students that ranged in age from 11 to 14 involving BASIC computer programming. They discovered that few of the students used abstract problem-solving abilities as designated by defining hierarchical planning strategies. An important consideration might be whether this age group of students is cognitively ready to develop such abstract strategies.

Another serious concern was that very few of the studies have been conducted in the classroom, many have been done in the laboratory (Goldman, 1965; Hoffman & Maier, 1961; Waugh, 1996). Exceptions include studies by Johnson, Johnson, and Smith (1991) and Johnson and Johnson (1994) who have done extensive work with elementary students. However, even their research has been criticized for its methodological treatment of the participants and data (Slavin, 1990) Others have decision making as a secondary outcome (Johnson and Johnson, 1985; Klemm, 1994; Slavin, 1990) The concern of these studies was the more humanistic goals of helping others achieve success whether it is decision making, learning content, or improving social interaction. Given these problems

with research and the complex nature of group decision making, several findings or counter findings did consistently appear in the literature. These have been discussed as key features in the next several paragraphs.

Issues in Group Decision Making

An examination of the literature revealed that the effect of group decision making on performance remains controversial and continues to need empirical study. Issues that impact group decision making were discussed in subsequent sections and included process gain versus process loss, the influence of ability, the role of discussion, and homogeneity versus heterogeneity of personality.

Process gain versus process loss. Much of the literature on group decision making and performance addressed the extent to which group decisions were better or worse than would be expected given the abilities of the members of the group. Numerous studies found one or the other or both. Three excellent literature reviews served as the basis for much of the information in this section-- Hill (1982), Stasson and Bradshaw (1995), and Salazar (1995). Process gain occurs when the decisions of the group are superior in quality to the decisions that would have been made based upon the individual abilities brought to the group. Process loss occurs when the decisions are of less quality than would have been predicted based upon the abilities of the members of the group. The decisions predicted from the "best member" or majority rule models are used to compare the decisions of the group to determine process gain or process loss.

Salazar (1995) provided support for process gain. Exams given to college age students as individuals and in groups found a process gain in 97% of the

groups with the average gain of about 9% points above the best member. In solutions given to the NASA Moon Problem, group performance was better than best member performance only 33% to 72% of the time. Waugh (1996) found process gain in a majority of the groups he studied after investigating the role of instruction and consensus in decision making.

Libby, Trotman, and Zimmer (1987) studied the accuracy of loan officers predicting bankruptcy based upon financial profiles of several companies. The prediction of the group was inferior to the predictions of the best members. Hill's (1982) rather extensive literature review concluded that although groups would consistently outperform the average member, they would seldom have higher quality decisions than the best member. This meant process loss occurred when the best member became part of a group. Hill (1982) proclaimed that individuals are better at arriving at quality solutions than groups.

Stasson and Bradshaw (1995) found support for both process gain and process loss when group decision making was employed. Participants were given a pretest and then immediately divided into groups of five. The test was either repeated by groups of five or by individuals. When the group contained one or more members that had correctly solved the problem initially, the group selected the incorrect answer 14% of the time. Even more surprising was that in groups that contained only one member that had correctly solved the problem on the pretest, the group answered incorrectly 35% of the time. The group frequently outperformed the average member. The groups that outperformed the best

member had individuals who had complementary knowledge, so that they could answer questions that the best member could not answer.

Ability. The studies on the influence of ability on decision making were quite complex as various ability levels were “mixed and matched” and the findings for each did not fall into consistent patterns. Goldman (1965) conducted analyses of data that were collected on undergraduate psychology students who were divided into paired homogenous ability groups and paired heterogeneous ability groups. He found that performance was improved for all levels (high, medium, and low) of the homogenous ability groups compared to their performance as individuals. Although high scorers helped their partners more than low scorers helped their partners, the low ability pairs improved more than the high ability pairs. (High ability groups had less room to move upward.) However, Bracey (1994) found that low ability dyads mutually extinguished each other’s achievement.

Goldman (1965) discovered that high ability individuals significantly improved their decision making capabilities regardless of which ability group they were assigned. However, high ability individuals did not improve more when working with another high ability person as compared to a low ability person. Hill (1982), however, showed that high ability individuals suffer “a process loss” when working with those of lower ability levels. In fact, she found that a group with only one high ability member did not perform better than a group with no high ability member; in heterogeneous groups, high ability members were detrimentally affected unless there were three or more high ability members. However, Goldman (1965) reported that high ability

individuals working alone outperformed middle ability pairs and middle ability individuals outperformed low ability pairs. Also, the middle ability pairs outsourced the pairs composed of one middle ability and one low ability performer that scored at the level of the homogenous low ability pairs. A similar result was described by Hill (1982). These findings might suggest that there was “process loss” when a middle ability person was placed in a group with lower ability individuals.

Hill (1982) cited a study by Tuckman and Lorge (1962) that employed the Mined Road Problem where 11% of the time groups scored lower than their best members' performance. When summarizing the findings from the literature review, Hill (1982) concluded that the concept of process loss frequently occurred in groups and thus lowered individual productivity. However, she concluded that group performance was better than the average individual and as such decisions may be improved with a group approach.

Role of discussion. Several researchers (Hoffman and Maier, 1961; Salazar, 1995; Yager, Johnson, and Johnson, 1985) have found that discussion and communications play an important role in groups making a decision and in the quality of that decision. When group members have substantially different perspectives or the problem is ambiguous, members of the group must communicate with each other to grasp the problem initially. Explanations and checking for errors expressed by others help group members develop a deeper understanding of the “big picture”. Others (Lambert, 1978; Zaleska, 1978) found that discussion influenced whether the majority would decide the solution. In

Lambert's study (1978), the majority rule was not used as often for decision making when there was discussion; whereas, Zaleska (1978) found that the discussions supporting the most frequent responses ruled the decision. Interestingly, a computer programming study conducted by Webb (1986) involving students age 11 to 14 failed to find a positive relationship between group members giving explanations and improved achievement. But, responses to specific questions did improve performance. Interaction appeared to be important for writing a quality program, but a lengthy explanation was not.

Salazar (1995) identified the process of communications and the opportunity for members of the group to discuss relevant issues important in arriving at group decisions that led to process gain or process loss. This process was governed by three influences--disruptive, facilitative, and counteractive. Disruptive influences led to process loss by detracting from the task at hand such as turning power over to one individual in the group, making derogatory remarks about other members, and not allowing adequate discussion of the problem. In other words, they inhibited discussion and communication. Facilitative influences encouraged process gain and promoted careful examination of the many facets of the problems such as resolving disagreements, answering questions, and providing positive or negative feedback. Counteractive influences led to process gain when they were exerted to get the group back to the task of solving the problem.

Homogeneity versus heterogeneity of personality. Hoffman and Maier (1961) expanded upon a previous study of Hoffman's to determine if the quality of

solutions produced by groups of dissimilar personalities (heterogeneous groups) differed from groups of like personalities (homogeneous groups). The participants were students in psychology classes at the University of Michigan. Problems were employed that required new-modified or integrative solutions (i.e., Mined Road, Painter-Inspector Argument). For all the problems, the solutions for the heterogeneous groups were significantly better or the same as the homogeneous groups; whereas, the homogeneous groups never outperformed or made better decisions than the heterogeneous groups. In addition, one mixed-sex group outperformed all-male groups.

Hoffman and Maier (1961) concluded that the heterogeneous groups brought many more directions and perceptions to the decision making process, resulting in more discussion and seeking more possible options. In homogeneous groups, the decision may be made prior to discussion since the group members had similar perceptions. Therefore, the number of options considered was limited and lowered the quality of the solutions. Interestingly, few groups were able to understand the issues involved with the overall problems or the “big picture” and generally dealt with only the initial problem. It appeared that homogeneous groups with limited perspectives had more difficulty generating high quality decisions.

This was not the finding of Waugh (1996) when he reproduced the NASA Moon Problem study. His investigation introduced two variables not present in the Hoffman and Mayer research--instruction and consensus requirement. No process loss occurred in any of the homogeneous-instructed groups while 33% of

the heterogeneous-instructed groups experienced a process loss. However, 56% of the homogeneous-noninstructed group experienced a process loss. The heterogeneous-noninstructed groups had the weakest performance.

The results discussed in this section punctuate the complex nature of group decision making and the importance of identifying the multitude of variables that affect performance. The literature review suggested that just grouping students may hinder decision making and performance resulting in process loss. However, this outcome is in opposition to the current goals of education. As four-year business programs search for ways to promote problem-solving abilities and to develop academic competencies, it is imperative that group activities, such as collaborative study and paired test taking, result in process gain for students. Decrements in performance for some group members are unacceptable and research must be conducted to understand what variables (i.e., ability, discussion, homogeneity of group members) impact the learning environment so that graduates from four-year business programs can have opportunities to develop to their fullest potential and have adequate preparation for entering the workforce.

Cooperative Learning and Collaborative Learning

Although many authors and educators have found little difference between cooperative and collaborative learning, a review of the literature indicated major divisions between the two. In a subsequent section, these differences will be delineated. However, the next two sections discuss the major elements and characteristics of cooperative learning and collaborative learning.

Cooperative Learning

Authors frequently begin their writings on cooperative learning with a definition. This is a fairly straightforward process since cooperative learning has become highly structured and defined. Although many definitions found in the literature are adequate, Slavin's definition (1988) incorporated the basic components. Cooperative learning consists of "instructional methods in which students of all performance levels work together in small groups toward a group goal. The essential feature of cooperative learning is that the success of one student helps other students to be successful" (p. 8). Johnson and Johnson (1994), Johnson, Johnson, and Smith (1991), Yager, Johnson, and Johnson (1985), and Slavin (1988, 1990, 1995) have researched and promoted cooperative learning and have written excellent books and journal articles on the topic. It is from their work that much of the discussion of cooperative learning was drawn.

At the root of cooperative learning is the differentiation of three goal structures for learning—cooperative, competitive, and individualistic. Competition is viewed as harmful and inhibits learning for the majority of students. In competition, winning is a scarce commodity and coveted—the winners can only be successful if several others lose. This creates a system of "I'm better, and smarter, and more worthwhile than you." "Losers" quickly buy into this scenario and "just want to sink into their seats." This is a torturous situation that occurs on a daily basis for many students. "Thus a student may spend twelve years in public schools being confronted daily with the fact that he is a 'loser'" (Johnson & Johnson, 1994, p. 160). The outcome is often avoidance of failure that leads to

such behaviors as pervasive cheating, interference with problem solving, low self esteem, feelings of worthlessness, and high anxiety levels (Hamm & Adams, 1992; Hilke, 1990; Johnson & Johnson, 1991; Slavin, 1995).

Individualistic learning as a goal structure means that students learn on their own with assistance only from the classroom teacher. Student outcomes have no relationship to the fate of other students and learners have no interaction with each other. Their performance is judged on a criterion-referenced evaluation system for excellence. However, for students to achieve at a high level they must perceive the task as relevant and important. Frequently the benefits apply only for short term tasks that can be completed within a specified time frame. An unlimited number of students can achieve success, but the responsibility for learning and completing the tasks rests with the students who work at their own pace. Johnson and Johnson (1994, pp. 154-155) identified potential problems with individualistic learning:

1. Talking and interacting with others--The more socializing, the lower the productivity.
2. Competing with others--Persons working in close proximity tend to begin to compete with others.
3. Complex or new tasks--Individualistic learning is more appropriate for simple tasks, but inadequate for complex tasks.
4. Unimportant goal--Attention and effort quickly wane if goal is perceived as unimportant.

5. Unclear rules and procedures--Authority figure may not have time to explain tasks until they are clearly understood.
6. Lack of materials, resources, and skills--Every person is a self-contained unit and without adequate resources efforts to complete tasks stop.

“All cooperative learning methods share the idea the students work together to learn and are responsible for their teammates’ learning as well as their own” (Slavin, 1995, p. 5). In fact, success is only achieved and the work considered completed when all students in the group have mastered the task. Johnson and Johnson (1994) and Johnson, Johnson, and Smith (1991) identified five key components of cooperative learning and Slavin (1988) defined six principal characteristics. However, many researchers, educators, and authors (Hamm & Adams, 1992; Klemm, 1994; Rau & Heyl, 1990) referred to elements discussed by Johnson and Johnson (1994) and those elements will also be used in this study. They included positive goal interdependence, face-to-face promotive interaction, individual accountability, social skills, and group processing. In order for cooperative learning to achieve the expected outcomes, all of these components must be organized into a highly structured learning environment.

A brief discussion of the five elements was necessary to understand the structure of successful cooperative learning. Positive interdependence is best characterized by the phrase “sink or swim together.” All group members are aware that they are directly accountable for the learning of their teammates. They have two responsibilities that include recognizing that each group member’s efforts are required and each group member has a contribution to make.

Promotive interaction encourages students to do their “real work” together. It is distinguished by the oral discussions between the students as they explain how they reached a conclusion, solved a problem, or found an answer. This activity is frequently completed when students summarize their learning tasks. Individual accountability makes each student personally responsible for his or her performance to guard against the effects of “free loading.” In order to counter some of these negative consequences, individual performance is assessed and linked to a group reward. Interpersonal and small group skills must be taught to group members. Students do not instinctively know how to interact with each other to accomplish tasks effectively and efficiently. Group members are frequently assigned specific functions or roles such explainer, listener, checker, observer, etc. Group processing is the final step and involves the reflection of groups, individuals, and teachers on how cooperative learning is working and how it can be improved.

Cooperative learning has been zealously advocated by some for the realization of benefits for students and society (Hamm & Adams, 1992; Johnson & Johnson, 1994; Johnson, Johnson, & Smith, 1991, Slavin, 1988). One benefit that has been of obvious concern is achievement. However, another equally important objective to some educators has been to “teach children that all people—regardless of race, ethnicity, or gender—can achieve their goals in society if they aim high and are tenacious” (Hamm & Adams, 1992, p. v). This commitment to a diverse school population has required that group members be as heterogeneous as possible. School desegregation and an increasing minority

population have made positive intergroup relations a top priority for cooperative learning. An extension of this concept has been the acceptance of academically and physically handicapped students as they have been mainstreamed into regular classrooms.

Many educators and researchers credit cooperative learning with advancing a vital psychological outcome—improved self-esteem (Hamm & Adams, 1992; Johnson & Johnson, 1990; Slavin, 1995). “Students’ beliefs that they are valuable and important individuals are of critical importance for their ability to withstand the disappointments of life, to be confident decision makers, and ultimately to be happy and productive individuals” (Slavin, 1995, p. 60). Along this same line of acquiring life skills, students were found to be more cooperative, altruist, and able to take another’s perspective when they had participated in cooperative learning groups.

Among the studies that showed significant academic gains due to cooperative learning were Hamm and Adams (1992), Johnson and Johnson (1994), Johnson, Johnson, and Smith, (1991), Klemm, 1994, and Slavin (1988, 1990, 1995). Much of the research has shown significant gains for students in academic achievement. Interestingly, studies have shown overwhelming success even though those who passionately advocate its practice confess that it takes significant training and years of experience to become a competent practitioner. Hamm and Adams (1992), Johnson and Johnson (1994), Johnson, Johnson, Smith (1991), and Slavin (1988; 1990; 1995) mention, in passing, some possible problems and hazards usually related to “social loafing” or “free riding.” However,

one teacher/researcher (Melton, 1996) gave a realistic account of her struggles and failures encountered when she attempted to institute cooperative learning in a mathematics class composed largely of minority students. In the final analysis she declared cooperative learning pedagogies to be successful, but it was only her strong determination to see the process through to the end and the establishment of short-term goals that provided even a limited victory.

Few studies were found suggesting that cooperative learning outcomes were no different than the control groups. Slavin (1995) addressed this issue in more detail in his book *Cooperative Learning: Theory, Research, and Practice*. In fact, he is critical of the methodology employed by Johnson and Johnson who have made a significant contribution to the body of knowledge on cooperative learning (Slavin, 1990, 1995). Slavin completed an extensive review of the literature and summarized the results in concise, easy to understand format. He selected only studies that met his rigorous criteria for methodologically sound research. None of the Johnson and Johnson studies qualified for review under Slavin' well-defined standards. Only one study came close to qualifying for his review and that was the Yager, Johnson, and Johnson study (1985).

Even though the Yager, Johnson, and Johnson (1985) study was methodologically adequate, a brief discussion may illuminate some of the lack of attention to detail that may call some of their results into question. In the study, *Oral Discussion, Group-to-Individual Transfer, and Achievement in Cooperative Learning Groups*, the researchers wrote, "The results indicate a very powerful group-to-individual transfer effect resulting from learning in cooperative

groups....This was true for high-, medium-, and low ability students” (p. 63). The E tests showed significant ability effects, but the researchers did not elaborate on where the effects were greatest. Such questions as what was the ratio of high, medium, and low achievers in each group, did this ratio seem to influence the results, which ability group seemed to benefit the most, which ability group seemed to benefit the least, or did all ability groups receive the same benefit were not addressed.

Collaborative Learning

Collaborative learning as an instructional method has only recently been officially recognized. Gamson (1994), a leading proponent of collaborative learning, states that she first encountered the term in 1983 when she was invited to address a conference on collaborative learning. In preparation for the speech she found herself looking up the word “collaboration” in the dictionary. The first meaning is “to work together, especially in an intellectual endeavor.” Based upon what many others described as collaborative, “intellectual” is an essential component. Another phrase associated with collaboration is “mutual engagement.” Michael Shrage (1990) characterized the art of collaboration as “an act of shared creation, and/or shared discovery” (p. 6). The literature provided a multitude of definitions (Gokhale, 1995; Matthews, Cooper, Davidson, & Hawkes, 1995; Bruffee, 1995) which can be quite different. One of the reasons for multiple definitions is that collaborative learning has not been as thoroughly researched and as a result it is not as highly structured as cooperative learning. Another reason that collaborative learning is not as clearly defined is that some writers

want to make it a philosophical issue. Bruffee (1995) questioned what embodies knowledge and Hawkes (1993) wanted to redefine classroom authority. These were not issues with cooperative learning where the empirical research and the major proponents (Johnson & Johnson, 1991; Slavin, 1988) were allowed to define cooperative learning, and the classroom authority remained unquestionably with the teacher. Smith and MacGregor (1992) are frequently referenced in the literature for their definition of collaborative learning. They wrote,

“Collaborative learning” is an umbrella term for a variety of educational approaches involving joint intellectual effort by students, or students and teachers together. In most collaborative learning situations students are working in groups of two or more, mutually searching for understanding, solutions, or meanings, or creating a product . . . most should center on the students’ exploration or application of the course material. . . . Learning unfolds in the most public of ways (p. 10).

Although collaborative learning has been used in many contexts, educational approaches, and different disciplines, a number of assumptions or themes provided a working foundation for educators to draw upon as they experiment with making the learning experience a more positive one for students. These have been primarily synthesized from the works of Smith and MacGregor (1992), Schrage, (1990), and Bruffee (1994, 1995). The categories developed by Smith and MacGregor (1992) will serve as a basis for the assumptions. Others were added to expand their offerings.

Learning is an active, constructive process. Students reorganize or reconceptualize prior knowledge to construct new meanings. Many times this involves accepting uncertainty and viewing problems to be solved as opportunities (Schrage, 1990).

Learning depends on rich contexts. Learning is embedded in context and application of theories and facts. Bruffee (1994) referred to this as “making the most of knowledgeable peers.” Schrage (1990) termed it competence and stated, “A collaboration of incompetents, no matter how diligent or well meaning, cannot be successful” (p. 152).

Learners are diverse. Diversity of backgrounds allows students to bring many rich experiences to the learning process. However, as Schrage (1990) emphasized it is important that the collaborators have mutual respect, tolerance, and trust in order for the task to be completed successfully. He reminded his audience that successful collaborators do not have to be friends as long as trust can be maintained.

Learning is inherently social. Communication, both verbal and nonverbal, is essential to acquiring in-depth understandings and creating new ideas for many learners. It is at the basis of constructing meaning and knowledge by creating intellectual synergy. Bruffee (1994) credited this sharing of knowledge as essential for learning how to exercise judgment in a field of expertise.

Learning has affective and subjective dimensions. Learners shift the authority for their intellectual development from others to themselves (Bruffee, 1994; Gamson, 1994). The collaborators become “creators of their own knowledge and meaning” (Smith & MacGregor, 1990, p. 11). Clear lines of responsibility remain, but there are no restrictive boundaries because “collaborative relationships are not managed” (Schrage, 1990, p. 158). This is a shift that is crucial to the development of learning for one’s lifetime.

Decisions do not have to be made by consensus. It is common for collaborators to disagree on major issues that frequently stimulate learners to take new ideas into unexplored territory or discover new creations. However, as Schrage (1990) succinctly stated, "If collaborators consistently diverge, the collaboration ultimately dissolves" (p. 159).

As has been acknowledged in the literature, few scientifically controlled studies on collaborative learning have been undertaken at the college or university level. The exceptions to this are researchers who have actively investigated the role of intelligent educational systems as co-learners (Blandford, 1994; Dillenbourg, 1996). The findings of two collegiate studies have been encouraging and provided strong support for the role of collaborative learning in college classrooms, even when the sections were large (Gokhale, 1995; Rau & Heyl, 1990). Gokhale (1995) compared collaborative learning to individual learning in a technology class on electric circuits. He examined its effect on "drill and practice" items and on critical thinking items. Students in the collaborative learning groups outperformed individual learners on the critical thinking items, but no statistical difference was found on the "drill and practice" items. Rau and Heyl (1990) found students in sociology classes performed significantly better on test questions that had been studied in a collaborative environment than the ones that had been studied individually. However, they compared undergraduates with graduates, used many of the elements associated with cooperative learning, and did not use a control group.

Differences in Cooperative and Collaborative Learning

A review of the literature revealed that some authors used the terms cooperative and collaborative learning almost interchangeably (Hamm & Adams, 1992; Klemm, 1994; Johnson, Johnson, & Smith 1991) while others insisted that they are completely different approaches (Bruffee, 1994, 1995; Gamson, 1994; Matthews, Cooper, Davidson, & Hawkes, 1995). To confuse the issue further, Smith and MacGregor (1992) in a publication "*What is Collaborative Learning?*" listed cooperative learning as a type of collaborative learning. A review of the literature highlighted some essential differences that have been summarized in Table 1. Differentiating between cooperative learning and collaborative learning is important so that each can be employed in its proper context to maximize its positive impact. Table 1 shows that they have several contrasting attributes that have significant implications for implementing the two learning strategies.

This study focused on using the knowledge within the paired groups as resources to be shared for achieving mutual gains. Gains that may not be possible when business students work in isolation on tests measuring linear programming knowledge and problem-solving abilities. Not only has the instructor's authority been relinquished, there may not be individual accountability as the grade on the test instrument was assigned to both test takers. However, the individually completed posttest taken in this study provided information on how well collaborative study and paired test taking facilitated using problem-solving skills in a linear programming knowledge domain to promote individual process gain.

Table 1

Differences in Cooperative and Collaborative Learning^a

Cooperative Learning	Collaborative Learning
Highly structured	Few structures or rules
Groups size usually four members	Group size varies from two to eight members—can include entire class
Teacher actively monitors group activities	Instructor takes hands-off approach—students organize, govern, and pace own work
Individual accountability within the group	May be no individual accountability
Group accountability with group awards	May be no group accountability
Students assigned specific social roles within group	Students determine own social structure within group
Students receive training in small-group social skills	No formal training in social skills—students rely on previously acquired skills
Teachers' training and experience essential elements for success	Instructors may not receive any formal training in social skills or small group processes
Students perform group processing tasks including how to improve performance	No formal group processing—students resolve group conflicts on participation issues
Teachers evaluate group processing tasks	Teachers only become involved in extreme cases of conflict—reassignment of group members undesirable
Considered useful for mastering lower-order and basic academic skills	Considered useful for mastering higher-order and conceptual skills

(table continues)

Table 1 (*continued*)

Cooperative Learning	Collaborative Learning
Generally designed and useful for elementary and middle school students	Generally designed and useful for adolescents and adults
Frequently work in parallel with other group members and consult others when having difficulty	More interactive exchange and sharing of ideas throughout the group work
Encourages group consensus	Encourages dissent and controversy
Group members carefully selected based on diversity of race, ethnicity, gender, ability, socioeconomic background	Group members can be assigned by self-selection, randomly, or criterion-based
Highly developed programs such as Student Teams—Achievement Division, Teams—Games—Tournaments	No well-defined programs
Facilitates foundational education	Facilitates nonfoundational education
Aim is basically to eliminate competition in the classrooms	Shift nature of competition from between individuals to between groups
Group relationships closely managed by teacher	Group relationships are not managed
Classroom authority remains with teacher	Authority shifts from teachers to students as students confront issues of power and authority
Well-established body of empirical research	Few empirical research studies

^aThis summary was developed by the researcher and reflects findings from the review of literature.

Summary

This study examined the impact of collaborative learning and paired test taking on problem-solving abilities within the domain of linear programming knowledge. Since problem solving was a vital component of the investigation, well-defined operational criteria were developed. They provided the rationale for constructing the test and posttest instruments, and allowed others to evaluate and reproduce the study. Mayer's (1983) work with problem solving and word problems and Trabasso's (1977) investigation of problem solving and encoding of relational facts served as the basis for the operational criteria.

Even though group decision making has been promoted as a way to get work done effectively, a review of the literature showed that group members could have decrements in performance. Many variables influenced the outcome of group decisions, but middle ability individuals were more at risk than either high or low ability level individuals for experiencing process loss. Many students majoring in business at four-year colleges are considered to possess moderate academic abilities, and they have increasingly been assigned group work. Some of these team assignments may be limiting their educational development. This study examined the influence of collaborative learning in a collaborative study and paired test taking environment while controlling for ability level differences of students majoring in business at a small liberal arts college in southwest Virginia.

Collaboration as an instructional strategy is a recent arrival to higher education. Nevertheless, it holds promise for intellectually engaging students in an active learning environment, especially those who have difficulty in the

traditional lecture, passive learning classrooms. Sharing knowledge in groups for mutual gain can increase understanding of course material and improve problem-solving abilities. When knowledge is used as a resource in a test taking situation, collaborative study and paired test taking can provide business students with the opportunity to take responsibility for their learning and assume ownership of the linear programming material, thereby increasing their performance. Educators must not accept limited mastery of analytical, communication, and leadership skills. Four-year colleges and universities must enter an era of experimentation in instructional methods that incite learning. Instructional experimentation along with new methods of assessment can be the key to assuring that college graduates develop essential skills.

CHAPTER III

Methodology

An experimental study was conducted to examine the influence of collaboration on problem-solving abilities within a discipline-specific domain for business students at a four-year, liberal arts college. Educators and managers frequently embrace teamwork and collaboration in an effort to motivate students and workers to reach higher levels of achievement. These efforts have frequently been encouraged without careful study of the literature on decision making and collaboration.

Educators, employers, and students recognize the urgency for college graduates, and especially business majors (the concern of this study), to have mastery of essential competencies such as analytical problem-solving abilities and communication skills, including working in teams. Collaborative learning may be one method to facilitate learning abilities needed in the workplace in the college classroom. Thus, this study examined collaborative learning and paired test taking under three levels of treatment while controlling for ability. The treatment groups were studying individually and completing the test individually (the control group), studying in paired groups and completing the test in paired groups, and studying in paired groups and completing the test individually.

The relationship between collaboration and problem-solving ability within a discipline-specific domain of linear programming theory was examined at two time periods—test and posttest. The test was administered immediately after a learning session, study period, and question-and-answer discussion.

Completing the test involved collaborative study and paired or individual test taking by two experimental groups (studying in paired groups and completing the test in paired groups, and studying in paired groups and completing the test individually) and a control group (individual study with individual test taking). To evaluate group-to-individual transfer of linear programming concepts from the use of collaborative learning strategies, a posttest was administered 17 days later with no subsequent instruction. All participants completed the posttest individually. The following null hypothesis was tested: No differences in treatment means measuring problem-solving abilities would be found based on students' test and posttest scores using two treatment groups of collaborative study, with collaborative or individual test taking, and a control group of individual study with individual test taking.

Participants

The participants selected for the study were students who had declared a major in business and who were enrolled in at least one class in the business program in the fall semester of 1997 at a liberal arts college located in southwest Virginia. The declared major of the participants was coordinated with the registrar's records to ensure that participants were current business majors. Students participating in the study were allotted 10 extra points that were added to a test of choice for a course within the business curriculum. In order to encourage students to do their best and to hold students individually accountable, participants scoring at least 90 points out of 100 on the posttest earned an additional five bonus points.

Since the content area for the study was linear programming theory, students who had taken or were taking the linear programming course in the fall of 1997 were eliminated from the study. They were assigned to a separate group that was used for the pilot study. All participants were randomly assigned to the treatment and control groups, and to the pairs within the treatment groups.

Data collected on each participant consisted of age, gender, class status, ethnicity, Scholastic Aptitude Test scores, and high school grade point averages. Thirty-three students participated in the pilot study. There were 11 participants in the individual study with individual test taking (control) group, 12 students in the paired study with individual test taking group, and 10 students in the paired study and paired test taking group. Forty-six students took part in the experimental study. There were 14 participants in the individual study with individual test taking group, 16 participants in the paired study with individual test taking group, and 16 participants in the paired study with paired test taking group. Human Subjects Clearance was obtained from the Institutional Review Board for Research Involving Human participants at Virginia Tech and the Academic Dean of the liberal arts college in southwest Virginia where the study was conducted.

Instructional Treatment

The instructions, as given in Appendix B, were given to students participating in the pilot and experimental studies. Students were supplied with all materials needed for taking part in the study. The diagram below outlines the various sessions and their respective time allotments.

SESSION	TIME (allotted in minutes)
Learning	45
Study and Homework Completion	25
Question-and-Answer Session	30
Taking Test	Unlimited

The treatment group of paired study with paired test taking attended the instruction session Friday afternoon, November 14, 1997 for 45 minutes. At the beginning of the instruction session, students were given a numbered packet of materials. It included a description of the word problems used in the class discussion, note paper, and pencils. Upon completion of the learning session, participants were given homework problems and proceeded to assigned rooms to study and complete the homework assignments. The study problems are included in Appendix C. Students were directed to work and discuss the problems together, rather than taking a problem and working it individually and turning in individual work as group work. In the paired study with paired test taking group, three study sessions were audio taped to document the quality of the discussion, as this could possibly affect group performance (Salazar, 1995). Twenty-five minutes were allotted for the study session. During this time, students could not ask the instructor questions, but had to rely upon the resources of their collaborators. However, students reconvened with the instructor for a 30 minute question-and-answer period where two homework problems were discussed. Upon completion of the question and answer session, all numbered materials were collected by the researcher. The paired test takers returned to their assigned rooms to work the test problems. Since collaboration may increase task

completion time, no time constraints were established for completion of the test instrument.

On Saturday afternoon, November 15, 1997 the above process was repeated for the treatment group of paired study with individual test taking. The exception to the above procedure was that students studied in pairs, but completed the test instrument individually. Three of the study sessions were audio taped.

On Sunday afternoon, November 16, 1997, the process was repeated for the control group in the afternoon. These participants studied individually and completed the word problem test individually. The diagram below contains the dates that each group received the instructions and completed the test.

GROUP	TEST DATE
Pilot Study	November 7, 1997
Treatment of Paired Study/ Paired Test Taking	November 14, 1997
Treatment of Paired Study/ Individual Test Taking	November 15, 1997
Control	November 16, 1997

At the completion of each question-and-answer session, participants were instructed that they would have no further verbal contact with the researcher. In other words, the researcher would not address questions or clarify any content in the instrument. Students in the treatment and control groups were instructed not to work on linear programming word problems between completion of the test and reconvening to complete the posttest. No additional instruction was given between the test and posttest sessions and no question-and-answer session was conducted. The researcher taught all of the learning sessions based upon well-defined instruction and conducted all the question and answer meetings to

control for influences introduced by the instructor. However, the instructions as given in Appendix B were reviewed by an associate professor of business familiar with linear programming theory and a research colleague with business subject teaching experience at the collegiate level.

In order to maintain a manageable class size for instructional treatment, the control group and both treatment groups received the instructions during separate learning sessions. Learning linear programming theory to construct mathematical models requires that students be able to request clarification or pose questions for enhanced understanding. This means that the participants in the different groups may not have received exactly the same set of instructions because of the interaction between the instructor and the students. Documentation of any instructional differences were maintained by audio recordings from the learning sessions and the question-and-answer discussions for all groups.

Test Instrument

The test instrument consisted of the word problem provided in Appendix D. It was developed and formulated based upon principles of linear programming model formulation. The researcher wrote the test instrument to ensure that students did not have prior access to the actual test question, to control the appropriate level of difficulty, and to ensure that all elements of the problem-solving criteria were included. The instruments included the following prompts for information: date, time started, time completed, and name(s). The test instrument was reviewed by an associate professor of business and a research colleague

with collegiate teaching experience in order to insure that it followed linear programming protocol.

Students taking the test in pairs received the same test score in order to increase the interdependence of the test takers. Those completing the test individually received individual scores. The possible range of scores on the test was 0 to 100. The model formulation components including defining the decision variables, developing the objective function, advancing the constraints, and determining the correct relational sign were assigned a specified number of points as shown in Appendix E.

The formulation of linear programming models was used as the content area for the instruction and the test instrument because it is a part of the core curriculum at the participating college and many other collegiate business programs. Mastering linear programming theory presents a challenge for many business students. The design of the test instrument was congruent with the operational definition of problem solving defined in the review of literature.

In order to guard against grade bias, the students' completed tests and posttests were graded by the researcher and another college professor familiar with linear programming theory. The performance evaluation by the researcher and the second grader were compared for interrater agreement. These data are provided in Appendix F. Disagreements were resolved through consensus reached by the researcher and the second grader.

Test Administration

The test was administered on the dates previously displayed. Participants receiving the treatment of paired test taking were assigned a separate room per pair within the same building. This physical arrangement allowed robust oral discussion and sharing of knowledge and resources without disrupting other test takers. Collaboration frequently increases task completion time. In order to minimize negative consequences related to time, tests given to treatment and control groups were untimed. Completion times were recorded and appear in Appendix G.

The researcher delivered each test taking pair a numbered test and a congruently numbered answer sheet. The participants recorded the date and time in the appropriate space, placed both of their names on the test and answer sheet, and began working on the instrument. The answer sheet was used to formulate and write the linear programming model generated by the linear programming word problem. Frequent monitoring was performed by the researcher. Upon completion of the tests, both participants returned the test to the researcher and the time of completion was recorded on the instrument. These recorded times were placed in Appendix G.

Students completing the test individually (control group and one treatment group) were asked to assemble in another room in the same building after the question and answer session. This was done to maintain similar activities between the control and treatment groups. Numbered tests with congruently-numbered answer sheets were placed face down on the desk. At the designated

time, participants were asked to turn the test over, record the date and time in the appropriate space, place their names on the test and answer sheet, and begin working on the instrument. The answer sheet was used to formulate and write the linear programming model generated by the linear programming word problem. Frequent monitoring was performed by the researcher. Upon completion of the test the completion time was written on each test. These times were recorded and placed in Appendix G.

Posttest Administration

Seventeen days after the test, a similar, but different, linear programming word problem posttest, as provided in Appendix H, was given to all participants. The dates for the posttest are given in the diagram below. The respective groups reconvened and all participants completed the test individually. No additional instruction was given. Participants signed a pledge, as shown in Appendix I, that they had no additional contact with the linear programming models. The researcher did not answer questions before or during posttest administration.

GROUP	POSTTEST DATE
Pilot Study	November 24, 1997
Treatment of Collaborative Study/Paired Test Taking	December 1, 1997
Treatment of Collaborative Study/Individual Test Taking	December 2, 1997
Control	December 3, 1997

Numbered tests with congruently numbered answer sheets were placed face down on the desk. At the designated time, participants were asked to turn the test over, record the date and time in the appropriate space, place their names on the test and answer sheet, and begin working on the instrument. The answer sheet was used to write out the linear programming model generated by the linear

programming word problem. Again, frequent monitoring was performed by the researcher. When the participants completed the tests, the completion time was written on each test. Posttest completion times were recorded and details were placed in Appendix J. Participants were assigned individual grades that were not related to the previous collaborative or individual test grades. The model formulation components for the posttest including defining the decision variables, developing the objective function, advancing the constraints, and determining the correct relational sign were assigned a specified number of points as shown in Appendix K. This scoring scheme was used to evaluate the performance on the posttest.

Pilot Study

The pilot study was conducted to evaluate the procedures described in the Instructional Treatment, Test Administration, and Posttest Administration Sections. The test dates for the pilot study were November 7, 1997 and November 24, 1997. The 31 participants were business majors that were eliminated from the experimental study because of their previous exposure to linear programming theory. They were divided into the same groups as those defined for the experimental study: paired study with paired test taking, paired study with individual test taking, and individual study with individual test taking. The groups were composed of 10 students, 12 students, and 11 students respectively. These participants received the same set of instructions, homework problems, test and posttest instruments, and procedural considerations as their respective groups in the experimental study.

The pilot study revealed that the original amount of time allocated for the learning session needed to be decreased from 70 minutes to 45 minutes. It also confirmed that the instructional treatment, test administration, and posttest administration could proceed as designed as no other problems surfaced.

Data Analysis

An analysis of covariance (ANCOVA) was selected for data analysis to partial out the influence of ability to reduce variance due to error. By adjusting the means of the test and posttest scores, the variance due to treatment was more accurately measured. The following null hypothesis was tested: No differences in treatment means measuring problem-solving abilities would be found based on students' test and posttest scores using two treatment groups of collaborative study, with collaborative or individual test taking, and a control group of individual study with individual test taking.

The independent variable consisted of treatment at three levels: paired study with paired test taking, paired study with individual test taking, and individual study with individual test taking. Ability was the single covariate. The dependent variables are shown in the diagram below.

DEPENDENT VARIABLE	TYPE OF VARIABLE	RANGE OF SCORE
Test Score	Continuous	0 - 100
Posttest Score	Continuous	0 - 100

Summary

This study examined collaborative learning (paired study and/or paired test taking) while controlling for ability as a covariate. The treatment levels were individual study and individual test taking (the control group), paired study with

individual test taking, and paired study with paired test taking. A posttest, that was completed individually by all participants, was administered 17 days after the initial test to provide information about group-to-individual transfer and individual accountability. It was important to determine if both members of the paired test taking group were benefiting from the collaborative learning environment, mastering the linear programming content, and increasing their ability to apply those concepts in problem-solving situations. If learning is facilitated through collaborative test taking, educators at all educational levels may need to rethink traditional achievement testing.

CHAPTER IV

Results

This chapter discusses the attributes of the participants, the role of the second grader, the audio taped recordings of the collaborative pairs, and the data analysis using ANCOVA. It addresses the assumptions of no differences on the ability covariate among the three treatment groups, the significance of ability on the test score and posttest score variables, and homogeneity of regression.

Demographics

Forty-six business majors participated in this experimental study that was divided into a control and two treatment groups. For the demographic composition of each group, refer to Table 2. Twenty-seven of the participants were males (58.7%) and nineteen were females (41.3%). Their ages ranged from 18 to 24 with a mean age of 20.5 and a standard deviation of 1.26. Ethnicity included Caucasian and African-American students, 35 participants (76.1%) and 11 participants (23.9%), respectively. Although 25 of the 46 participants had junior status (54.4%), 2 were freshmen (4.3%), 8 were sophomores (17.4%), and 11 were seniors (23.9%).

Second Grader and Test/Posttest Scores

To guard against researcher bias in evaluating the test and posttest instruments, a second grader scored both test independently. The scores of the first and second grader, as well as the assigned scores, appear in Appendix F. The same score was assigned to 21 out of 46 tests (45.7%). In 22 out of 46 tests (47.8%), there were two points or less difference and the first grader's

Table 2

Demographic Composition Of Treatment Groups

Groups	Gender		Ethnicity		Age		Academic Status			
	Male n	Female n	African- American n	Cauca- sian n	<u>M</u>	<u>SD</u>	FR n	SO n	JR n	SR n
Individual Study/ Individual Test Taking	7	7	3	11	19.9	1.10	2	3	7	2
Paired Study/ Individual Test Taking	11	5	3	13	20.9	1.40	0	2	10	4
Paired Study/ Paired Test Taking	9	7	5	11	20.7	1.10	0	3	8	5
Total	27	19	11	35	20.5	1.26	2	8	25	11

score was used. Only three out of 46 tests (6.5%) had a difference in the scores of greater than two points. These three tests were evaluated jointly by the first and second graders and an agreed upon reconciled score was assigned.

The same score was assigned to 23 out of 46 posttests (50%). In 20 out of 46 posttests (43.5%), there were two points or less difference and the first grader's

score was used. Only three out of 46 posttests (6.5%) had a difference in the scores of greater than two points. These three tests were graded jointly by the first and second graders and an agreed upon reconciled score was assigned.

Comments on Recorded Collaborative Study and Test Taking

Studies conducted by Salazar (1995) indicated that the process by which individuals communicate can influence group decision making outcomes. He categorized the types of communication into facilitative, disruptive, and counteractive. Others (Hoffman & Maier, 1961; Salazar, 1995; Webb, 1986; Yager, Johnson, & Johnson, 1985) discussed providing explanations and error checking to improve group decision making. During the study sessions, three pairs of the paired study with paired test taking and the three pairs of the paired study with individual test taking were audio taped to provide insights into the decision making process of the pairs. The same three pairs of the paired study with paired test taking groups were audio taped during the completion of the test instrument.

Of the six pairs that were audio taped, a dominant member emerged in five of them. In only one pair did both members seem to be roughly equivalent partners in the development of a solution. In four of the five groups with dominant

members, the leader attempted to include the other member in the problem-solving process. The most common ways of engaging the other member of the pair were explaining the concepts to promote understanding so the nondominant member could become a contributor, and error checking by asking questions that required a response and participation from the nondominant member. These questions were generally effective as the nondominant members increased their participation in solving the problem. By the end of the study session, the level of participation was generally equal among the group members for the four groups that initially had dominant members. In the one pair whose level of participation was equivalent from the beginning of the study session, they remained equal partners until its completion. However, the interaction, i.e., the number and detail of the explanations and error checking, between the members of the taped group especially during the study sessions, indicated ability differences.

After reading the problems, the periods of silence were approximately 20 to 65 seconds although a few were as long as two minutes. These periods of silence did not appear to be disruptive to the participants. The type of communication used in the paired groups was overwhelmingly facilitative—members stayed on task, did not try to avoid working the problem, and shared information. However as the collaboration continued, the participants seemed to become more interactive and more equivalent in their contribution of information toward formulating a solution. The exception was in one of the recorded groups during the study session where the participants were to take their tests individually. The dominant member exhibited disruptive communication

behavior when she refused to allow her partner to contribute his ideas. In the beginning of the process, he tried to be part of the decision making process and take counteractive behavior to find a satisfactory solution. However, she stated “I just kinda got on a roll” (Sessions, 1997) and she continued to work alone. As this behavior continued, her partner emitted fewer responses and little collaborative work was accomplished in this pair. Although the female participant’s ability score was 124.52 compared to 97.15 for the male participant, it is unclear if the difference in ability level contributed to the disruptive behavior. However, their test and posttest scores were equivalent: 95 test and 74 posttest scores for the female participant, and 91 test and 74 posttest scores for the male participant.

The audio recordings from paired groups during test taking revealed marked differences from the paired groups during the study session in the interaction and status of the paired group members. Members assumed more equal roles and it was more difficult to determine the dominant member. Both shared information immediately, error checking was decreased, and explanations were briefer and less detailed. On several occasions the member who had been nondominant in the study session provided complementary information that augmented the problem-solving process.

Data Analysis

Before ANCOVA could be used to analyze the data, assumptions had to be satisfied including determining the significance of ability covariate on variance in test and posttest scores, establishing that mean level of ability level was equal across the treatment groups, and determining the homogeneity of regression.

After meeting these assumptions, an ANCOVA was conducted to reveal the effect of treatment on the variance of the test and posttest scores. The ability covariate was measured by dividing the Scholastic Aptitude Test score by 1600 and the high school grade point average by 5.0 and summing the two values. SPSS, version 7.5, was used to analyze the data.

No Significance in Ability (Covariate) Means for the Treatment Groups

ANOVA was conducted to determine if the mean ability level was equal across the three treatment groups. No significant difference was found among the mean ability levels of the three groups, $F_{(2,43)} = 0.06$, $p = 0.94$. The means for the three groups were 107.5 for individual study with individual test taking, 106.4 for paired study with paired test taking, and 105.3 for paired study with individual test taking. Refer to Table 3.

Significance of Ability Covariate

Ability as a covariate must have a significant effect variance in the test score and posttest score in order to use ANCOVA for data analysis. The ability covariate was created by using Scholastic Aptitude Test scores and high school grade point averages, both of which had been measured before treatment occurred.

Therefore, treatment could not have an effect on ability. Ability as a covariate had a significant effect on the variance in the test scores, $F_{(1,42)} = 5.46$, $p = 0.02$, and the posttest scores, $F_{(1,42)} = 24.77$, $p = 0.00$. Refer to ANCOVA Tables 4 and 5.

The unadjusted and adjusted means for the test and posttest scores are given in Table 6. The ability covariate resulted in a larger adjustment in the means for the posttest scores than for the test scores. The test and posttest scores

Table 3

Analysis of Variance for Ability (Covariate) and Treatment Levels

Source	DF	SS	MS	F
A (Treatment)	2	35.98	17.99	0.06
ERROR	43	13302.11	309.35	
TOTAL(Adj.)	45	13338.09		

Table 4

Analysis of Covariance for the Test

Source	DF	SS	MS	F
X (ABILITY)	1	1287.084	1287.084	5.46*
A (TREATMENT)	2	1847.791	923.8955	3.92*
ERROR	42	9907.532	235.8936	
TOTAL (Adj)	45	12952.8		

* $p < .05$

Table 5

Analysis of Covariance for the Posttest

Source	DF	SS	MS	F
X (ABILITY)	1	12492.15	12492.15	24.77*
A (TREATMENT)	2	4476.571	2238.285	4.44**
ERROR	42	21181.94	504.3319	
TOTAL (Adj)	45	37476.98		

* $p < .01$

** $p < .05$

Table 6

Number of Participants, Range of Scores, and Unadjusted and Adjusted Means for the Test and Posttest Scores

Groups	Test Scores				Posttest Scores			
	N	Range	Unadjusted Mean	Adjusted Mean	N	Range	Unadjusted Mean	Adjusted Mean
Individual Study/ Individual Test Taking	14	28 - 97			14	9 - 85		
M			72.57	72.22			37.36	36.25
SE			4.31	4.10			7.48	6.00
Paired Study/ Paired Test Taking	16	64 - 100			16	12 - 97		
M			87.88	87.86			55.81	55.77
SE			4.03	3.84			7.00	5.61
Paired Study/ Individual Test Taking	16	42 - 100			16	19 - 100		
M			81.69	82.01			58.19	59.20
SE			4.03	3.84			7.00	5.61

increased as ability increased, but the effect of ability on posttest scores was greater.

Homogeneity of Regression

Homogeneity of regression or the assumption that the slopes of the ability covariate and test score variable, and of the ability covariate and posttest score variable were equal across the three levels of treatment was tested. To this end, interaction variables (C1 and C2) were created to test the interaction of the ability covariate and the treatment (group) variables. For both the test and posttest, membership dummy variables were developed by assigning three numeric values to a column named T1, and three numeric values to a column named T2. These assigned values were multiplied by the ability covariate values to create the interaction variables, C1 and C2. Table 7 and Table 8 show the ANCOVA results for the three levels of treatment for the test and posttest, respectively.

Equality of slopes for the three levels of treatment was tested using Tables 4 and 7 for the test, $F = -0.28$, and Tables 5 and 8 for the posttest, $F = 0.24$. Both F values were less than $F_{0.5(2,40)} = 3.23$. Based upon the respective F values, the slopes were assumed to be parallel for all three levels of treatment indicating that there was no interaction between the ability covariate and treatment.

Significance of Treatment

ANCOVA showed treatment had a significant effect on the variance in the test scores, $F = 3.92$, $p < .05$, and the posttest scores, $F = 4.44$, $p < .05$. Therefore, the null hypothesis that no differences in treatment means measuring problem-solving abilities would be found based on students' test and posttest scores using

Table 7

Analysis of Covariance for Testing the Homogeneity of Regression for the Three
Levels of Treatment for the Test

Source	DF	SS	MS	F
X (ABILITY)	1	1202.482	1202.482	4.92
X (C1)	1	.2334851	.2334851	0.00
X (C2)	1	124.2976	124.2976	0.51
A (TREATMENT)	2	271.9965	135.9982	0.56
ERROR	40	9771.903	244.2976	
TOTAL (Adj)	45	12952.8		

Table 8

Analysis of Covariance for Testing the Homogeneity of Regression for the Three Levels of Treatment for the Posttest

Source	DF	SS	MS	F
X (ABILITY)	1	10403.52	10403.52	19.88
X (C1)	1	216.9613	216.9613	0.41
X (C2)	1	.3365562	.3365562	0.00
A (TREATMENT)	2	521.0632	260.5316	0.50
ERROR	40	20932.06	523.3015	
TOTAL (Adj)	45	37476.98		

two treatment groups of collaborative study, with collaborative or individual test taking, and a control group of individual study with individual test taking was rejected. Refer to Table 4 and Table 5. Newman-Keuls post hoc test showed significant differences in the means between the groups for the test score variable and the posttest score variable. Refer to Table 9 and Table 10.

Significant differences were found between the adjusted means of the individual study with individual test taking group (72.22) and the paired study with paired test taking group (87.86) for the test score variable. The paired study with paired test taking group had the higher mean by 15.64 points. However, no significant differences were found between the means of the individual study with individual test taking group (72.57) and the paired study with individual test taking group (81.69) even though the paired study with individual test taking group scored 9.79 points higher. The two paired study groups had no significant differences. However, the paired study with paired test taking group scored 5.85 points higher than the paired study with individual test taking group. Refer to Table 9.

For the posttest score variable, significant differences were found between the adjusted means of the individual study with individual test taking group (36.25) and the paired study with paired test taking group (55.77), and between the individual study with individual test taking group (36.25) and paired study with individual test taking group (59.20). In both collaborative study groups the means were higher than in the individual study group, 19.52 and 22.91 points, respectively. However, there was no significant difference in the means of the paired study (collaborative) groups. Refer to Table 5. Although no significance

Table 9

Differences in Means of the Treatment Groups and Results of Newman-KeulsPost Hoc Test for the Test

	Differences in Means			
	Means	Group 1 ^a	Group 3 ^b	Group 2 ^c
Group 1 ^a	72.22	—	9.79	15.64*
Group 3 ^b	82.01	9.79	—	5.85
Group 2 ^c	87.86	15.64*	5.85	—

^aIndividual study with individual test taking

^bPaired study with individual test taking

^cPaired study with paired test taking

*p < .05

Table 10

Differences in Means of the Treatment Groups and Results of Newman-KeulsPost Hoc Test for the Posttest

	Differences in Means			
	Means	Group 1 ^a	Group 2 ^b	Group 3 ^c
Group 1 ^a	36.25	—	19.52*	22.95*
Group 2 ^b	55.77	19.52*	—	3.43
Group 3 ^c	59.20	22.95*	3.43	—

^aIndividual study with individual test taking

^bPaired study with paired test taking

^cPaired study with individual test taking

*p < .05

was found between the means of the paired study with individual test taking group (59.20) and the paired study with paired test taking group (55.77), the paired study with individual test taking group had a higher mean by 3.43 points on the posttest than the paired study with paired test taking group. Refer to Table 10.

Summary

No significant difference was found among the means of the ability levels (covariate) of the three levels of treatment indicating that ability was equal across the groups. However, the ability covariate significantly contributed to the variance in the test and posttest scores and was partialled out to reduce the error variance. The slopes of the three treatment groups were equal for both the test and the posttest studies indicating that there was no interaction between the ability covariate and treatment.

Having met the above prerequisites, ANCOVA was used for data analysis and significant differences among the means were found between the treatment groups for both the test and posttest scores. Both of the collaborative study groups had higher adjusted means than the individual study group on both the test and the posttest scores. Refer to Table 6. Newman-Keuls post hoc test showed significant differences between the means of the test scores for the individual study with individual test taking group and the paired study with paired test taking group as shown in Table 9. Newman-Keuls post hoc test showed significant differences between the means of the posttest scores of the individual study with individual test taking group and paired study with paired test taking group, and

between means of the individual study with individual test taking group and paired study with individual test taking group as shown in Table 10.

CHAPTER V

Summary, Implications, Recommendations, and Conclusion

The final chapter summarizes the investigation of the effects of collaborative learning strategies on formulating solutions to linear programming problems, discusses the implication of the findings, and suggests areas for future research. Implications and suggestions for future research have focused on how the results can be used by college practitioners and researchers, who teach in four-year business programs, to increase problem-solving abilities while preparing students for the work world through the application of collaborative learning strategies.

Summary

Forty-six students majoring in business at a small liberal arts college in southwest Virginia participated in the investigation that studied the effects of using collaborative learning for formulating solutions to linear programming word problems. Linear programming theory was selected because it is a required core course in the business curriculum and presents a formidable challenge for many business majors. Further, the word problems could be designed to require problem-solving skills as defined by Mayer (1983) and Trabasso (1977). The following null hypothesis was tested: No differences in treatment means measuring problem-solving abilities would be found based on students' test and posttest scores using two treatment groups of collaborative study, with collaborative or individual test taking, and a control group of individual study with individual test taking. The test was completed in the treatment groups as defined

in the null hypothesis and the posttest was completed individually by all participants. To provide additional insights into collaborative problem solving, three pairs in the study sessions from both collaborative treatment groups were audio taped.

Although the participants were not randomly selected, they were randomly assigned to the three treatment groups and to the pairs within the treatment groups. The tests and posttests were evaluated based upon well-defined criteria that can be found in Appendix E and Appendix K. A second grader independently scored the tests and posttests to guard against researcher bias. Tests or posttests that had a difference in scores of more than two points were jointly evaluated by the researcher and second grader; otherwise, the researcher's score was used. Analyses were completed that established that the means for ability between the three groups were equal, that the ability covariate had a significant effect on variance in the test and posttest scores, and that the slopes of the treatment groups were parallel for the ability covariate and the test and posttest variables.

An analysis of covariance (ANCOVA) was performed on the test and posttest data to partial out variance due to ability to increase the precision of the variance due to treatment. Differences between the means were found for both the test and posttest score variables, $F = 3.92$, $p < .05$ and $F = 4.44$, $p < .05$, respectively. Newman-Keuls post hoc test showed significant differences between the adjusted means of the individual study with individual test taking group (72.22) and the paired study with paired test taking group (87.86) for the test score variable.

Significant differences were found between the adjusted means of the individual study with individual test taking group (36.25) and the paired study with paired test taking group (55.77), and between the individual study with individual test taking group (36.25) and paired study with individual test taking group (59.20) for the posttest score variable.

Implications of Findings

The findings from this experimental study with two types of collaborative treatment and a control group need to be examined at two levels, after differences in ability were partialled out. Firstly, statistical significance between collaboration and improved problem solving needed to be established. Secondly, just as important is the practical impact on student achievement and problem-solving abilities as measured by test and posttest scores.

This investigation was an experimental study that controlled for ability, as a covariate, and consisted of two treatment levels and control group. In addition, strict controls were maintained that included developing the test and posttest instruments that were examined by colleagues in the area of linear programming, administering the test and posttest instruments based upon well defined procedures, assigning scores after being evaluated by a second grader, and meeting the demanding assumptions of ANCOVA. Since empirical data on collaborative learning and group decision making at the collegiate level is sparse, the results of this experimental study contribute to the evidence supporting the use of collaborative learning and group decision making at four-year colleges.

The outcomes raised some issues and concerns that need further examination before these methodologies are imported into classroom environments. The next three sections discuss implications for the use of collaborative strategies emerging from this research. Two of them specifically consider implications arising from results of the test and posttest where each finding is discussed, and the other addresses more general issues of employing collaborative learning strategies as was discussed in Chapter 1.

Test Score Variable Results

To determine the effect of treatment on the variance of the test score variable, three outcomes need to be examined. These included differences, if any, between the individual study with individual test taking group and paired study with paired test taking group, individual study with individual test taking group and paired study with individual test taking group, and paired study with individual study group and paired study with paired test taking group. The implications of each outcome are examined individually.

Differences between the individual study with individual test taking and paired study with paired test taking. Significant differences were found between these two groups, with means of 72.22 for the individual study with individual test taking group and 87.86 for the paired study with paired test taking group. This difference of more than 15 points, on a 100 point scale, could convert to more than two letter grades higher. If grades adequately assess mastery of course material including problem solving abilities, collaborative learning could be particularly meaningful to college students with an academically at-risk profile. However,

individual accountability is difficult or impossible to determine as students complete the test interactively and individual contribution is de-emphasized or discouraged.

As educators continue to search for models that interface with the work world, the collaborative model is more applicable than the old competitive model for organizations that must successfully compete in the global marketplace (American Workers and Economic Change, 1996; Boyett & Boyett, 1995; "Changing Nature," 1997). As the nature of work changes (Bridges, 1994; Freiberg & Freiberg, 1996), teams of individuals are being assembled to work collaboratively. The quality of the team's work is what employers are assessing, not each member's individual effort. There is more responsibility put on the team to deal with members who are "loafers" because the team is accountable for the results. The treatment group of paired study with paired test taking closely resembles this team model that continues to evolve in the work world.

A reduction in test taking anxiety could also result when students study and take the test collaboratively. Many students find test taking situations extremely stressful and this interferes with their processing and articulation of information (Paulman & Kennelly, 1984; Mealey & Hurt, 1992). Collaborative partners can provide these students with a support system that could ease their apprehensions and confirm their correct responses, not only during the test taking session but during the study sessions providing them with positive feedback and assistance in preparing for the test. Additionally, students can learn important abilities from their collaborative partners through modeling. Some of these could include how to

reason through a problem or the development of people skills. These valuable attributes help students in their transition to the work world. As discussed in the Introduction, Chapter 1, learning to work in teams and improving problem-solving abilities benefit preparation for entering the work world after obtaining a bachelor's degree (Bridges, 1994; Freiberg & Freiberg; 1996; Green & Seymour, 1991; "High Stakes, High Skills," 1997).

Differences between the individual study with individual test taking and paired study with individual test taking. Even though there was a difference of 9.79 points, on a 100 point scale, between the individual study with individual test taking group (72.22) and the paired study with individual test taking group (82.01), it was not significant. This may have been due to the small number of participants in each group (14 to 16) and to the range of scores on the criterion variable (28 to 97 and 42 to 100, respectively). However, on this traditional 100 point scale used in many four-year colleges, an increase of 9.79 points could result in one letter grade higher. This increase in the grades of at-risk students could make a difference in their academic successful. Individual accountability is maintained with the treatment group of paired study with individual test taking and, as such, would appeal to educators who are not ready to embrace fully some aspects of collaborative learning strategies. One difficulty with implementing this strategy is ensuring that the students take the collaborative study seriously as they may not see an immediate gain since they would take the test individually.

Differences between the paired study with individual test taking and paired study with paired test taking. No difference was found between the collaborative

study groups (individual test taking with a mean of 82.01 and paired test taking with a mean of 87.86). The participants in the two groups were 14 and 16, respectively, and the ranges of scores on the criterion variable were 42 to 100 and 64 to 100, respectively. The increase of 5.85 points, though not statistically significant, may have practical significance and could result in students receiving one letter grade higher. Some possible reasons that the mean score for the collaborative test taking group was higher are that students may have reduced test anxiety, have complementary knowledge and were able to learn from each other while taking the test, and approached the test taking situation with a positive attitude instead of one of dread. These may have resulted in students feeling more in control of their learning situation and this confidence may have been reflected in their test scores.

Posttest Score Variable Results

The posttest was given 17 days after the instruction session and the test instrument, and the posttest was completed individually. It had a maximum possible score of 100 points. Because of the difficulty of the material (formulating solutions to linear programming word problems) and lack of reinforcement, the overall mean of the posttest scores for all treatment groups (51.02) was lower than the overall mean of the test scores for all treatment groups (81.07). Although all treatment groups had difficulty recalling and applying linear programming theory on the posttest, greater losses were suffered by the control group.

Differences between the individual study with individual test taking and paired study with paired test taking. When determining the effect of treatment on

the variance of the posttest score variable, significant differences were found between the individual study with individual test taking group (36.25) and the paired study with paired test taking group (55.77). The difference of 19.52 points between means of the groups on the posttest was remarkable, especially given that the posttest was completed individually. The difference between the means was greater on the posttest (19.52) than the test (15.44) for these two groups. Certainly the previous discussion on implications associated with the differences in the test scores of the treatment groups is applicable for the posttest scores.

At the college level, many professors may be reluctant to use collaborative strategies, particularly when administering criterion-related achievement tests because individual accountability is difficult to evaluate. Professional integrity is compromised when students successfully complete a course as determined by their final grade (frequently based on tests) and at a later time appear not to have an appropriate grasp of the content. This is particularly problematic when employers are disappointed in the preparation of the college graduate. If the tests are completed in pairs, the possibility exists that students could receive a high passing grade (based upon the knowledge of the paired member) and would not have mastered any of the material. However, the finding that the participants of the paired study with paired test taking group scored almost 20 points higher on a posttest that was completed individually is a strong indicator that individual learning may be substantially enhanced by collaboration including collaborative test taking. If achievement tests measure acquisition of knowledge, this numeric difference in the posttest scores between the individual study with individual test

taking group and the paired study with paired test taking group would represent a significant contribution to students' mastery of domain-specific content.

Differences between the individual study with individual test taking and paired study with individual test taking. Significant differences were found between the individual study with individual test taking group (36.25) and the paired study with individual test taking group (59.20). The difference of 22.95 points between means of the groups on the posttest was substantial, especially given that the posttest was completed individually. The difference between the means was greater on the posttest (22.95) than the test (9.79) for these two groups. Certainly the previous discussion on implications associated with the differences in the test scores of the treatment groups is applicable for the posttest scores..

Although the researcher expected that the paired study with individual test taking group would outperform the individual study with individual test taking group on the posttest, the disparity in the means from the test score and posttest score for the paired study with individual test taking group was unanticipated. The adjusted mean scores were 36.25 for the individual study with individual test group (control), and 59.20 for the paired study with individual test taking group. One reason for this outcome may be that collaborative in conjunction with individual effort plays a key role in mastering abstract theories and enhancing problem-solving abilities.

Differences between the paired study with individual test taking and paired study with paired test taking. No significant difference was found between the paired study with individual test taking group (59.20) and the paired study with

paired test taking group (55.77) for the posttest outcome. However, the paired study with individual test taking group had a higher mean than the paired study with paired test taking group by 3.43 points.. This result was somewhat unexpected, especially since the paired study with individual test taking group had a mean of 5.85 points lower than paired study with paired test taking group on the initial test instrument with scores of 82.01 and 87.86, respectively, and less time was spent working collaboratively. Although no significant differences were found between the two collaborative treatment groups, the small sample size and extreme range of scores may have clouded the results.

A possible explanation for a higher mean on the posttest of the paired study with individual test taking group is that those members encoded the information differently during the group study session knowing they would be solely responsible for their score on the initial test instrument. The paired test takers may have relied more upon their partners because they did not feel the urgency of being solely responsible for knowing the material. Therefore, the paired test takers may have approached the study session differently. Even though all participants understood that they would take the posttest individually, participants in the paired test taking group may not have considered the impact of this during the study sessions since the posttest was not to be taken for 17 days. However, working individually with the linear programming concepts in conjunction with collaborative study may be an important variable in developing proficiencies in many disciplines. Even though additional research is needed to more clearly define the relationship between individual work and collaboration, the results of

this study would indicate that educators can integrate collaboration into the college classroom while still maintaining individual accountability.

General Issues Associated with Collaborative Strategies

When examining the test and posttest studies, the results suggest that students majoring in business at a four-year college had significantly improved performance when formulating solutions to linear programming word problems when working collaboratively in paired groups. These are students, who as an aggregate, present an academically at-risk profile. The difference between the scores of the treatment groups on the posttest, that were taken individually, was marked between 19.52 and 22.95 points increase over the control group. On the traditional 100 point scale used in many four-year colleges and universities, this improved performance could convert to more than a two letter grade difference.

Since the word problems were designed to incorporate problem-solving abilities, the results on the posttest score would indicate that collaborative learning strategies may be more effective than traditional instructional methods for mastering domain-specific content and problem-solving skills. Further, collaborative pairs, both study and test taking, had a positive impact on group-to-individual transfer for increased understanding of domain-specific content as suggested by the significantly higher posttest scores for both collaborative groups.

Although it is unclear as to the specific level of responsibility that students can assume for their learning, the higher posttest scores suggest that allotting students of college age authority for their learning can have a positive impact on their performance. It was interesting to find that the paired study with individual

test taking group had a higher score on the posttest than the paired study with paired test taking group. Continued research is needed to determine the mix of individual and group responsibilities that would optimize performance.

At the instructional level, this study would indicate that college professors and administrators need to consider other instructional strategies and move away from “doing business as usual.” Administrators can offer incentives and provide for professional development programs to encourage professors to embrace collaborative strategies. These incentives could include release time for instructors to research alternative strategies and develop appropriate courses or attend conferences and workshops on collaboration, and perhaps a cash stipend could be offered for incorporating collaborative learning strategies into the curriculum. The outcomes of this study, along with an accumulating body of evidence, can be used by college instructors to support instructional policies and curriculum changes at the operational level--in the classroom. Group work, including comprehensive projects, homework, class work, and tests, can become integral to successful completion of course requirements.

Recommendation for Further Research

This study raised important issues and concerns that need further investigation in order to optimize the benefits of collaborative learning and group decision making strategies in a four-year college environment. The issues addressed in this section have impact on the college age student and have been of particular interest to the researcher. Future studies need to be designed using larger samples so that their results will not be as limited in generalizability.

Ethnicity and Gender

The researcher found no studies that had been conducted on groups composed of specific ethnic groups or females. Even the extensive studies conducted by Hoffman and Maier (1961) included only one all female group in more the two years of research. This is of particular importance as collaborative and cooperative learning strategies have been used to advance the academic skills of disadvantaged populations that include minority groups.

Enhanced Learning for Drill and Practice Items

The studies on group decision making and collaborative learning have focused on improved performance for problem-solving or critical thinking abilities (Goldman, 1965; Gokhale, 1995; Hoffman & Maier, 1961; Klemm, 1994; Libby, Trotman, & Zimmer, 1987; Waugh, 1997; Webb, Ender, & Lewis, 1986). Much domain-specific content of various disciplines, including business, has required students to acquire knowledge, such as vocabulary and assumptions, that can be classified as “drill and practice” information. Frequently, difficulty has arisen when applying the discipline-specific theories to problem-solving situations when the basic foundational information has not been mastered. Although this study did not address this issue directly, application of linear programming principles requires the retention of foundational information. Studies at the elementary level (Johnson & Johnson, 1994; Johnson, Johnson, & Smith, 1991; Slavin, 1990; Yager, Johnson, & Johnson, 1985) have shown that cooperative learning can enhance learning “drill and practice” content. However, few studies have examined the effect of collaborative learning and group decision making on retention of drill and

practice content for college age students. The one exception to this was Gokhale's study (1995) where no significant difference on "drill and practice" items was found, $F = 1.91$, $p > .05$.

Effect upon Problem Solving in Other Disciplines

This study was narrowly focused on current business majors whose academic profile suggests that traditional lecture classes as conducted in many colleges may interfere with learning course content. There is some support (Gokhale, 1995; Klemm, 1994; Rau & Heyl, 1990) that collaborative learning strategies may increase the performance of college students, although these alternative strategies have not become part of the mainstream on most campuses. The results of the current study showed considerable improvement in test and posttest scores on formulating solutions to linear programming word problem solutions that required problem-solving abilities. Although additional studies are needed to support these results for business majors, students majoring in other areas such as the liberal arts may likewise receive similar benefits. Studies (American Assembly, 1992; Green & Seymour, 1991; Porter & McKibbin, 1988; Useem, 1989) suggested that liberal arts majors have academic profiles indicative of stronger academic abilities. However, this should not indicate that they cannot realize benefits that will increase their academic performance while acquiring abilities needed in the work world. The researcher would like to replicate the conditions of this study with a representative group of liberal arts majors.

Other Treatments

Although the body of knowledge on collaborative learning has been accumulating, it is a relatively recent arrival to the educational arena and lacks a theoretical framework (Gamson, 1994). Researchers have proceeded to identify variables that maximize performance when employing collaborative learning strategies. Continued research is needed to isolate and determine the impact on performance variables from the relevant treatment variables. The next paragraph discusses variations in treatment that have been of particular interest to the researcher.

Although no significant difference was found on the posttest score between the paired study and individual test taking group and the paired study with paired test taking group, the higher mean from the paired study with individual test taking was unexpected. Because the paired study with paired test taking group had more exposure working collaboratively, the researcher had anticipated that this group would have the higher mean on the posttest score. This raised the issue as to whether there might be an interaction between individual work and collaborative work. Individual and collaborative effort need to be manipulated to determine what ratio of these two variables optimizes learning. Performance from the use of collaborative learning strategies might be improved if the strategies were combined with some level of individual effort.

Another area for future research would be to include an accountability variable such as peer evaluations where every member of the group evaluated each member's contribution to the final product. The audio taped sessions clearly

indicated, in all but one of the groups, a dominant member. If participants were receiving a portion of their course grade based upon peer evaluations, their behavior in the group study and test taking sessions may alter their participation level and affect performance.

The optimal size of the group for maximizing performance has not been determined from the extant research. In order for collaboration to be effective, all members of the group must participate. The audio tapes indicated that even with a two member group, participation was not equal. As the group size increased, the incidence of "social loafing" would be expected to increase as well. With fewer group members, there is a decreased likelihood of those members having complementary knowledge and resources to bring to the learning situation. In the studies reviewed in Chapter II, none investigated the effects of group size.

The effect of group composition has not been clarified. In fact, it seemed that the more studies that have been completed, the more the issue has been clouded (Goldman, 1965; Hill, 1982; Hoffman & Maier, 1961; Salazar, 1995; Stasson & Bradshaw, 1995; Waugh, 1996). Many variables continue to need examination, including ability, personality types, ethnicity, and gender. Although research has yielded conflicting results on group composition, the effects from selection of group members must continue to be examined to avoid process loss.

Collaborative learning and its influence on problem-solving abilities must be studied in the classroom instead of simulated in a laboratory setting. Although some researchers claim to have accomplished this (Gokhale, 1995; Klemm, 1994; Rau & Heyl, 1990), their studies were closely aligned with cooperative

learning and they did not control for collaboration outside the classroom. In fact, one of the more difficult aspects of studying the effects of collaboration is how to prohibit students from helping participants in other groups outside the classroom or assigned study sessions. Collaboration across groups would certainly bias the results. However, regardless of the obstacles, studies on collaborative learning in actual learning situations should be conducted.

Perceptions of Students

Classroom and learning strategies have frequently been implemented without obtaining input from the audience they are trying to help, in this case the college age students. Participants could provide important insights into problems, caveats, and strengths of a developing paradigm that would maximize benefits of the collaborative learning and group decision making strategies. Not only does this issue need to be studied with quantitative procedures, but qualitative studies need to be undertaken to understand the perceptions of students involved in collaborative learning. Some questions that should be researched include the following: Do students feel as if they have a better grasp of the concepts? Are they more satisfied with and more excited about the learning experience? Are they more willing to do the work? Do they feel that they have more reliable support systems? Is their test anxiety reduced? Do they feel like they have more control over their learning and educational experience? Do they feel more confident taking the test? What are the negative aspects of collaborative learning? How might they be mitigated? If questions such as these could be answered after careful thought and investigation, the positive impact of collaborative learning would encompass

more than increasing students' achievement test scores. College students would be developing attributes that would provide them with advantages in their work and personal lives.

Conclusion

Based upon the results of this study, collaborative learning strategy seems to be an effective method of learning linear programming theory and promoting problem-solving abilities as the collaborative study groups had higher mean scores for both the test and the posttest. A crucial point in this investigation was that the posttest was taken individually by participants in all treatment groups after a 17 day interlude between instruction and posttest completion. Numeric differences between the means of the collaborative treatment groups and the control group were greater for the posttest scores as compared to the test scores.

The following null hypothesis was tested using ANCOVA with ability as a single covariate, and it was rejected: No differences in treatment means measuring problem-solving abilities would be found based on students' test and posttest scores using two treatment groups of collaborative study, with collaborative or individual test taking, and a control group of individual study with individual test taking. Significant difference in the means of the test score variable was found between the individual study with individual test taking group (72.22) and paired study with paired test taking group (87.86). No differences were found between the two groups taking the test individually (paired study and individual study) or between the two paired study groups. Significant differences in the means of the posttest score variable were found between the means of the

individual study with individual test taking group (36.25) and the paired study with individual test taking group (59.20), and between the means of the individual study with individual test taking group (36.25) and the paired study with paired test taking group (55.77). Again, no difference in the means of the posttest score was found between the paired study groups.

Collaborative learning resulted in larger numerical differences in the adjusted test and posttest scores of paired study and test taking groups (paired and individual) as compared to the individual study with individual test taking group. The differences in the means of the test scores were 9.79 points between the individual study with individual test taking group and paired study with individual test taking group, and 15.84 points between individual study with individual test taking group and paired study with paired test taking group. The disparity between the collaborative groups and control group was even more pronounced for the posttest scores. The differences between the individual study with individual test taking group and the paired study with paired test taking group were 19.52 points, and between the individual study with individual test taking group and paired study and individual test taking group were 22.95 points. At the actual classroom level, these increases in achievement test scores could have a major impact on the academic status of students and indicate that college professors should not “continue to do business as usual.” Many educators and businesspeople think that only minor changes to courses may be necessary to incorporate collaboration strategies at the classroom level (Business Higher, 1997; “Changing Nature,” 1997). However, changing the mindset of professors,

who have functioned as content brokers and become dependent upon historically entrenched curricula, presents a formidable challenge for most four-year institutions of higher education (Business Higher, 1997; Gardiner, 1994; Green & Seymour, 1991). Resources need to be reserved for professional development to advance the use of collaborative learning in the classroom. In the current climate of reduced budgets, college administrators may be reluctant to reallocate funds from publishing activities to those that would encourage new teaching strategies. However, the advantages accruing to students involved in collaborative learning would not only impact mastering the course content, but also help them develop attributes that would be beneficial in the work world, i.e., teamwork and problem solving.

Although this study may be limited in its generalizability, the findings can be generalized to similar populations, including students at small colleges who are taking courses that involve mastering domain-specific content that require problem-solving abilities. Since business students (the participants for this experiment), as an aggregate, present with an academically at-risk profile, collaborative study and collaborative test taking have the potential for substantially increasing their understanding of course material and promote their academic success.

In addition, the study raised a number of issues and concerns that need further examination to avoid any detrimental effects to students from using collaboration and group decision making learning strategies. Some of these include the effect on the performance of different ethnic groups, the applicability to

all types of learning including “drill and practice,” the perceptions of students and potentially positive psychological outcomes, the ratio of individual and collaborative work to optimize performance, and the effects of collaborative learning strategies on outcomes of students from other disciplines.

The results of this investigation provide a contribution to the growing body of knowledge on collaboration, especially regarding its feasibility at the collegiate level for business majors. This group of college students need learning strategies that can help them realize their potential while preparing them for the work world and for being positive contributors to various organizations and society at large. At the same time, strategies used to promote learning should be closely examined before being implemented at the classroom level in order to avoid individual process loss. This makes continued research on collaboration and group decision making pivotal issues in developing effective learning strategies and undertaking curriculum changes.

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Appendix A

Types of Knowledge in Test and Posttest Conforming to Problem-Solving Criteria

TYPES OF KNOWLEDGE IN TEST AND POSTTEST CONFORMING TO PROBLEM-SOLVING CRITERIA

Test Instrument

Fresh Snackers, Inc. Linear Programming Word Problem

KNOWLEDGE	EXAMPLE FROM TEST INSTRUMENT
Linguistic	<p>“Snacks are produced in lots of 100 packages” means that each time the snacks are made, there are 100 packages made of the same product.</p> <p>“...[H]ow many lots of each product to produce to maximize profits for a weekly time period” means that the decision maker wants to know how many 100-lot packages to produce over a seven-day period.</p>
Factual	<p>Production of the three snacks cannot exceed the 640 pounds of flour because that is the total amount available for a weekly time period.</p> <p>For every lot of Cookie Delight that is produced, \$5.70 will be added to profit.</p>
Schema	<p>This type of problem is maximization of profit based upon linear programming principles.</p>
Strategic	<p>How many lots of 100 packages of Cup Cake Supreme should be produced to maximize profits?</p> <p>How many pounds of chocolate are needed to produce the optimal number of Cup Cake Supreme and Cookie Delight?</p>
Algorithmic	<p>x_1 = the number of 100-lot packages of Cup Cake Supreme to be produced</p> <p>The objective function is represented by $\text{Max } Z = 6.00 x_1 + 7.39 x_2 + 5.70 x_3$.</p>
Abstract	<p>Management wants to have at least two times as many Snacker Crackers as Cup Cake Supreme. This comparison relationship is represented as $x_2/x_1 \geq 2$.</p> <p>Demand for Cookie Delight has never been greater than 12 lots. This comparison relationship is represented as $x_3 \leq 12$.</p>

The format for delineating the types of knowledge was based upon the table used by Mayer (1985, p. 131) in his work on problem solving.

Posttest Instrument

Sports Accessory R U, Inc. Linear Programming Word Problem

KNOWLEDGE	EXAMPLE FROM POSTTEST INSTRUMENT
Linguistic	<p>“The pieces of sports furniture are also popular as separate items” means that customers can buy only one piece without purchasing all three in a set.</p> <p>“The company refuses to take back orders” means that the company does not produce additional items of a produce to meet a previous period’s demand.</p>
Factual	<p>“The labor requirements for the baseball toy chest and the football chest are the same at 1.5 hours each” means that it takes 1.5 hours of labor to produce each baseball toy chest and 1.5 hours of labor to produce each football chest.</p> <p>For each soccer end table that is produced, the cost will be \$118 (which is have to be subtracted from profit).</p>
Schema	This type of problem is maximization of profit based upon linear programming principles.
Strategic	<p>How many units of each piece of sports furniture need to be produced to maximize profit?</p> <p>How many dollars are needed in the budget to produce the optimal pieces of furniture given the other limited resources?</p>
Algorithmic	<p>x_2 = the number of football chest-of-drawers to produce</p> <p>The budget constraint is represented by $65x_1 + 134x_2 + 118x_3 \leq 7,000$.</p>
Abstract	<p>“Management does not want more than a three-to-one ratio of football chests to soccer end tables. This comparison relationship is represented as $x_2/x_3 \leq 3$.</p> <p>The maximum demand for soccer end tables is about 40 per week. This comparison relationship is represented as $x_3 \leq 40$.</p>

The format for delineating the types of knowledge was based upon the table used by Mayer (1985, p. 131) in his work on problem solving.

Appendix B

Model Formulation Instructions

MODEL FORMULATION INSTRUCTIONS

Brief Review of Models

All models deal with variables, parameters, and the relationship between the variables and parameters. Variables can take on an infinite number of values depending upon the values of the parameter. Look at the example based on the following equation:

$$12 x_1 + 4 x_2 = 32$$

If $x_1 = 2$, then $x_2 = 2$. However, if $x_1 = 1$, then $x_2 = 5$. We could even plug in such numbers as .0001 for x_1 and solve for x_2 . Variables are symbols that can assume an infinite number of values.

Parameters are generally constant, numerical values that can change, but only for different cases of the same problem. Many of the parameters are the coefficients for the variables, but they can also exist alone as the number 32 does. In the above example the numbers 12, 4, and 32 are the parameters. Parameters can be changed to observe the effect on variables. If the parameters change, the numeric values of the variables could change as well.

The relationship between the parameters and the variables must be properly determined so that the model accurately represents the situation that it defines. For example, if x_1 represents the number of chairs to be produced and 12 pounds is the amount of wood to produce each chair, the relationship between the wood and production of chairs is represented by $12 x_1$. However, if that relationship should change and the pounds of wood to make each chair were 14

pounds, it is important that it be properly symbolized by $14x_1$. Otherwise, the model would misrepresent the actual situation.

Linear Models

Linear models are used by organizations, both profit and nonprofit, to extract relevant elements from a decision making situation, manipulate them, and arrive at a feasible solution. The bottom line is that linear models are used to help businesses make decisions. They are mathematical models consisting of three interacting components that includes:

- identifying the decision variables
- developing the objective function
- determining the systems constraints

Identifying the Decision Variables

Decision variables are mathematical symbols (i.e., x_1 , x_2 , and x_3) that represent problems to be solved or opportunities to be exploited. In other words, they are things that managers make decisions about, and they are sometimes referred to as solution variables. They represent some level of activity by an organization and take on numeric values in the final solution. The final values of the decision variables represent what the manager is making the decisions about.

Decision variables may be products to be produced, sales persons to be allocated, money to be invested, and iron scrap to be minimized, to name a few. For example in the equation $3x_1 + 5x_2 = 40$, x_1 could represent number of chairs to be produced and x_2 could represent number of tables. One possible solution

could be $x_1 = 10$ and $x_2 = 2$ where 10 chairs and 2 tables were produced. The final values of the decision variables constitute the decision.

Developing the Objective Function

The objective function mathematically represents the objective of the firm, which is usually to maximize profit or minimize cost, although it can symbolize such goals as minimizing iron scrap or maximizing the allocation of personnel. The objective function describes this relationship in terms of the decision variables and represents the sum total contribution of each decision variable toward the objective of maximizing profit or minimizing cost. It is generally measured in dollars and is represented by the symbol Z . However, because of the limited time for conducting the learning sessions, only maximization problems will be discussed.

An example of an objective function is $\text{Max } Z = 100x_1 + 250x_2$. Obviously, this objective function is to maximize profit based upon two products: x_1 (chairs) and x_2 (tables). The parameters represent the amount of profit per product produced. Chairs (x_1) contribute \$100 per unit to profit and tables (x_2) contribute \$250 per unit to profit. If, as given earlier, 10 chairs and 2 tables should be produced to maximize profit, the Z value would be \$1,500. Chairs would contribute \$1,000 to profit (100×10) and tables would contribute \$500 to profit (250×2).

Determining the Constraints

The last component of linear models is determining the system constraints. The constraints represent the limited available resources that cannot be exceeded or conditions that must exceed a minimum requirement. Usually the constraints are inequalities, either \geq or \leq . Occasionally, the constraint is an equality, but that greatly reduces the feasible solutions.

An example of a constraint is $3x_1 + 4x_2 \leq 80$ where 80 represents available pounds of wood. As previously stated, x_1 is the number of chairs to be produced and x_2 is the number of tables to be produced. It is important to remember that profit can be maximized or cost minimized without using all 80 pounds of the wood, which is the reason for using \leq instead of $=$. The parameter 3 represents the pounds of wood needed to produce each chair. If 10 chairs were produced, the amount of wood to produce those 10 chairs is 30 pounds. The amount of wood to produce each table is 4 pounds. The amount of wood to produce 2 tables is 8 pounds. In this case, 38 pounds of wood would be used to produce the chairs and tables. This product mix would not use all the available wood.

Each time you have an available resource or a minimum requirement, it will need to be modeled as a constraint involving parameters, variables, and the relationship between them. In addition, the constraints are to be preceded by “subject to” or “s. t.” because the objective function is maximized based upon the resources needed for each decision variable and the available resources as they are presented in the constraints.

Problems for Learning Session Work

The problems in the learning session were worked following the linear programming guidelines by identifying the decision variables, developing the objective function, and determining the systems constraints. Several of the problems were taken from the Quantitative Methods text used at the liberal arts college where the research was conducted (Taylor, 1996). They were used in the regular, semester class and the researcher wanted to provide as much similarity between the actual class and the investigation as possible.

Various parts of the word problem were analyzed to reduce them to manageable units. They were then synthesized into a coherent model representing the problem to be solved or the opportunity to be exploited. The discussion included how to determine the decision variables and the objective function, as well as how to symbolize the relationship between the parameters and the decision variables in both the objective function and the constraints. Each student participating in the study was given a copy of each problem to refer to throughout the learning session.

First Learning Session Problem

The Colonial Pottery Company produces designer bowls and mugs. The company has limited amounts of three resources used in the production of these products—clay, labor, and solvent. Given these limited resources, the company wants to know how many bowls and mugs to produce each day in order to maximize profit. Resource utilization for each product and the total available units of each resource are given in the diagram below.

Product	Labor (hours/unit)	Clay (pounds/unit)	Solvent (ounces/unit)
Bowl	1	4	5
Mug	2	3	3.5
Total Available	40	120	65

The profit from each bowl is \$40 and from each mug is \$55.

Identify decision variables

x_1 = number of bowls to produce

x_2 = number of mugs to produce

Develop the objective function

$$\text{Max } Z = 40x_1 + 55x_2$$

Develop the system constraints

subject to

$$x_1 + 2x_2 \leq 40 \text{ labor constraint}$$

$$4x_1 + 3x_2 \leq 120 \text{ clay constraint}$$

$$5x_1 + 3.5x_2 \leq 65 \text{ solvent constraint}$$

Second Learning Session Problem

An investor has \$70,000 to invest in several alternatives. They include municipal bonds with a return of 6.5%, certificates of deposit with a return of 8.3%, treasury bills with a return of 7.8%, and growth stock with a return of 12%. The amount of time until maturity is the same for each alternative. However, each investment alternative has a different perceived risk to the investor, and as a result she wants to diversify. The investor wants to know how much to invest in each

alternative to maximize the return. She has five requirements. They are given below.

- 1) No more than 20% of the total investment should be in growth stock.
- 2) The amount invested in certificates of deposits should not exceed the amount invested in the other three alternatives.
- 3) At least 30% of the investment should be in treasury bills and certificates of deposit.
- 4) The ratio of the amount invested in municipal bonds to the amount invested in treasury bills should not exceed one to three.
- 5) The investor wants to invest the entire \$70,000.

Identify the decision variable

x_1 = dollars invested in municipal bonds

x_2 = dollars invested in certificates of deposit

x_3 = dollars invested in treasury bills

x_4 = dollars invested in growth stock

Develop the objective function

$$\text{Max } Z = .065 x_1 + .083 x_2 + .078 x_3 + .12 x_4$$

Determine the systems constraints

subject to

$$x_4 \leq 14,000 \text{ invested in growth stock}$$

$$x_2 \leq x_1 + x_3 + x_4 \text{ invested in certificates of deposit}$$

$$\text{converted to } x_2 - x_1 - x_3 - x_4 \leq 0$$

$x_3 + x_2 \geq 21,000$ invested in certificates of deposit and treasury bills

$x_1/x_3 \leq 1/3$ ratio of municipal bonds to treasury bills

converted to $3x_1 - x_3 \leq 0$

$x_1 + x_2 + x_3 + x_4 = 70,000$ total invested

Explain why this constraint would be better represented with \leq inequality.

Third Learning Session Problem

Quik Screen is a clothing manufacturing company that specializes in producing commemorative shirts immediately following major sporting events like the World Series, Super Bowl, and Final Four. The company has been contracted to produce a standard set of shirts for the winning team, either State University or Tech, following a college football bowl game on New Year's Day. The items produced include two sweatshirts, one with silk screen printing on the front and one with print on both sides, and two T-shirts of the same configuration. The company has to complete production of the sweatshirts and T-shirts within 72 hours after the game. At that time, a trailer truck will pick up the shirts. The company will work around the clock. The truck has enough capacity to accommodate 1,200 standard-size boxes. A standard-size box holds 12 T-shirts, whereas a box of one dozen sweatshirts is three times the size of a standard box. The company has budgeted \$25,000 for the production run. They have 500 dozen blank sweatshirts and 500 blank T-shirts each in stock ready for production. The processing time (in hours) for sweatshirts (per dozen) printed on the front is 0.10, for sweatshirts printed on front/back is 0.25, for T-shirts printed on the front is .08, and for T-shirts print on front/back is 0.21. The cost (in dollars) to produce the

shirts (per dozen) is \$36 for sweatshirts printed on the front, \$48 for sweatshirts printed on front/back, \$25 for T-shirts printed on the front, and \$35 for T-shirts printed on front/back. Profit (per dozen) is \$90 from the sweatshirts printed on the front, \$125 for sweatshirts printed on front/back, \$45 for T-shirts print on the front, and \$65 for T-shirts printed on the front/back.

The company wants to know how many dozens (boxes) of each type of shirt to produce to maximize profit.

Identify the decision variables

x_1 = number of dozens of sweatshirts with front printing

x_2 = number of dozens of sweatshirts with front/back printing

x_3 = number of dozens of T-shirts with front printing

x_4 = number of dozens of T-shirts with front/back printing

Develop the objective function

$$\text{Max } Z = 90 x_1 + 125 x_2 + 45 x_3 + 65 x_4$$

Determine the systems constraints

subject to

$$0.10 x_1 + 0.25 x_2 + 0.08x_3 + 0.21x_4 \leq 72 \text{ Processing hours}$$

$$3x_1 + 3x_2 + x_3 + x_4 \leq 1,200 \text{ Truck storage—capacity in standard size boxes}$$

$$36 x_1 + 48 x_2 + 25 x_3 + 35 x_4 \leq 25,000 \text{ Budget}$$

$$x_1 + x_2 \leq 500 \text{ Total sweatshirts available}$$

$$x_3 + x_4 \leq 500 \text{ Total T-shirts available}$$

Appendix C

Linear Programming Study Problems

Linear Programming Study Problems

Problem #1

A publishing house publishes three weekly magazines--*Daily Life*, *Agriculture Today*, and *Surf's Up*. Publication of the magazines requires production time, paper, and storage. *Daily Life* requires 0.01 hour of production time; *Agriculture Today*, 0.03; and *Surf's Up*, 0.02. The paper requirement for *Daily Life* is 0.2 pounds; *Agriculture Today*, 0.5 pounds; and *Surf's Up*, 0.3 pounds. The storage requirements for *Daily Life* are 0.125 square feet; *Agriculture Today*, 0.2 square feet; and *Surf's Up*, 0.125 square feet.

Each week the publisher has 120 hours of production time and 3,000 pounds of paper available to produce the magazines. Total circulation for all three magazines must exceed 5,000 issues per week if the company is to keep its advertisers. Total storage space is 4,000 square feet. The selling price per issue is \$2.25 for *Daily Life*, \$4.00 for *Agriculture Today*, and \$1.50 for *Surf's Up*. Based on past sales, the publisher knows that the maximum weekly demand for *Daily Life* is 3,000 issues; for *Agriculture Today*, 2,000 issues; and for *Surf's Up*, 6,000 issues. The production manager wants to know the number of weekly issues of each magazine to produce to maximize total sales revenues.

Formulate a linear programming model for this problem.

Solution #1

Identify the decision variable

x_1 = number of *Daily Life*

x_2 = number of *Agriculture Today*

x_3 = number of *Surf's Up*

Develop the objective function

$$\text{Max } Z = 2.25 x_1 + 4.00 x_2 + 1.50 x_3$$

Determine the system constraints

subject to

$$.01 x_1 + .03 x_2 + .02 x_3 \leq 120 \text{ hours of production}$$

$$.2 x_1 + .5 x_2 + .3 x_3 \leq 3,000 \text{ pounds of paper}$$

$$.125 x_1 + .2 x_2 + .125 x_3 \leq 4,000 \text{ square feet of storage}$$

$$x_1 + x_2 + x_3 > 5,000 \text{ minimum total circulation}$$

$$x_1 \leq 3,000 \text{ maximum demand for } \textit{Daily Life}$$

$$x_2 \leq 2,000 \text{ maximum demand for } \textit{Agriculture Today}$$

$$x_3 \leq 6,000 \text{ maximum demand for } \textit{Surf's Up}$$

Problem #2

The Southfork Feed Company makes three types of feed mix, Ultra Supreme, Premium, and Budget, in 100 pound bags. Four ingredients, consisting of oats, corn, soybeans, and a vitamin supplement, are used in varying amounts for each of the three types of feed. The company has 1300 pounds of oats, 1400 pounds of corn, 1600 pounds of soybeans, and 1150 pounds of vitamin supplement available for the mixes.

Each bag of Ultra Supreme takes 40 pounds of vitamin supplement, each bag of Premium takes 25 pounds, and each bag of Budget takes 5 pounds. Corn is the cheapest ingredient. Each bag of Ultra Supreme takes 10 pounds of corn,

each bag of Premium takes 20 pounds of corn, and Budget takes 50 pounds of corn. Each bag of Ultra Supreme takes 25 pounds of oats, each bag of Premium takes 20 pounds of oats, and each bag of Budget gets 20 pounds of oats.

Soybeans are an essential ingredient because they contain vital ingredients for farm animals. Each bag of Ultra Supreme takes 25 pounds of soybeans, each bag of Premium takes 45 pounds, and each bag of Budget takes 20 pounds.

Southfork's management has decided that the production must include at least 175 bags of feed and at least 70 bags need to be the Budget line of feed. The maximum demand for Ultra Supreme is 50 bags. The ratio of Budget to Premium feed cannot exceed 2 to 1. The cost to produce a bag of Ultra Supreme is \$3.75, a bag of Premium is \$3.25, and a bag of Budget is \$1.50. The feed company has a budget of \$5,000 to produce the feed. The profit from a bag of Ultra Supreme is \$9.50, from a bag of Premium is \$7.75, and from a bag of Budget is \$5.00. The production manager at Southfork Feed Company wants to know how many bags of each type of feed to produce to maximize profit.

Formulate a linear programming model for this problem.

Solution #2

Identify the decision variable

x_1 = number of 100 pound bags of Ultra Supreme

x_2 = number of 100 pound bags of Premium

x_3 = number of 100 pound bags of Budget

Develop the objective function

$$\text{Max } Z = 9.50 x_1 + 7.75 x_2 + 5.00 x_3$$

Determine the systems constraints

subject to

$$25 x_1 + 20 x_2 + 20 x_3 \leq 1300 \text{ pounds available oats}$$

$$10x_1 + 20 x_2 + 50 x_3 \leq 1400 \text{ pounds available corn}$$

$$25 x_1 + 45 x_2 + 20 x_3 \leq 1600 \text{ pounds available soybeans}$$

$$40 x_1 + 25 x_2 + 5 x_3 \leq 1150 \text{ pounds available vitamin supplement}$$

$$x_1 + x_2 + x_3 \geq 175 \text{ total bags of feed}$$

$$x_3 \geq 70 \text{ bags of Budget feed}$$

$$x_1 \leq 50 \text{ maximum demand for Ultra Supreme feed}$$

$$x_3/x_2 \leq 2 \text{ ratio of Budget to Premium feed}$$

$$\text{converted to } x_3 - 2x_2 \leq 0$$

$$3.75 x_1 + 3.25 x_2 + 1.5 x_3 \leq 5000 \text{ total budget for production of feed}$$

Problem #3

The Friendly family grows apples on its farm, which they harvest each fall and make into three products, apple butter, applesauce, and apple jelly. They sell these three items at several local grocery stores, at craft fairs in the region, and at their Friendly Farm Pumpkin Festival which lasts for two weeks in October. Their primary resources are cooking time in their kitchen, their own labor time, and the apples. They have a total of 500 cooking hours available, and it requires 3.5 hours to cook a 10-gallon batch of apple butter, 5.2 hours to cook 10 gallons of applesauce, and 2.8 hours to cook 10 gallons of jelly. A 10-gallon batch of apple butter requires 1.4 hours of labor, a batch of sauce takes 0.8 hour, and a batch of

jelly requires 1.5 hours. They have 240 hours of labor available during the fall. They produce about 6,500 apples each fall. A batch of apple butter requires 40 apples, a 10-gallon batch of applesauce requires 55 apples, and a batch of jelly requires 20 apples. After the products are canned, a batch of apple butter will generate \$190 in sales revenue, a batch of applesauce will have a revenue of \$170, and a batch of jelly will generate sales revenue of \$155. The apple jelly has the greatest demand so the Friendlys want a least 30% of the product mix to be apple jelly. There is a budget of \$15,000 and the cost of producing a 10-gallon batch of apple butter is \$100, a batch of applesauce is \$65, and a batch of apple jelly is \$60. Demand for apple butter is at least 32 10-gallon batches.

The Friendlys want to know how many batches of apple butter, sauce, and jelly to produce to maximize their profit.

Formulate a linear programming model for this problem.

Solution #3

Identify the decision variables

x_1 = number of 10-gallon batches of apple butter

x_2 = number of 10-gallon batches of applesauce

x_3 = number of 10-gallon batches of apple jelly

Develop the objective function

$$\text{Max } Z = 90 x_1 + 105 x_2 + 95 x_3$$

Determine the system constraints

subject to

$$3.5 x_1 + 5.2 x_2 + 2.8 x_3 \leq 500 \text{ hours of cooking}$$

$$1.4 x_1 + 0.8 x_2 + 1.5 x_3 \leq 240 \text{ hours of labor}$$

$$40 x_1 + 55 x_2 + 20 x_3 \leq 6,500 \text{ apples}$$

$$x_3 \geq .3 (x_1 + x_2 + x_3) \text{ ratio of apple jelly to product mix}$$

$$\text{converted to } -0.3x_1 - 0.3 x_2 + .7 x_3 \geq 0$$

$$100 x_1 + 65 x_2 + 60 x_3 \leq 15,000 \text{ dollars in budget}$$

$$x_1 \geq 32 \text{ demand for apple butter}$$

Appendix D
Instrument for Test

INSTRUMENT FOR TEST

Description of Problem

Fresh Snackers, Inc. produces three snack products, Cup Cake Supreme, Snacker Crackers, and Cookie Delight, to serve a small, regional district. The main ingredients are flour, sugar, chocolate, milk, eggs, salt, and cream cheese. The main processes are preparation hours and packaging hours. The snacks are produced in lots of 100 packages.

The flour requirement for Cup Cake Supreme is 17 pounds, Snacker Crackers is 15.1 pounds, and Cookie Delight is 16 pounds. Cup Cake Supreme requires 17 pounds of sugar, Snacker Crackers takes 10 pounds, and Cookie Delight takes 16 pounds. Chocolate is only used to make Cup Cake Supreme and Cookie Delight using 7 pounds and 4 pounds, respectively. Milk requirement is in gallons and Cup Cake Supreme needs 5 gallons, Snacker Crackers need 3 and Cookie Delight needs 2. Snacker Crackers and Cookie Delight both require one dozen eggs, while Cup Cake Supreme takes 2 dozen. All three products take 0.4 ounces of salt per batch per product. Snacker Cracker requires 15 pounds of Cream Cheese. Cup Cake Supreme requires 1 hour of preparation time, while both Snacker Crackers and Cookie Delight both require 2 hours each. All three products each require 1 hour of packaging to prepare them for the grocery stores and vending machines.

Each lot of Cup Cake Supreme requires 0.025 transportation storage space, Snacker Crackers require 0.01 transportation storage space, and Cookie Delight requires 0.015 transportation storage space. Management has the

following resources available: 640 pounds of flour, 800 pounds of sugar, 150 pounds of chocolate, 400 gallons of milk, 80 dozens of eggs, 20 ounces of salt, 255 pounds of cream cheese, 80 hours of preparation time, 80 hours of packaging, and 4 delivery trucks.

Fresh Snackers has a budget of \$2,700 for the weekly production. It cost \$23.50 to produce each lot of Cup Cake Supreme, \$21.00 for Snacker Crackers, and \$25.30 for Cookie Delight. The revenues from a lot of Cup Cake Supreme are \$29.25; from Snacker Crackers, \$28.39; and from Cookies Delight, \$31.00.

Snacker Crackers are the most popular product and Cup Cake Supreme the least demanded. Management wants to product all three products to maintain a diverse product line, and wants to have at least two times as many Snacker Crackers as Cup Cake Supreme. In addition, demand for Cookie Delight has never been greater than 12 lots.

Management wants to know how many lots of each product to produce each week to maximize profits. Formulate the word problem based upon the linear programming principles.

Model Solution

Identify The Decision Variables

x_1 = number of 100 item lots of Cup Cake Supreme

x_2 = number of 100 item lots of Snacker Crackers

x_3 = number of 100 item lots of Cookie Delight

Develop The Objective Function

$$\text{Max } Z = 5.75 x_1 + 7.39 x_2 + 5.70 x_3$$

Determine System Constraints

subject to

$$17 x_1 + 15.1 x_2 + 16 x_3 \leq 640 \text{ pounds of flour}$$

$$17x_1 + 10 x_2 + 16 x_3 \leq 800 \text{ pounds of sugar}$$

$$7x_1 + 4 x_3 \leq 150 \text{ pounds of chocolate}$$

$$5x_1 + 3x_2 + 2x_3 \leq 400 \text{ gallons of milk}$$

$$2x_1 + x_2 + x_3 \leq 80 \text{ dozens of egg}$$

$$15 x_2 \leq 255 \text{ pounds of cream cheese}$$

$$0.4 x_1 + 0.4 x_2 + 0.4 x_3 \leq 20 \text{ ounces of salt}$$

$$x_1 + 2x_2 + 2x_3 \leq 80 \text{ hours of preparation}$$

$$x_1 + x_2 + x_3 \leq 80 \text{ hours of packaging}$$

$$0.025 x_1 + 0.01 x_2 + 0.015 x_3 \leq 4 \text{ truck}$$

$$23.50 x_1 + 21.00 x_2 + 25.30 x_3 \leq 2,700 \text{ dollars for budget}$$

$$x_2/x_1 \geq 2 \text{ ratio of Snacker Crackers to Cup Cake Supreme}$$

converted to $x_2 - 2x_1 \geq 0$

$x_3 \leq 12$ maximum demand for Cookie Delight

Appendix E

Criteria to Evaluate Performance on Test Instrument

CRITERIA TO EVALUATE PERFORMANCE ON TEST INSTRUMENT

The following diagram shows the criteria to evaluate and assign a grade to the formulated test model. These criteria are to be used in conjunction with the model solution by the researcher and the second grader to evaluate the performance test takers. Participants will start with a grade of 100 and the points defined below will be subtracted for incorrect answers. Any discrepancies in the assigned grade will be jointly resolved by the researcher and second grader.

OPERATION	ALLOCATION OF POINTS
Identify the decision variables	15 points total
x_1 = Cup Cake Supreme product if include unit of measure of 100 item lots	3 points 2 points
x_2 = Snacker Crackers product if include unit of measure of 100 item lots	3 points 2 points
x_3 = Cookie Delight product if include unit of measure of 100 item lots	3 points 2 points
Develop the objective function	7 points total
State objective function as a Max Z problem	1 point
Include all decision variables	3 points
Assign the correct profit value (parameters)	3 points
Determine the system constraints	66 points total
Include s t for "subject to"	1 point
Understand each resource requirement 13 resource constraints	3 points each for 39 points
Assign correct relational sign to constraint 13 constraints with relational signs	2 points each for 26 points
Construct unsubstantiated constraints	12 points total
Mathematical representation of constraints that do not have corresponding requirements in the word problem.	3 points for up to 4 unsubstantiated constraints

Appendix F

Grades Assigned by Researcher and Second Grader

GRADES ASSIGNED BY RESEARCHER AND SECOND GRADER

This appendix contains the evaluation of the test and posttest instruments as scored by the first grader (researcher) and the second grader. If the scores differed by two points or less, the first grader's score was assigned. A difference of three or more points in the test or posttest score was jointly rescored by the first and second grader and a reconciled score was recorded.

ID Number	TEST SCORES			POSTTEST SCORES		
	Primary Grader	Second Grader	Assigned/ Reconciled Score	Primary Grader	Second Grader	Assigned/ Reconciled Score
1	100	100	100	89	89	89
3	37	36	37	12	13	12
4	99	99	99	100	100	100
6	64	64	64	12	12	12
7	90	88	90	80	80	80
8	61	61	61	21	21	21
9	97	97	97	55	56	55
10	74	74	74	12	12	12
11	62	63	62	21	21	21
12	78	72	73	56	57	56
13	77	78	77	21	21	21
14	96	94	96	60	58	60
15	88	86	88	65	65	65
16	92	93	92	72	72	72
18	39	46	42	27	18	22
19	97	97	97	82	82	82
22	90	88	90	16	15	16
23	95	95	95	73	73	73
24	100	100	100	82	81	82
25	83	81	83	91	89	91
26	64	64	64	21	21	21
28	91	92	91	74	73	74
29	96	94	96	58	56	58
30	76	76	76	76	76	76
31	83	82	83	48	60	54

(diagram continues)

ID ^a Number	TEST SCORES			POSTTEST SCORES		
	Primary Grader	Second Grader	Assigned/ Reconciled Score	Primary Grader	Second Grader	Assigned/ Reconciled Score
32	79	79	79	51	51	51
36	64	64	64	26	26	26
37	82	84	82	75	73	75
38	65	67	65	19	19	19
39	68	66	68	15	15	15
40	97	97	97	83	83	83
41	83	81	83	21	22	21
43	64	64	64	12	11	12
45	62	63	62	82	83	82
46	92	92	92	25	27	25
47	28	43	28	10	12	10
49	92	93	92	39	37	39
50	79	79	79	48	48	48
51	100	100	100	47	45	47
52	95	95	95	74	75	74
53	94	92	94	61	60	61
54	97	97	97	89	89	89
55	90	92	90	50	50	50
56	82	82	82	81	78	81
57	69	68	69	26	12	11
58	83	81	83	73	73	73

^aThe missing identification numbers in the above diagram are due to participants dropping out of the study before the test instrument was administered.

Appendix G

Recorded Times for Completing Test

RECORDED TIMES FOR COMPLETING TEST

The test times are sorted by treatment group and recorded in the diagram

below.

TREATMENT GROUP	SUBJECT CODE	MINUTES
1*	3	19
1	9	16
1	10	16
1	13	18
1	23	21
1	25	15
1	36	15
1	39	15
1	43	22
1	48	16
1	53	21
1	55	16
1	56	22
1	57	20
2**	1	18
2	6	18
2	7	15
2	11	25
2	14	20
2	16	20
2	19	14
2	22	15
2	26	18
2	29	20
2	40	14
2	41	26
2	45	25
2	49	20
2	51	18
2	58	26
3***	4	20
3	8	22
3	12	24
3	15	20
3	18	17
3	24	20

(diagram continues)

TREATMENT GROUP	SUBJECT CODE	MINUTES
3	28	15
3	30	21
3	31	19
3	32	17
3	37	17
3	38	19
3	46	23
3	50	18
3	52	20
3	54	20

*Treatment group 1 had individual study with individual test taking.

**Treatment group 2 had collaborative study with collaborative test taking.

***Treatment group 3 had collaborative study with individual test taking.

Appendix H
Instrument for Posttest

INSTRUMENT FOR POSTTEST

Description of Problem

Sports Accessories R U, Inc. produces three pieces of sports shaped furniture. They include a baseball toy chest, a football chest-of-drawers, and a soccer end table. Although these sports are not the same, many customers, buy all three as a set to be placed in their sons' and daughters' rooms and use the soccer end table as a bedside stand. They are also popular as separate items. For example, the soccer end tables are becoming popular additions to dens. However, the demand for soccer end tables has been only about 40 per week. The company refuses to take back orders but as many football chests as can be produced can be sold. Management wants at least a 3 to 1 ratio of football chests to soccer end tables.

The available resources include 1450 pounds of wood, 910 gallons of paint, 60 ounces of glue, 1050 screws, 12 cans of finishing solution, and 306 hours of labor. The available machine hours are 42 hours of sanding, 80 hours of cutting, and 28 hours of lathing. The company owns a warehouse that provides 1500 square feet of storage space.

The baseball toy chest requires 2.3 pounds of wood, the football chest requires 7.9 pounds, and the soccer table requires 4.9 pounds. The paint requirement for the baseball chest is 1.5 gallon, for the football chest is 0.8 gallon, and for the soccer end table is 0.8 gallon. All products take 0.7 ounces of glue. The baseball toy chest takes 8 screws, the football chest 16 screws, and the soccer table 12 screws. The fumes from the finishing solution are irritating to the

workers and only the minimum amount is applied which is 0.08 can for the baseball toy chest, 0.12 can for the football chest, and 0.1 can for the soccer end table. The labor requirements for the baseball toy chest and the football chest are the same at 1.5 hours each, while the soccer end table requires 2 hours of labor.

The machine hours for each product include the following. The baseball toy chest requires 0.2 hours of sanding, the football chest requires 0.10 hours, and the soccer end table requires 0.35 hours. The cutting hour requirement for the baseball toy chest is 0.8 hours, for the football chest 0.5 hours, and for the soccer end table 1.2 hours. Only two products require the lathe machine; the baseball toy chest takes 0.4 hours and the football chest takes 0.3 hours. Each baseball toy chest requires 6 square feet of storage space, each football chest-of-drawers requires 8 square feet, and each soccer end table requires 3.5 square feet. The revenues received for the sale of each baseball toy chest is \$105, for each football chest-of-drawers is \$189, and for each soccer end table is \$156. Sports Accessory R U, Inc. has a maximum weekly budget of \$7,500 for production of these three products. The cost to produce each baseball toy chest is \$65, for each football chest-of-drawers is \$134, and for each soccer end table is \$118.

Management wants to know how many units of each product to produce to maximize profits for a weekly time period. Formulate the word problem based upon linear programming principles.

Model Solution

Identify The Decision Variables

x_1 = the number of baseball toy chest to produce

x_2 = the number of football chest-of-drawers to produce

x_3 = the number of soccer end tables to produce

Develop The Objective Function

$$\text{Max } Z = 40 x_1 + 55 x_2 + 38 x_3$$

Determine The System Constraints

subject to

$$2.3 x_1 + 7.9 x_2 + 4.9 x_3 \leq 1450 \text{ pounds of wood}$$

$$1.5 x_1 + 0.8 x_2 + 0.8 x_3 \leq 910 \text{ gallons of paint}$$

$$0.7 x_1 + 0.7 x_2 + 0.7 x_3 \leq 60 \text{ ounces of glue}$$

$$8 x_1 + 16 x_2 + 12 x_3 \leq 1050 \text{ number of screws}$$

$$0.08 x_1 + 0.12 x_2 + 0.1 x_3 \leq 12 \text{ cans finishing solution}$$

$$1.5 x_1 + 1.5 x_2 + 2 x_3 \leq 306 \text{ hours of labor}$$

$$0.2 x_1 + 0.1 x_2 + 0.35 x_3 \leq 42 \text{ machine hours for sanding}$$

$$0.8 x_1 + 0.5 x_2 + 1.2 x_3 \leq 80 \text{ machine hours for cutting}$$

$$0.4 x_1 + 0.3 x_2 \leq 28 \text{ machine hours for lathe work}$$

$$x_3 \leq 40 \text{ maximum demand for soccer end tables}$$

$$6 x_1 + 8 x_2 + 3.5 x_3 \leq 1500 \text{ square feet of storage space}$$

$$x_2/x_3 \leq 3 \text{ ratio of football chests-of-drawers to soccer end tables}$$

converted to $x_2 - 3x_3 \leq 0$

$65x_1 + 134x_2 + 118x_3 \leq 7500$ dollars available to produce product mix

Appendix I

Pledge

PLEDGE

I, _____, pledge that I have received
PARTICIPANT'S NAME—PRINT YOUR NAME

no additional instruction and have not engaged in additional
study

of linear programming theory.

SIGNATURE OF TEST TAKER

Appendix J

Recorded Times for Completion of Posttest

RECORDED TIMES FOR COMPLETION OF POSTTEST

The posttest times are sorted by treatment group and recorded in the diagram below.

TREATMENT GROUP	SUBJECT CODE	MINUTES
1*	3	26
1	9	16
1	10	23
1	13	10
1	23	18
1	25	12
1	36	21
1	39	21
1	43	15
1	48	12
1	53	31
1	55	18
1	56	21
1	57	17
2**	1	13
2	6	46
2	7	22
2	11	20
2	14	15
2	16	26
2	19	34
2	22	15
2	26	20
2	29	18
2	40	25
2	41	20
2	45	30
2	49	18
2	51	20
2	58	15
3***	4	40
3	8	21
3	12	24
3	15	15
3	18	17
3	24	14

(diagram continues)

TREATMENT GROUP	SUBJECT CODE	MINUTES
3	28	27
3	30	15
3	31	17
3	32	16
3	37	16
3	38	10
3	46	25
3	50	15
3	52	15
3	54	15

*Treatment group 1 had individual study with individual test taking.

**Treatment group 2 had collaborative study with collaborative test taking.

***Treatment group 3 had collaborative study with individual test taking.

Appendix K

Criteria to Evaluate Performance on Posttest Instrument

CRITERIA TO EVALUATE PERFORMANCE ON POSTTEST INSTRUMENT

The following diagram shows the criteria to evaluate and assign a grade to the formulated model based on the posttest instrument. These criteria are to be used in conjunction with the model solution by the researcher and the secondary grader to evaluate the performance of the test takers. Participants will start with a grade of 100 and the points defined below will be subtracted for incorrect answers in the following categories. Any discrepancies in the assigned grade will be jointly resolved by the researcher and secondary grader.

OPERATION	ALLOCATION OF POINTS
Identify the decision variables	15 points total
x_1 = Baseball toy chest product	3 points
if include the unit of measure of number	2 points
x_2 = Football chest-of-drawers product	3 points
if include the unit of measure of number	2 points
x_3 = Soccer end table product	3 points
if include the unit of measure of number	2 points
Develop the objective function	7 points total
State objective function as a Max problem	1 point
Include all decision variables	3 points
Assign the correct profit value (parameters)	3 points
Determine the system constraints	66 points total
Include s t for "subject to"	1 point
Understand each resource requirement	3 points each for
12 resource constraints	39 points
Assign correct relational sign to constraint	2 points each for
12 constraints with relational signs	26 points
Construct unsubstantiated constraints	12 points total
Mathematical representation of constraints	3 points for up to 4
that do not have corresponding requirements	unsubstantiated
in the word problem.	constraints

VITA

N. Faye Angel was born in Huntingburg, Indiana on June 11, 1947. In 1968 she received a diploma degree in nursing from Deaconess School of Nursing and University of Evansville. She returned to higher education in 1985 and completed Master of Business Administration degree from Virginia Polytechnic and State University in 1988. Upon completion of the master's degree, she began teaching at Ferrum College where she remains as Assistant Professor of Business. In 1993 she returned to Virginia Polytechnic and State University where she entered the doctoral program in Vocational Education. One of her primary educational interests is to integrate theory and practice, and she stresses that education should have rigorous applications as its focus. In addition, she believes that community service should be an integral part of the collegiate experience.

Faye is a member of Beta Gamma Sigma, Delta Pi Epsilon, Phi Delta Kappa, the American Vocational Association, and Alpha Chi. In the spring of 1998, she received the Outstanding Faculty Member Award from the Student Government Association at Ferrum College. She is published in the areas of elementary career awareness, the concept of work in children's literature, technology and teaching, computer literacy, evaluating employees by computer, and the impact of information on problem solving.