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The efficacy of teaching oxyacetylene welding prior to gas metal arc welding for introductory materials and process courses in industrial technology

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The efficacy of teaching oxyacetylene welding prior to gas metal arc welding for introductory materials and process courses in industrial technology

by

Sergio Domenico Sgro

A dissertation submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Major: Industrial and Agricultural Technology

Program of Study Committee:
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Dedication

This work is dedicated to my father, Gesino Sgro, and my mother, Marianna Sgro, who have sacrificed much of their own time and effort for their children. In particular to my father who exemplifies hard work in everything he does. I can only hope to be half the father and husband he is.

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To Dr. James Laporte for allowing me to take up an entire week of your ITEC 130 class in the spring of 2006 at Millersville University to conduct my experiment.

To Mr. John Boyer and Mr. Doug Long of the Lancaster County Career and Technology Center. Your background in welding education was an integral and irreplaceable part of this study. Thank you for your selfless contributions to the efficacy of this study. As well as to Dr. Tim Bianchi, thank you for making this possible.

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Dr. Steve Freeman: you added a dimension of comic relief at the times I needed it most. Thank you for contributing so much of your time and expertise in this study. Without your firsthand knowledge of so many important details, I would have not have been able to complete this.

Dr. Dennis Field: I think I’ve worn a path between your office and mine. THANK YOU would not be enough. I could not have asked for a better major professor. You are a wonderful person, colleague, and a true friend.

Finally, to my wife Susie and children, Josiah and Anna. You make life worth living. Thank you for being as patient with me as humanly possible. I love you.

ABSTRACT

Industrial technology programs around the country must be sensitive to the demands of manufacturing and industry as programs continue to replace “vocational” curriculum with high-tech alternatives. Entry-level managers who understand the practical as well as the theoretical nature of technology are still required. Much of the facility and vocational equipment infrastructures at institutions remain intact, albeit a bit dusty, and should be utilized to revitalize or reorganize a hot metals curriculum to meet the demands of industry. This research examines a curriculum that bolsters manual gas metal arc welding skills within the current time constraints of lab/lecture curriculums by allotting more hands-on gas metal arc welding time to students without sacrificing or impeding other subject matter. Simply put, which approach to teaching welding yields most effectively and efficiently the skill sets required by industrial technology students?

The study compared three different instructional methods for teaching arc welding: (1) oxyfuel welding with filler, (2) oxyfuel welding without filler, and (3) gas metal arc welding. All three groups tested on gas metal arc welding to determine which, if any, instructional method yielded the skill sets required for gas metal arc welding by industrial technology students. The results to the study indicated insufficient evidence to suggest any significant difference between the three groups at the 0.05 alpha level with the limited practice time allotted to each group.

The study concluded that technology programs, in particular those with welding, must have students and industry in mind – this means that gas metal arc welding is a critical component of the industrial technology curriculum. Under the conditions of this study, teaching oxyfuel welding prior to gas metal arc welding does not impact gas metal arc welding skills and removing oxyfuel welding may be an option for programs that struggle to find time for both technologies. Furthermore, gas metal arc welding was found to be used more extensively in industry and may therefore be considered a more valuable skill than oxyfuel welding for industrial technology students.

CHAPTER 1. INTRODUCTION

Introduction

Many industrial technology programs struggle to identify and institute curricular activities that adequately serve all of the needs of local and regional industry. In light of new technologies, such as, Computer Numeric Control (CNC), Computer Integrated Manufacturing, and the ever-growing robotics and automation markets, it is no surprise that the perceived importance of vocational skills steadily decreases. Of particular interest to this research are manual arc welding skills widely utilized in industry.

H. A. Sosnin (1982) supports the researcher's understanding and experience from various vocational instructors regarding welding education when he writes, "It has been proven, many times, that when a student learns to weld with an oxyacetylene torch first, he learns to weld quicker and better with the other processes" (p. 48). Unfortunately, there are no data or research that support the prevailing notion of the vocational community. Furthermore, R. Depue and C. Pollock (personal communication, October 5, 2005), both American Welding Society (AWS) Educational Division directors, disagreed with the statement unless it was applied exclusively to gas tungsten arc welding, also known as Tungsten Inert Gas (TIG) welding. Sosnin (1982) also indicates that oxyacetylene welding (herein oxyfuel gas welding) is a traditional method that should be utilized as much as possible in production for economic and efficiency benefits. However, literature that is more current limits the extent of oxyfuel welding to maintenance and repair exclusively (American Welding Society [AWS], 2004).

To that end, there is a disparity between what some teachers accepted as fact at National Association of Industrial Technology (NAIT) accredited institutions (based on the researchers own experience as a student as well as a teacher) for the sequence of the welding curriculum versus the direction, and more importantly, the needs of managing welding technologies in industry. It is the researcher's belief that there are a number of schools that continue to stress the importance of oxyfuel welding, and its direct benefits to arc welding, without the use of empirical data to support the assumption.

Literature Review

This section is an abridged review of the literature. The Journal of Technology Studies (Chapter 2) allows for a substantive literature review and it is therefore found in the second chapter of this dissertation. However, a brief introduction and discussion of overall findings of the literature are appropriate as a preface to the whole study. Three broad areas were investigated: (1) the state of the welding industry, (2) welding education, and (3) cost considerations of the welding lab. These topics were chosen for their involvement with welding education in industrial technology.

It was found and confirmed by personal communications with American Welding Society personnel (personal communication, October 5-7, 2005) that arc welding has surpassed oxyfuel welding for most applications (AWS, 2004). The literature points to comparisons of shielded metal arc welding versus gas metal arc (AWS & American National Standards Institute [ANSI], 2001), but seldom oxyfuel to arc welding. An attempt to better understand oxyfuel and gas metal arc welding and their perceived contributions and importance in industrial technology requires knowledge of how both are used in industry today as well as the approach that welding schools take to teaching both. The literature points to the ever-growing manual arc welding industry, especially gas metal arc welding (Pekkari, 2000). In a report on the welding industry, the U. S. Department of Commerce (2002), in conjunction with several other organizations, reported that welding inclusive of its labor component represents a sizeable contribution to the United States economy.

It was found that welding education is focused primarily on students learning arc welding processes (see Chapter 2). Oxyfuel welding, on the other hand, is typically coupled with cutting operations or it is coupled with soldering and brazing (operations that can also be performed with an oxygen acetylene torch). The current Welding Handbook (AWS, 2004) has a chapter devoted entirely to oxyfuel gas welding. However, it should be noted that it is also qualified by the following statements:

1. "Oxyfuel welding has been surpassed by the arc welding processes for most applications" (p. 468).
2. "Oxyacetylene welding is almost universally used for maintenance and repair" (p. 469).

The cost of equipment for both oxyfuel and gas metal arc welding was reviewed. One can argue that oxyfuel welding equipment is significantly less expensive, but the cost of the equipment versus the time students spend creating and moving puddles is generally ignored. Based on the material thickness and travel speed time figures presented in the literature review, a student using gas metal arc welding can weld over seven times the amount of linear distance than that processed by a student oxyfuel welding (Althouse, Turnquist, Bowditch, Bowditch, and Bowditch, 2003; AWS, 2004). These numbers are conservative given that they do not include learning curves for understanding how to properly light and adjust a torch, not to mention the coordination required to add filler material. Generally speaking, welding schools no longer teach oxyfuel welding as an individual welding component, but rather incorporate it into a cutting and brazing program.

Research Questions

The research questions posed by this study are as follows:

Research Question 1

Does teaching the manipulative skills of oxyfuel welding with filler enhance beginning gas metal arc welding skills?

Research Question 2

Does teaching the manipulative skills of oxyfuel welding without filler enhance beginning gas metal arc welding skills?

Research Question 3

Is there a statistically significant difference in gas metal arc welding skills between those students who were taught to oxyfuel weld with filler versus those students who were taught to oxyfuel weld without filler?

Research Question 4

Is there a statistically significant difference in gas metal arc welding skills between students who were taught to oxyacetylene weld (with or without filler) versus those students who were not taught any oxyfuel welding?

Research Question 5

Is there a difference in the aggregate economic factors between oxyacetylene and gas metal arc welding that would lend one a preferred teaching selection over the other by industrial technology four-year programs? This research question is answered primarily through literature review and is further qualified by the findings of this study.

Hypotheses of the study

Null Hypothesis 1

There is no statistically significant difference in gas metal arc welding skills between those students who were taught to oxyfuel weld with filler material versus those who were taught to oxyfuel weld with filler.

Null Hypothesis 2

There is no statistically significant difference in gas metal arc welding skills between those students who were taught to oxyfuel weld without filler material versus those who were taught to oxyfuel weld without filler.

Null Hypothesis 3

There is no statistically significant difference in gas metal arc welding skills between those students who were taught to oxyfuel weld with filler material versus those who were taught to oxyfuel weld without filler.

Null Hypothesis 4

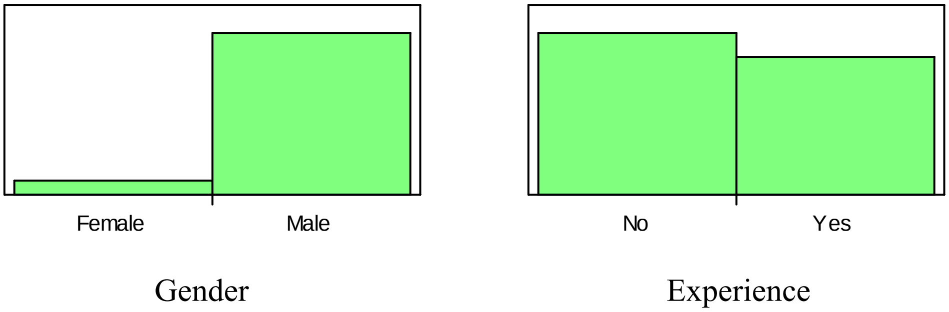
There is no statistically significant difference in gas metal arc welding skills between those students who were taught to oxyfuel weld (with or without filler material) versus those who were taught to oxyfuel weld (with or without filler).

Exploratory Data Analysis

Exploratory data analysis was examined by the use of histograms for gender and prior welding experience in the participants. Figures 1 through 3 below are grouped by instructional method.

Figure 1

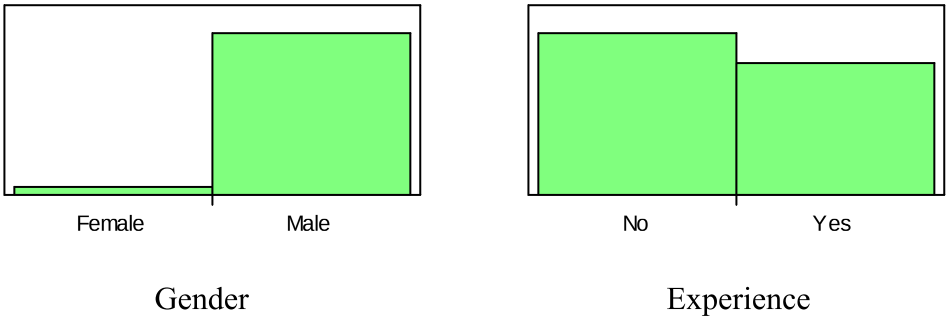
Exploratory Data Analysis – Oxyfuel with filler



N = 2 22 13 11

Figure 2

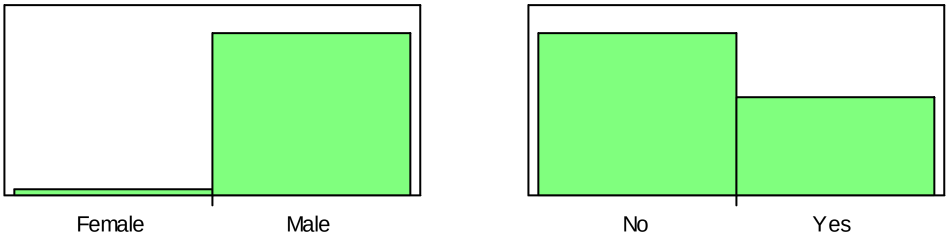
Exploratory Data Analysis – Oxyfuel without filler



N = 1 19 11 9

Figure 3

Exploratory Data Analysis – GMAW



Gender Experience

N = 1 23 15 9

Given that the majority of participants were male, gender was deemed an inappropriate covariate with only one or two females in each group. Experience, on the other hand, was better balanced and was considered appropriate for further investigation. Figures 4 and 5 below represent the line graphs of the mean scores of each test by group. Figure 4 represents only those students who did not have any experience while Figure 5 represents those students who indicated some type of prior welding experience.

Figure 4

Line graph of mean individual test scores for students with no experience

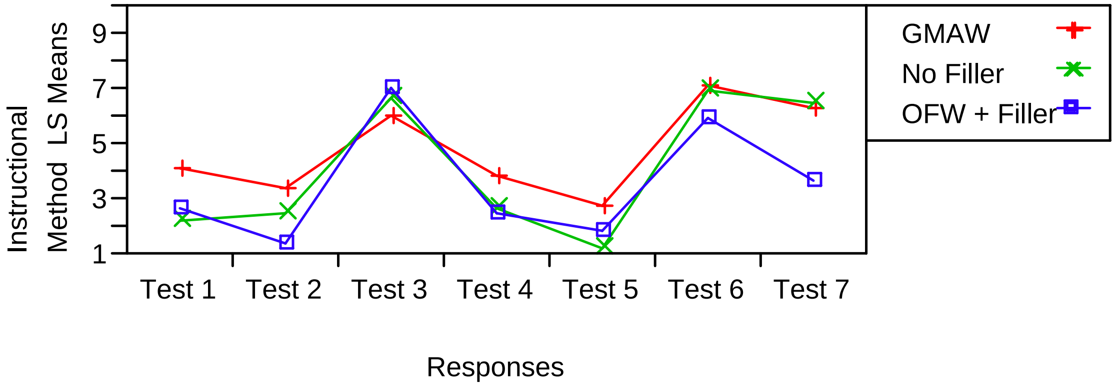
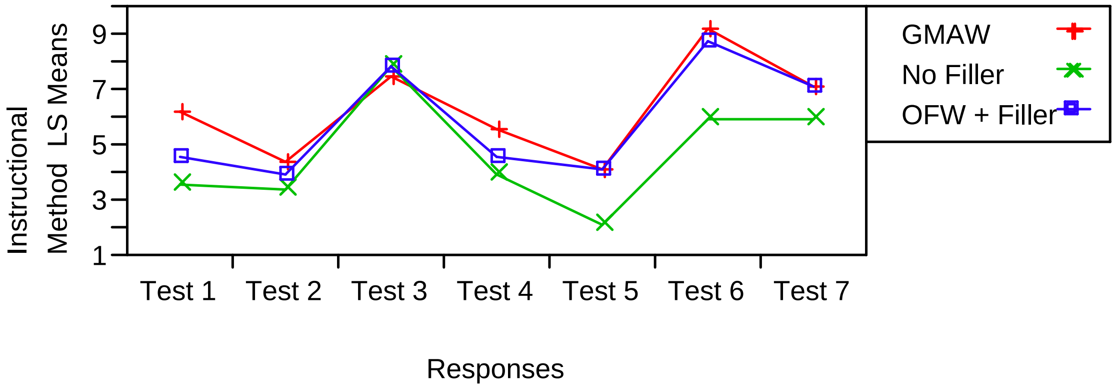


Figure 5

Line graph of mean individual test scores for students with prior welding experience



Generally, those students with experience (Figure 5) had higher scores than those students without experience (Figure 4). The sample sizes for each test were approximately half the size of the original sample sizes and are presented in Table 1. Furthermore, the graphs generated similar forms indicating that with or without experience, students performed better on some tests than on others.

Table 1

Sample sizes of groups sorted by experience

	With Filler	No filler	GMAW
No	13	11	15
Yes	11	9	9
Total	**24**	**20**	**24**

While one could argue that this level of experience has an impact on scoring, outside the instructional method, it should be noted that all groups had several individuals with this level of experience.

Specific experience in gas metal arc welding was further investigated by comparing groups into four experience categories: (1) those with no prior gas metal arc experience, (2) those with less than 2 hours of experience, (3) those with 2 to 20 hours of experience, and (4) those with greater than 20 hours of experience. Those graphs with their respective sample sizes are found in figures 6 through 9 below.

Figure 6

Line graph of mean individual test scores for no experience

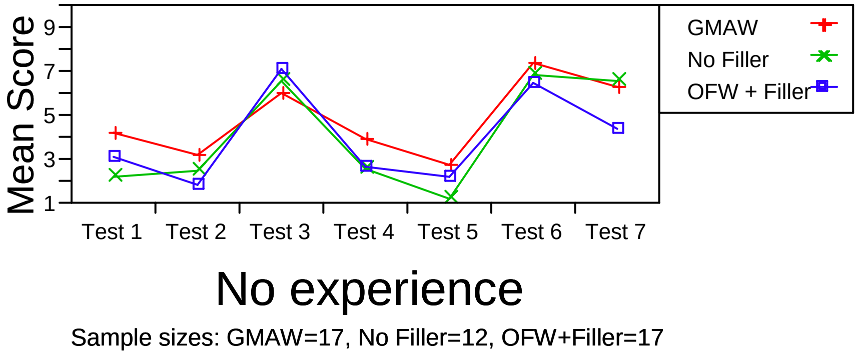


Figure 7

Line graph of mean individual test scores for less than 2 hours of experience

Figure 8

Line graph of mean individual test scores for 2 to 20 hours of experience

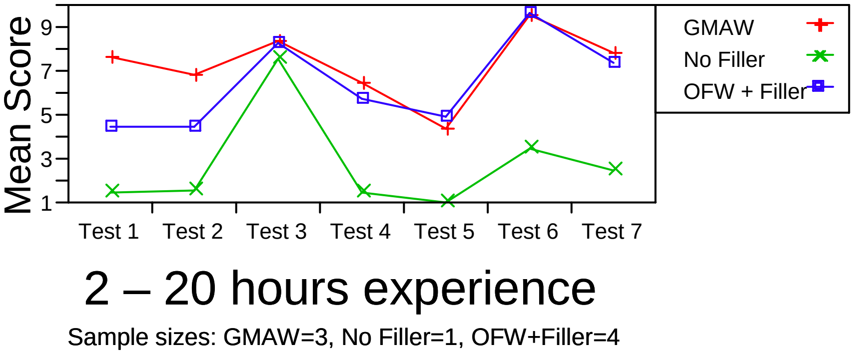
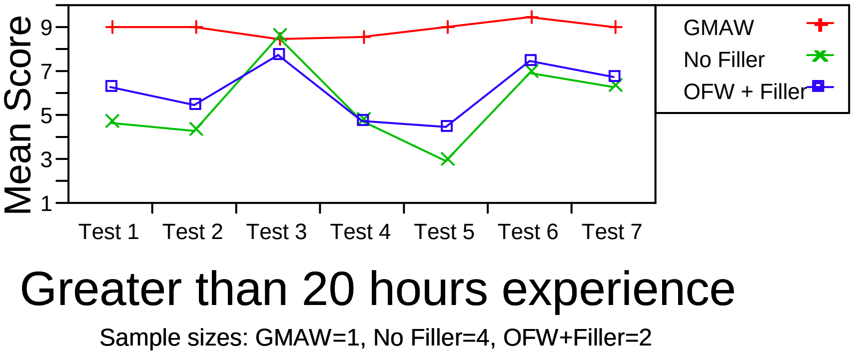


Figure 9

Line graph of mean individual test scores for greater than 20 hours of experience



The overall shapes of the graphs reflect the basic patterns seen in Figures 4 and 5 above. As experience level rose, the line graphs tended to have generally higher mean test scores. The small sample sizes in some cases (n = 1) should be noted.

Assumptions

1. The participants will work to the best of their abilities on all welding specimens.
2. The participants are representative of undergraduate industrial technology students at Millersville University.

3. The participants' welding test will demonstrate what they learned through the experiment.
4. The material to be used during the welding experiments will be consistent and will not detract from the quality of the weld bead.

Delimitations

1. Only students who enrolled in the Spring 2006 semester of ITEC 130: Materials and Processes were invited to participate in the study.
2. The weld test specimens were inspected by visual examination only.
3. This study did not gather data regarding individual subjects' learning styles or seek to discover how learning styles may impact the results.

Dissertation Organization

This dissertation is organized around three related journal articles. Chapter 1 is a general introduction to the study and the articles. Chapters 2, 3, and 4 are the journal articles. Chapter 5 is a general discussion of the results based on the findings of the study as well as recommended future research.

Article 1 (Chapter 2)

Article 1, *Oxyfuel or gas metal arc welding: which should we be teaching in the classroom?* was written and formatted for the Journal of Technology Studies. It answers Research Question 4 (Is there a statistically significant difference in the ability to gas metal arc weld between students who were taught how to oxyfuel weld (with or without filler) versus those students who were not taught any oxyfuel welding?).

Article 2 (Chapter 3)

Article 2, *a comparison of teaching oxyfuel and gas metal arc welding in Industrial Technology*, was written and formatted for the Journal of Industrial Technology. The article answers Research Question 1 (Does teaching the manipulative skills of oxyfuel welding with filler enhance beginning gas metal arc welding skills?) and Research Question 2 (Does teaching the manipulative skills of oxyfuel welding without filler enhance beginning gas metal arc welding skills?).

Article 3 (Chapter 4)

Article 3, *transferability of oxyfuel skills to gas metal arc welding skills* was written and formatted for the Welding Journal. The article answers Research Question 3 (Is there a statistically significant difference in gas metal arc welding skills between those students who were taught to oxyfuel weld with filler versus those students who were taught to oxyfuel weld without filler?).

Definition of Terms

American Welding Society (AWS): "The American Welding Society (AWS) was founded in 1919 as a multifaceted, nonprofit organization with a goal to advance the science, technology and application of welding and related joining disciplines" (AWS, 2005a).

Arc welding (AW): "A group of welding processes that produces coalescence of workpieces by heating them with an arc" (AWS & ANSI, 2001, p. 3).

Arc welding electrode: "A component of the welding circuit through which current is conducted and that terminates at the arc" (AWS & ANSI, 2001, p. 3).

Automatic welding: “Welding with equipment that requires only occasional or no observation of the welding, and no manual adjustment of the equipment controls” (AWS & ANSI, 2001, p. 3).

Defect: “A discontinuity or discontinuities that by nature or accumulated effect render a part or product unable to meet minimum applicable acceptance standards or specifications” (AWS & ANSI, 2001, p. 10).

Electrode: “a component of the electrical circuit that terminates at the arc, molten conductive slag, or base metal” (AWS & ANSI, 2001, p. 13).

Filler material: “The material to be added in making a brazed, soldered, or welded joint” (AWS & ANSI, 2001, p. 14).

Fuel gas: A gas such as acetylene, natural gas, hydrogen, propane, stabilized methylacetylene propadiene, and other fuels normally used with oxygen in one of the oxyfuel processes and for heating” (AWS & ANSI, 2001, p. 17).

Gas metal arc welding (GMAW): “An arc welding process that uses an arc between a continuous filler metal electrode and the weld pool. The process is used with shielding from an externally supplied gas and with the application of pressure” (AWS & ANSI, 2001, p. 18).

Gas tungsten arc welding (GTAW): An arc welding process that uses an arc between a tungsten electrode (nonconsumable) and the weld pool. The process is used with shielding gas and without the application of pressure” (AWS & ANSI, 2001, p. 18).

Globular transfer: “Gas metal arc welding. The transfer of molten metal in large drops from a consumable electrode across the arc” (AWS & ANSI, 2001, p. 19).

Industrial technology: "A field of study designed to prepare technical and/or management oriented professionals for employment in business, industry, education, and government" (National Association of Industrial Technology [NAIT], 2005).

Inert gas: "A gas that normally does not combine chemically with materials" (AWS & ANSI, 2001, p. 21).

Lap joint: "A joint between two overlapping members in parallel planes" (AWS & ANSI, 2001, p. 23).

Manual welding: "Welding with the torch, gun, or electrode holder held and manipulated by hand" (AWS & ANSI, 2001, p. 24).

Metal Deposition Rate: "Rate of weld metal deposited, lb/h (kg/h)" (AWS & ANSI, 2001, p. 18).

MAG welding: Metal Active Gas Welding. A nonstandard term for gas metal arc welding using active shielding gases such as CO2.

MIG welding: Metal Inert Gas welding. "A nonstandard term for… GMAW" (AWS & ANSI, 2001, p. 25) using non-chemically reactive shielding gas such as Argon.

National Association of Industrial Technology (NAIT): "The premier professional association responsible for: the promotion of industrial technology in business, industry, education, and government" (NAIT, 2005).

Oxyacetylene welding (OAW): "An oxyfuel gas welding process that uses acetylene as the fuel gas" (AWS & ANSI, 2001, p. 27).

Oxyfuel gas welding (OFW): "A group of welding processes that produces coalescence of workpieces by heating them with an oxyfuel gas flame" (AWS & ANSI, 2001, p. 27). This term is used throughout this study to identify oxyacetylene welding.

Semiautomatic welding: “Manual welding equipment that automatically controls one or more of the welding conditions (AWS & ANSI, 2001, p. 33).

Shielded metal arc welding (SMAW): “An arc welding process with an arc between a covered electrode and the weld pool. The process is used with shielding from the decomposition of the electrode covering (AWS & ANSI, 2001, p. 34).

Shielding gas: “Protective gas used to prevent or reduce atmospheric contamination” (AWS & ANSI, 2001, p. 34).

Short circuiting transfer: “Gas metal arc welding. Metal transfer in which molten metal from a consumable electrode is deposited during repeated short circuits” (AWS & ANSI, 2001, p. 34).

Spray transfer: “Gas metal arc welding. Metal transfer in which molten metal from a consumable electrode is propelled axially across the arc in small droplets” (AWS & ANSI, 2001, p. 36).

Stick electrode welding: “A nonstandard term for shielded metal arc welding” (AWS & ANSI, 2001, p. 37).

Welding: “A joining process that produces coalescence of materials by heating them to the welding temperature, with or without the application of pressure or by the application of pressure alone, and with or without the use of filler metal” (AWS & ANSI, 2001, p. 42).

Welding filler material: “The metal or alloy to be added in making a weld joint that alloys with the base metal to form weld metal in a fusion welded joint” (AWS & ANSI, 2001, p. 43).

CHAPTER 2: OXY-FUEL OR GAS METAL ARC WELDING: WHICH SHOULD WE BE TEACHING IN THE CLASSROOM?

A paper submitted to *The Journal of Technology Studies*

Sergio D. Sgro, Dennis W. Field, Steven A. Freeman

Abstract

Industrial technology programs around the country must be sensitive to the demands of manufacturing and industry as programs continue to replace “vocational” curriculum with high-tech alternatives. This article examines whether or not teaching oxyacetylene welding in the industrial technology classroom is required to aid in better learning arc welding processes. The research suggests that the gas metal arc welding industry is growing globally. To that end, under certain instructional conditions, there would appear to be little impact, in terms of gas metal arc welding skills, associated with removing oxyacetylene welding from the curriculum when time constraints play a role in choosing to teach one welding process over another.

Introduction and Background

Many industrial technology programs struggle to identify and institute curricular activities that adequately serve all of the needs of local and regional industry. In light of “new” technologies, such as CNC, CAD/CAM, and the ever-growing robotics and automation markets, it is no surprise that the perceived importance of vocational skills steadily decreases. But the emphasis over the past decades to pursue less physically demanding careers has resulted in profound labor shortages throughout almost all industries

(Brat, 2006), particularly manual welding, as evidenced by a recent Wall Street Journal Online Marketplace article:

> The average age of welders, currently 54, keeps climbing. As a wave of retirements loom, welding schools and on-site training programs aren't pumping out replacements fast enough. As a result, many companies are going to great lengths to attract skilled welders, sending recruiters to faraway job fairs and dangling unprecedented perks (Brat, 2006, ¶ 10).

Industrial technology programs around the country must be sensitive to these demands as programs continue to replace “vocational” curriculum with high-tech alternatives. Entry-level managers who understand the practical as well as the theoretical nature of technology are still required. “The primary distinguishing characteristic of technological knowledge is that it derives from, and finds meaning, in activity” (Herschbach, 1995). Much of the facility and vocational equipment infrastructures at our institutions remain intact, albeit a bit dusty, and should be utilized to revitalize or reorganize our hot metals curriculum to meet the demands of industry. This research examines a curriculum that bolsters manual arc welding skills within the current time constraints of lab/lecture curriculums by allotting more hands-on welding time to students without sacrificing or impeding other subject matter. Simply put, which approach to teaching welding yields, most effectively and efficiently, the skill sets required by industrial technology students?

This article delves into welding education as it looks to which processes, if any, are helpful for the student to learn first if he or she is to become proficient in arc welding. In particular, the researcher has chosen oxyfuel welding, also known as oxyacetylene welding, and gas metal arc welding (GMAW) as the two test vehicles. Oxyfuel welding is the oldest welding process that burns oxygen and acetylene in a flame to melt metal beyond its solid state. It has been largely superseded by arc welding (American Welding Society [AWS], 2004). Gas metal arc welding continues to grow globally (Pekkari, 2000) and is used extensively in “industrial manufacturing, agriculture, construction, shipbuilding and mining” (AWS, 2004, p. 148). Gas metal arc welding uses an electric power source, rather than a flame, to produce an arc that melts metal beyond its solid state.

Literature Review

Current welding literature is largely consumed with articles of arc welding technologies. The literature points to deposition rate comparisons of shielded metal arc welding versus gas metal arc welding (AWS, 2001), but it seldom, if ever, compares oxyfuel welding to any arc welding process. The majority of the literature presents advantages and disadvantages of the different processes but does so superficially without quantitative comparison of arc processes versus oxyfuel welding (AWS, 2004). In an effort to provide a brief side-by-side comparison of the two types of welding, three broad topics are selected for review and are presented as follows:

1. State of the welding industry
2. Cost considerations for the metals lab
3. Welding education

State of the Welding Industry

“The highly increased consumption of solid wires in 1999 over 1998 by almost 35% (in USA) reflects extremely good business conditions” (Pekkari, 2000, p. 3). Pekkari (2000) goes on to show the immense change from manual metal arc (MMA) (also known as shielded metal arc welding or "stick") to gas metal arc welding in the last quarter of the 20th century. In 1975, manual metal arc utilized just over 50% of all arc welding; by the turn of the century, the number had fallen to approximately 15% of arc welding. Contrary to its counterpart's demise, gas metal arc welding has ballooned from approximately 20% of all arc welding to almost 60% (Pekkari, 2000). In fact, Pekkari continues this comparison with the following statement, "The number of arc welding applications has continuously been growing since 1975" (Pekkari, 2000, p. 5). More importantly, many more shops and manufacturing facilities look to robotic welding for reduced production time and increased quality (Harris, 2005).

In 2002, the U. S. Department of Commerce (2002) released a study entitled "Welding-Related Expenditures, Investments, and Productivity in U.S. Manufacturing, Construction, and Mining Industries". The first two major findings of the report represent credible evidence in regards to this study that industrial technology students must be adequately prepared to manage current welding technology as effectively as possible within the limited time allotted in the classroom. Those findings are as follows (U.S. Department of Commerce, 2002, p. 1):

1. "Welding expenditures represent a substantial contribution to the U.S. economy."
2. "By far, labor represents the largest proportion of total welding expenditures".

More recently, the Wall Street Journal Online Edition published an article describing how manufacturers, both large and small, are dealing with a shortage in qualified welders (Brat, 2006).

From an educational standpoint, teachers should also be prepared to purchase or update existing equipment that will aid in the preparation of the managers. The need to consider costs is an important component of purchasing new equipment and curriculum considerations.

Cost Considerations for the Metals Lab

The American Welding Society (2001) defines a cost estimate in the following manner, "A cost estimate is a forecast of expenses that may be incurred in the manufacture of products or components or in the implementation of new processes or operations" (p. 2). These incurred costs fall under four areas, they are equipment costs, energy costs, labor costs, and material costs (AWS, 2004). Of particular interest to this research is equipment costs and student contact time (actual time welding) on the equipment. The following is a general introduction to the equipment and its use.

Oxyfuel Welding Equipment

Oxyfuel welding equipment, also known as oxygen acetylene welding, is relatively inexpensive, portable, and versatile (AWS, 2004). It is used for welding, cutting, brazing, and soldering. A proportionally equal mixture of oxygen and acetylene is burned at a temperature of 5,589° Fahrenheit (Althouse, Turnquist, Bowditch, Bowditch, Bowditch, 2003). Equipment costs, excluding rented gas cylinders, can range from several hundred dollars (torch outfit and gas regulators) to approximately one thousand dollars.

Students must first learn to light the oxyfuel flame, adjust the neutral flame, and learn how to heat up the base metal before beginning to weld. These steps alone, notwithstanding the dangers and nuances of gas regulators and the addition of filler metal, can absorb a lot of class time. This is especially critical to schools with limited space and limited curriculum time allotment for welding. In this situation, a student could spend most of his or her time adjusting the flame, heating up the base metal, or trying to understand the two-handed coordination of creating a puddle, adding filler material, and moving the puddle.

Gas Metal Arc Welding Equipment

Unlike oxyfuel welding, Gas metal arc welding equipment can range from about $2,500.00 for a stand-alone welder up to $9,000.00 for a multi-process welding machine[1]. Most Gas Metal Arc welders now come equipped with recommended weld settings for wire speed and voltage. Students are generally able to quickly set dials or similar apparatuses to the intended material thickness and begin welding. No time is needed to adjust the flame, heat up the base metal or learn how to add filler material into the weld puddle; this is done automatically.

Travel speed comparison

Given that welding is a physical activity, an important function in student learning is allotting as much practice time as possible. One aspect of this learning time can be a function of the welding travel speed. “Travel speed is defined as the linear rate at which the arc is moved along the weld joint” (AWS, 2004, p. 183). For instance, the welding test performed for this research utilized 0.1875 inch thick plate. Table 1 below is an approximate travel speed comparisons between oxyfuel and gas metal arc welding of 0.1875 inch mild steel thick plate.

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[1] Multiprocess welders are capable of several welding processes such as, but not limited to, Gas Metal Arc Welding, Shielded Metal Arc Welding “Stick”, and Gas Tungsten Arc Welding (TIG).

Table 1

Travel Speed Comparison – oxyfuel welding versus gas metal arc welding

Welding Type	Approximate travel speed (inches per minute)
Oxyfuel gas welding	2.8 (Althouse, et al, 2003)
Gas metal arc welding	20 - 22 (AWS, 2004)[2]

Some of this time difference is attributed to heating up the base metal in oxyfuel welding, changing or replenishing filler material in oxyfuel welding, but most important is the welding speed.

Welding Education

Industrial technology students are generally exposed to oxyfuel welding, shielded metal arc welding, and gas metal arc welding in materials and processes courses. At some institutions, students are asked to perform a practical test to demonstrate a certain level of competency in one or more of these welding processes. It is useful at this time to examine different approaches to welding as it is viewed by several well-known welding schools.

There are many welding schools around the country, but these schools typically teach according to some standard curriculum, usually benchmarking to the American Welding Society's conventions. Given that oxyfuel welding was the first type of welding and that the process has not changed in over a century (AWS, 2004), it is no wonder that the basic method of teaching welding (from oxyfuel to arc welding) is still practiced today (Sosnin, 1982). This section gives a brief curriculum overview of the larger, well-known national welding schools with special focus on oxyfuel and gas metal arc welding. For instance, the

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[2] Spray Transfer with 98% argon and 2% oxygen

Hobart Institute for Welding Technology [HIWT] (2005) has made efforts to upgrade their video/DVD training modules to incorporate current teaching techniques. In particular, the online description of their 24-module GMAW introductory course includes the following overview:

> Each skill module includes a demonstration of the weld that students are expected to perform, featuring dramatic, close-up shots of the arc and puddle. Theory modules contain all the essential information associated with the gas metal arc welding process, and feature attractive animated graphics to illustrate key concepts. Male and female narrators alternate throughout, to maintain student interest and highlight key points (¶ 2).

The video/DVD series is three hours and 35 minutes in length.

Modern Welding (Althouse et al., 2003), a complete entry level textbook, correlates the entire book and its chapters to the American Welding Society's Guide for Training and Qualification of Welding Personnel – Entry Level Welder learning objectives. These objectives are:

- Occupational Orientation
- Drawing and Weld Symbol Interpretation
- Arc Welding Principles and Practices
- Oxyfuel Gas Cutting Principles and Practices
- Arc Cutting Principles and Practices
- Welding Inspection and Testing Principles

It should be noted that oxyfuel welding is not a principle learning objective but rather a subset of the oxyfuel gas cutting learning objectives.

The Lincoln Welding School (n.d.) covers only the fundamentals of oxyfuel welding in the introduction to their Plasma, Oxy-Fuel, Alloy, & Hardening course description.

Need for the Study

H. A. Sosnin (1982) summarizes the prevailing anecdotal evidence uncovered by the researcher during conversations and classroom lectures with various vocational instructors regarding welding education when he writes, “It has been proven, many times, that when a student learns to weld with an oxyacetylene torch first, he learns to weld quicker and better with the other processes” (p. 48). Unfortunately, there has been no data or research that has been uncovered and supports that notion. Furthermore, R. Depue and C. Pollock (personal communication, October 5, 2005), both American Welding Society (AWS) Educational Division directors, disagreed with the statement unless it was applied exclusively to Gas Tungsten Arc Welding, also known as TIG welding. Sosnin (1982) also indicates that oxyacetylene welding (also known as oxyfuel gas welding) is a traditional method that should be utilized as much as possible in production for economic and efficiency benefits. However, literature that is more current limits the extent of oxyfuel welding to maintenance and repair exclusively (AWS, 2004).

To that end, there is a disparity between Sosnin’s assumption regarding the sequence of the welding curriculum versus the direction, and more importantly, the perceived needs for technical managers of welding in industry. It is the researcher’s belief that there are a number of schools that continue to stress the importance of oxyfuel welding, and its direct benefits to arc welding, without the use of empirical data to support the assumption. To that end, the question becomes: Should we be devoting limited time and resources in industrial technology classes to this technology? This research answers this question both empirically and through literature of current trends in the welding industry.

Today's manual welding industry is largely dependent on arc welding technology (AWS, 2004) and despite the technological growth of robotic arc welding equipment, there remains a growing need for skilled welders (Althouse, et al., 2003; Brat, 2006). For the industrial technologist, this means, as part of their formal education, more experience of arc welding processes that are currently employed throughout industry in order to become better managers of those technologies. As stated previously, many scholars and tradesmen of the vocational era apparently still believe that oxyfuel welding is the most critical welding process to learn; however, Dolby (2003) finds that arc welding has been the primary welding source for half a century. In particular, he stresses its dominance in the engineering construction sector. This is further warranted by the lack of literature pertaining to the use of oxyfuel welding. For example:

- Air Products, PLC (1999) published their Welder's Handbook without any mention of oxyfuel welding, only oxyfuel gas cutting.
- Deposition rates and economic sections of welding books and handbooks compare different arc welding processes, but never arc welding to oxy-fuel welding (R. Depue & C. Pollock, personal communication, October 5, 2005).
- Early on, it was recognized that welding repair and maintenance work was inherently not steady (Plumley, 1949); a reality the researcher has experienced first hand as a metal worker over fifty years later.

- In their Curriculum Guide for the Training of Welding Personnel: Level 1 – Entry Level (AWS, 2005), oxyfuel welding is not included as a part of the recommended entry-level welder profile.

Purpose of the Study

This study aims to identify whether or not teaching oxyfuel welding prior to gas metal arc welding, also known as Metal Inert Gas "MIG" welding, significantly improves gas metal arc welding skills for industrial technology students in a National Association of Industrial Technology (NAIT) accredited, four-year institution. This should be understood to take place under the typical teaching conditions encountered by the students in industrial technology.

Given the advances and enormity of the welding industry (especially in automatic, plastics, and specialty alloy welding), the research focuses on oxyfuel and gas metal arc welding specifically for the following reasons:

1. "Oxyacetylene is one of the oldest welding processes" (AWS, 2004, p. 468).
2. It was noted that many vocational scholars asserted and still believe learning oxyfuel welding before arc welding is imperative (Sosnin, 1982).
3. Gas metal arc welding has a higher metal deposition rate than either shielded metal arc welding (SMAW – also known as "stick welding") and gas tungsten arc welding (GTAW – also known as "TIG welding") (Althouse, et al., 2003), a fact that directly affects student contact and practice time.
4. No literature has been uncovered that compares oxyfuel welding directly to gas metal arc welding (R. Depue & C. Pollock, personal communication, October 5, 2005).

Many industrial technology programs inherently stress the importance of oxyfuel welding and students continue to spend limited class time trying to adequately master the technique.

Research Question

Is there a statistically significant difference in the ability to gas metal arc weld between students who were first taught to oxyfuel weld (with or without filler) versus those students who were not taught to oxyfuel weld?

Statistical Hypothesis 1

Ho: $\mu_{\text{OFW+filler}} = \mu_{\text{OFW-filler}} = \mu_{\text{GMAW}}$

Ha: $\mu_{\text{OFW+filler}} \neq \mu_{\text{OFW-filler}} \neq \mu_{\text{GMAW}}$

Statistical Hypothesis 2

Ho: $\mu_{\text{OFW(with and without Filler)}} = \mu_{\text{GMAW}}$

Ha: $\mu_{\text{OFW(with and without filler)}} \neq \mu_{\text{GMAW}}$

Methodology

Population and Sample

The research was conducted in three sections of an introductory materials processing course (ITEC 130: Production Materials and Processes) in the Department of Industry and Technology at Millersville University in the Spring 2006 semester. The population for this study is industrial technology students with a focus on four-year technical management programs. Each section of the course meets for a total of four hours and 10 minutes of contact time per week. The entire experiment was conducted over two class periods. During this time, each class was given lecture, manipulative/practice time, and final gas metal arc welding test. Given that this is all the time that is allotted to welding during other semesters at Millersville University (and sometimes less), it provides an opportunity to perform the experiment in a normal semester setting. Furthermore, students are given lab time each week, outside the normal course schedule, to practice their skills (not just welding skills) and complete projects, if they choose to do so.

Prior to the experiment, a survey was administered to each student to collect information pertaining to any prior welding experience. The survey gathered information about which welding process, if any, the student had previously learned. When a student indicated prior welding experience, he or she was asked to specify between (1) oxyacetylene welding (not oxyacetylene cutting), (2) shielded metal arc welding, (3) gas metal arc welding, (4) gas tungsten arc welding, or (5) some other type not identified above. In addition, those students who indicated prior welding experience were asked to complete how much welding time was spent on the specified welding experience. Three choices were available for each welding process selection, they were: (1) greater than zero but less then two hours of experience, (2) two to twenty hours of welding experience, or (3) greater than 20 hours of experience.

Statistical Design

The study is a one-factor experiment with three treatment groups with two stages of analysis. Stage one is a one-way analysis of variance (ANOVA) with three treatment groups and one factor of interest. The treatment groups and sample sizes can be found in Table 2 below.

Table 2

Experimental setup of three groups

Group/Class	Treatment Groups	Total
1	OFW w/ Filler + GMAW	24 Students
2	OFW w/out Filler + GMAW	20 Student
3	GMAW + GMAW	24 Students

On day one of the study, each group was taught and practiced only one type of welding (oxyfuel with filler, oxyfuel without filler, or gas metal arc welding). On day two, each class practiced and was immediately tested on gas metal arc welding. Each weld was independently evaluated by two welding instructors for seven pre-defined characteristics on a one to ten scale[3]. The two evaluators' scores were averaged for each of the seven scores, and those seven averaged scores were used to compute an overall mean score per student. In order to evaluate the effect of oxyfuel welding (with and without filler, collectively) on gas metal arc welding skills, the effects of oxyfuel welding were pooled together and compared to the gas metal arc welding group.

Stage two of the experiment is an evaluation of how students performed on specific parts of the weld. More specifically, it evaluated whether teaching oxyfuel welding prior to gas metal arc welding significantly improves any gas metal arc welding test characteristics. An analysis of variance with a narrow alpha level (0.01) was used for each individual test. A narrower alpha level for each of the seven tests is used to ensure a higher confidence level

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[3] Points allotted indicated competency as a percentage of the overall weld. For example, if only about 30% of the weld had correct height (sequentially or sporadically), then a 3 was assigned; if 90% of the weld was correct, then a 9 was assigned.

overall called a Bonferroni correction (Agresti & Finlay, 1997) also known as Bonferroni's inequalities (Snedecor & Cochran, 1989).

The researcher utilized lectures previously given to ITEC 130 students in the Spring 2004 semester when he was an instructor at Millersville University. The lecture material follows the curriculum guide of the American Welding Society (for GMAW only).

Practice

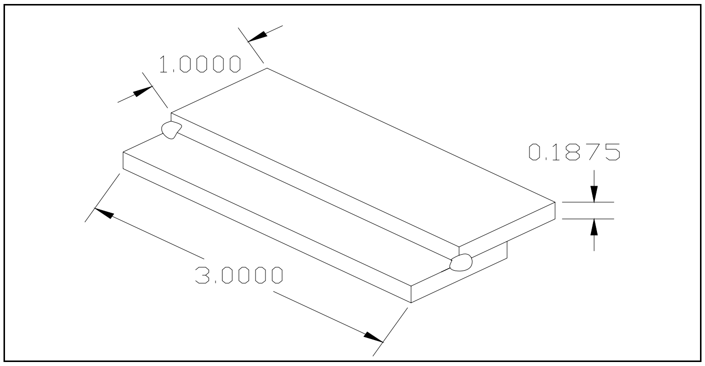
The experiment spanned two class periods. Day one was largely devoted to introduction of welding and practicing the weld process assigned to that particular class. Day two included instruction with a shorter practice time and the actual welding experiment on the gas metal arc welding process. The following procedures describe what the researcher taught and demonstrated in each class, respectively. Given that there were only two oxygen acetylene torch outfits and one gas metal arc welder, practice time was limited to two minutes per student. During the oxyfuel practice times, the researcher demonstrated lighting and flame adjustment and handed a torch to the student. The researcher had an assistant whose only job was to help the student start the puddle, relight the torch, and/or adjust the flame if the researcher was helping the other student. The researcher gave the only instruction during practice of oxyfuel welding. Each student practiced for a total of two minutes. For the class that was taught how to add filler material into the weld puddle, practice time was divided into two parts. One minute was given for puddle creation and moving, and one minute was given for practicing puddle creation, adding filler material, and then moving the puddle. Those students who did not have any oxyfuel training practiced for two minutes on gas metal arc welding.

Testing

On the second day of the experiment, each group was given the same practice/testing sequence on gas metal arc welding. Every student practiced for one minute on an unmarked lap joint with the researcher's guidance. Immediately following the one minute of practice, the student welded the test specimen lap joint to the best of their ability. There was no guidance from the instructor during the final welding test. An example of the lap joint test specimen is shown in Figure 1 below. Each student was randomly called to perform the test.

Figure 1

Lap joint test specimen



An Airco Dip-Pak 250 welder was used for practice and testing of all participants. The welder was set to the manufacture's recommended short-circuiting arc voltage and wire feed for 0.1875 inch thick mild steel with 0.035 inch diameter wire using 75% Argon – 25% Carbon Dioxide shielding gas. The welder was set to "1" on the medium voltage range and "4" for the wire feed speed. Although the Dip-Pak 250 is no longer manufactured and the researcher could not find any manuals for the welder, the actual voltage and wire feed speed can be estimated using the Typical Conditions for the Gas Metal Arc Welding of Carbon and Low-Alloy Steels in the Flat Position (Short-Circuiting Transfer) of the American Welding

Society Welding Handbook; they are: 20 Volts and 265 inches per minute of wire feed (AWS, 2004, p. 186).

Inspection

Two welding instructors from the Lancaster County Career and Technology Center, Lancaster, Pennsylvania, inspected each test specimen on each of the following seven quality characteristics: 1) Test 1 - weld height, 2) Test 2 - weld width, 3) Test 3 - undercut, 4) Test 4 - uniformity of weld, 5) Test 5 - proper contour, 6) Test 6 - surface contaminants/porosity, and 7) Test 7 - penetration at top. This rubric was developed jointly by the researcher and the welding instructors to identify areas the instructors look at for their beginning students. At this level of competency and practice time, that is, with only a few minutes of practice time, it was not deemed appropriate to perform mechanical testing. Visual inspections determine whether or not the students understand the basic concept of creating and moving a molten weld puddle.

Results

The data table for all seven tests are presented below.

Table 3

Data table and overall mean scores

Group	n	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Overall mean	s
OFW+F	24	3.52	2.53	7.40	3.42	2.85	7.19	5.23	4.59	1.95
OFW-F	20	2.83	2.90	7.18	3.23	1.63	6.50	6.25	4.36	1.54
GMAW	24	4.92	3.73	6.54	4.46	3.25	7.90	6.56	5.33	1.83
Overall	68	3.81	3.06	7.03	3.73	2.63	7.24	6.00	4.79	

The one-way analysis of variance of the overall mean scores between oxyfuel welding with filler, oxyfuel welding without filler, and gas metal arc welding indicated no significant differences at the 0.05 alpha level (p = 0.168).

Table 4

Analysis of Variance for the three individual groups

Source	df	F	p
Instructional Method	2	1.835	0.1678
Error	65		

A subsequent analysis comparing oxyfuel welding, with and without filler, versus gas metal arc welding was performed using the least squares contrast function of JMP 6.0 (SAS Institute, 2005) with coefficients of -0.5, -0.5, and 1 for oxyfuel welding with filler, oxyfuel welding without filler, and gas metal arc welding, respectively. The contrast compares the averages of the oxyfuel welding groups, collectively, to the third group, gas metal arc welding, utilizing the pooled estimate of variance for all three groups. Based on the contrast test, there is no significant difference in overall welding scores between those students who first learned to oxyfuel weld versus those students who did not learn to oxyfuel weld.

Table 5

Analysis of Variance for oxyfuel, with and without filler, versus gas metal arc welding

Source	df	F	p
Instructional Method	1	3.562	0.064
Error	65		

Given that the overall mean scores are made up of the seven individual test scores, a one-way analysis of variance was performed to assess whether any of the seven welding characteristics tested were significantly different between the oxyfuel and gas metal arc welding groups. In this analysis, oxyfuel welding with filler and oxyfuel welding without filler were once again contrast (n = 44) and compared to the gas metal arc welding group (n = 24). Each of the seven tests was performed on the weld specimens thereby making each test dependant on the other six tests. An adjustment was made for simultaneous confidence intervals with alpha = 0.01 for each individual test[4] for an approximate total margin of error equal to 0.05. The analysis of variance results for each weld test are presented below.

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[4] This is an approximation for a Bonferroni correction (0.05/7 = 0.00714)

Table 6

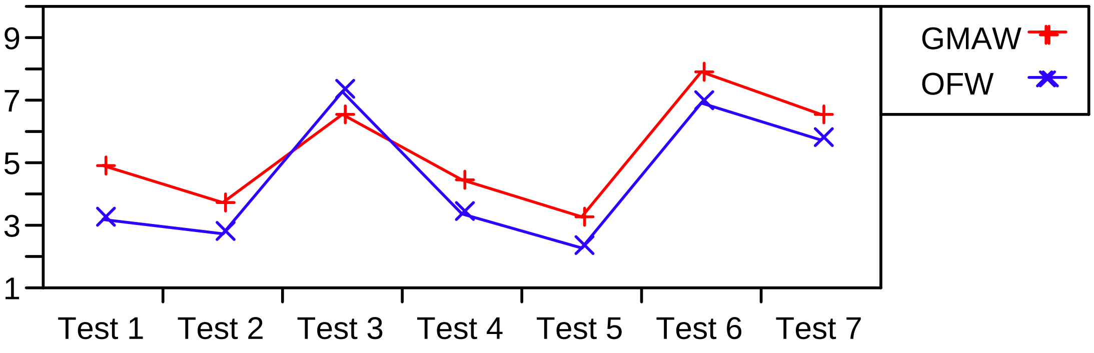
Analysis of Variance for each Individual Test (alpha = .01)

Source	df	F	p
Test 1	1	7.734	0.007
Test 2	1	2.621	0.110
Test 3	1	2.960	0.090
Test 4	1	4.490	0.038
Test 5	1	4.635	0.035
Test 6	1	2.917	0.092
Test 7	1	1.470	0.227
Error	65	*error term applies to each test*	

Of the seven weld characteristics evaluated, Test 1 (weld height) was the only statistically significant at the 0.01 alpha level (p = 0.007). For Test 1, those students who were taught gas metal arc welding scored higher than those students who were taught how to oxyfuel weld first. Test 2 through Test 7 were all found to be not significant: there was no significant difference between those students who were taught oxyfuel welding versus those who were not taught oxyfuel weld. The error term in the analysis of variance table above is 65 degrees of freedom per test. A graph of the mean scores for each of the seven tests is shown below.

Figure 2

Line Graph of the seven tests



The graph illustrates that on average, students tend to weld better in certain areas than they do in others regardless of their initial welding instruction. Only Test 1 was found to be significant and Test 3 (undercut) was the only test where, on average, those who learned how to oxyfuel weld first performed better, although it is not statistically significantly higher.

Discussion

The results of this research revealed that there is no statistically significant difference in arc welding skills between those students who were first taught to oxyfuel weld versus those who were not taught to oxyfuel weld. In fact, of the seven individual characteristic tests on each weld specimen, one individual weld test suggested that students who did not oxyfuel weld performed better than those who were not taught to oxyfuel weld at the 0.01 alpha level (p = 0.007). Under the conditions of this research, the outcomes did not support Sosnin’s (1982) assertion that students learned to weld other processes better and faster if they were first taught to oxyfuel. To that end, recommendations are presented in support of an industrial technology welding curriculum without the use of oxyfuel welding. It should be noted that these recommendations are for industrial technology programs whose main focus is technology management, not welding when time constraints are a factor in consideration. The outcome of the research does not impact or impede the importance of learning oxyfuel welding when gas tungsten arc welding or oxyfuel welding and cutting will be a significant skill set the student will learn for his or her profession.

From the surveys given before the experiment, over half of the students had no previous welding experience. Some students indicated some experience in either oxyfuel welding, shielded metal arc welding, gas metal arc welding, and/or gas tungsten arc welding. Although it makes sense to account for experience statistically (those with more experience scored significantly higher), it is typically not practical to separate those in an industrial technology class into those with and without experience. Additionally, sample sizes for the experience covariate, especially specific experience in any of the aforementioned categories, were reason for concern and were therefore not included in this analysis.

The literature pointed to a global increase in gas metal arc welding solid wire consumption (Pekkari, 2000). This is further supported by the U. S. Department of Commerce's (2002) findings that welding expenditures make up a substantial contribution to our economy, especially the labor portion, as well as a recent Wall Street Journal Online Edition (Brat, 2006) citing the present welding labor shortages. These economic indicators, coupled with the time a student can spend learning arc welding skills, call for efficient and effective instructional methodologies when time is limited.

One can argue that oxyfuel welding equipment is significantly less expensive, but the cost of the equipment versus the time students spend creating and moving puddles is generally ignored. Based on the material thickness and travel speed time figures presented in the literature review, a student using gas metal arc welding can weld over seven times the amount of linear distance than a student oxyfuel welding. These numbers are conservative given that they do not include learning curves for understanding how to properly light and adjust a torch, as well as the coordination required to add filler material with a second hand. Generally speaking, welding schools no longer teach oxyfuel welding as a major welding component, but rather incorporate it into a cutting and brazing program.

Future research in welding education is recommended to better understand where the true differences in learning each type of welding exist. This study indicated that those who were taught only gas metal arc welding performed better on welding height, but why? Subsequent studies should focus on longer practice time for both types of welding whereby true welding skills are developed and then tested using both destructive test methods, such as tensile tests or bend tests, as well as nondestructive and visual tests. Experiments should be set up to effectively evaluate different aspects of the weld (height, undercut, porosity, etc.) as well as strength and penetration. One suggestion to validate the findings of this research would be to increase the sample size of the groups and perform multiple tests on students as more practice is given to improve their skills. In doing so, researchers can better understand where beginning welders are typically stronger or where better teaching methods are required. Understanding where students struggle can be a powerful mechanism for streamlining the initial learning of welding. Industrial technology could benefit immensely in terms of time and program effectiveness by teaching welding more efficiently within the time constraints of teaching their students.

Finally, an article written by Litowitz (2002) entitled, When Did Shop Become a Four-letter Word, describes events in the 20th century that led society away from vocational careers, trivializing shop and the industrial arts. He writes:

> Given the limited time students have in school, the resources that schools have available, society's perception of the level at which career preparation should occur, and the literacy it will take to function today, shop does not appear to be part of the solution (Litowitz, 2002, p. 13).

Amid these comments, manufacturers are desperately looking for skilled workers (Brat, 2006), the gas metal arc welding industry continues to expand (Pekkari, 2000; U. S. Department of Commerce, 2002), and shop classes have become more about hobbies rather than industry (Litowitz, 2002). Technology programs, in particular those with welding, must have students and industry in mind – this means that gas metal arc welding is a critical component of the industrial technology curriculum.

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CHAPTER 3: A COMPARISON OF TEACHING OXYFUEL AND GAS METAL ARC WELDING IN INDUSTRIAL TECHNOLOGY

A paper submitted to *The Journal of Industrial Technology*

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Abstract

Many industrial technology programs continue to stress the importance of oxyacetylene welding in introductory materials and processing courses. Over the past 25 years, arc welding, in particular gas metal arc welding, has grown globally. Industrial technology programs around the country must be sensitive to the demands of industry as programs continue to replace “vocational” curriculum with high-tech alternatives. Entry-level managers who understand the practical as well as the theoretical nature of technology are still required. This research examines whether teaching oxyacetylene welding prior to gas metal arc welding bolsters the skills of arc welding as it has been anecdotally accepted in the profession. The study compares both oxyacetylene with filler material and oxyacetylene without filler material versus gas metal arc welding.

The findings of the literature and subsequent experiment suggest that, given the limited welding experience in the industrial technology classroom, gas metal arc welding should be taught over oxyacetylene welding. The outcomes did not suggest that first teaching oxyacetylene welding, with or without the use of filler material, improved arc welding skills in those students.

Introduction and Background

Many industrial technology programs struggle to identify and institute curricular activities that adequately serve all of the needs of local and regional industry. In light of "new" technologies, such as CNC, CAD/CAM, and the ever-growing robotics and automation markets, it is no surprise that the perceived importance of vocational skills steadily decreases. But the emphasis over the past decades to pursue a less physically demanding career has resulted in profound labor shortages throughout almost all industries (Brat, 2006), particularly manual welding, as evidenced by a recent Wall Street Journal Online Marketplace article:

> The average age of welders, currently 54, keeps climbing. As a wave of retirements loom, welding schools and on-site training programs aren't pumping out replacements fast enough. As a result, many companies are going to great lengths to attract skilled welders, sending recruiters to faraway job fairs and dangling unprecedented perks (Brat, 2006, ¶ 10).

Industrial technology programs around the country must be sensitive to these demands as programs continue to replace "vocational" curriculum with high-tech alternatives. Entry-level managers who understand the practical as well as the theoretical nature of technology are still required. "The primary distinguishing characteristic of technological knowledge is that it derives from, and finds meaning, in activity" (Herschbach, 1995). Much of the facility and vocational equipment infrastructures at our institutions remain intact, albeit a bit dusty, and should be utilized to revitalize or reorganize our hot metals curriculum to meet the demands of industry. This research examines a curriculum that bolsters manual welding skills within the current time constraints of lab/lecture curriculums by allotting more hands-on welding time to students without sacrificing or impeding other subject matter. Simply put, which approach to teaching welding yields, most effectively and efficiently, the skill sets required by our students?

This article delves into welding education as it looks to which processes, if any, are helpful for the student to be taught first if he or she is to become proficient in arc welding. In particular, the researcher has chosen oxyfuel welding, also known as oxyacetylene welding, and gas metal arc welding (GMAW) as the two test vehicles. Oxyfuel welding is the oldest welding process that burns oxygen and acetylene in a flame to melt metal beyond its solid state. Oxyfuel welding requires two coordinated activities to properly weld. The first is to properly create and move a molten weld puddle. The other is to insert a solid metal rod, called filler material, into the molten weld puddle for strength. This research examines whether or not teaching one or both of these activities improves arc welding skills. The importance of knowing whether or not teaching either of these oxyfuel activities affects arc welding skills is due to the amount of time it takes to learn the coordination of oxyfuel welding. These effects must be a consideration during program review because oxyfuel welding has been largely superseded by arc welding (American Welding Society [AWS], 2004). Gas metal arc welding continues to grow globally (Pekkari, 2000) and is used extensively in “industrial manufacturing, agriculture, construction, shipbuilding and mining” (AWS, 2004, p. 148). Gas metal arc welding, also known as Metal Inert Gas “MIG” welding, uses an electric power source, rather than a flame, to produce an arc that melts metal beyond its solid state.

This research is part of a larger study that examines three broad areas of interest in preparing future technologists to the area of welding; those areas are the state of the welding industry, cost considerations for the metals lab, and welding education.

Given the advances and enormity of the welding industry (especially in automatic, plastics, and specialty alloy welding), the research focuses on oxyfuel and gas metal arc welding specifically for the following reasons:

1. "Oxyacetylene is one of the oldest welding processes" (AWS, 2004, p. 468).
2. It was noted that many vocational scholars asserted and still believe learning oxyfuel welding before arc welding is imperative (Sosnin, 1982).
3. Gas metal arc welding has a higher metal deposition rate than either shielded metal arc welding (SMAW – also known as "stick welding") and gas tungsten arc welding (GTAW – also known as "TIG welding") (Althouse, Turnquist, Bowditch, Bowditch, & Bowditch, 2003), a fact that directly affects student contact and practice time.
4. No literature has been uncovered that compares oxyfuel welding directly to gas metal arc welding (R. Depue & C. Pollock, personal communication, October 5, 2005).

Many industrial technology programs inherently stress the importance of oxyfuel and students continue to spend time trying to adequately master the technique.

Need for the Study

H. A. Sosnin (1982) summarizes the prevailing anecdotal evidence uncovered by the researcher during conversations and classroom lectures with various vocational instructors regarding welding education when he writes, "It has been proven, many times, that when a student learns to weld with an oxyacetylene torch first, he learns to weld quicker and better with the other processes" (p. 48). Unfortunately, there has been no data or research that has been uncovered and supports that notion. Furthermore, R. Depue and C. Pollock (personal communication, October 5, 2005), both American Welding Society (AWS) Educational Division directors, disagreed with the statement unless it was applied exclusively to gas tungsten arc welding, also known as TIG welding. Sosnin (1982) also indicates that oxyacetylene welding (also known as oxyfuel gas welding) is a traditional method that should be utilized as much as possible in production for its economic and efficient benefits. However, literature that is more current limits the extent of oxyfuel welding to maintenance and repair exclusively (AWS, 2004).

To that end, there is a disparity between Sosnin's assumption regarding the sequence of the welding curriculum versus the direction, and more importantly, the perceived needs of welding in industry. It is the researcher's belief that there are a number of schools that continue to stress the importance of oxyfuel welding, and its direct benefits to arc welding, without the use of empirical data to support the assumption.

Today's welding industry is largely dependent on arc welding technology (AWS, 2004) and despite the technological growth of robotic arc welding equipment, there remains a growing need for skilled welders (Althouse, et al, 2003, Brat, 2006). For the industrial technologist, this means more experience of arc welding processes currently employed throughout industry in order to become better managers of the technologies. As stated previously, many scholars and tradesmen of the vocational era apparently still believe that oxyfuel welding is the most critical welding process to learn; however, Dolby (2003) finds that arc welding has been the primary welding source for half a century. In particular, he stresses its dominance in the engineering construction sector.

Research Questions

Two research questions are examined in this study.

(1) Is there a statistically significant difference in the ability to gas metal arc weld between students who were taught how to oxyfuel weld with filler versus those students who were not taught to oxyfuel weld?

Statistical Hypothesis 1

Ho: $\mu_{\text{OFW + filler}} = \mu_{\text{GMAW}}$

Ha: $\mu_{\text{OFW + filler}} \neq \mu_{\text{GMAW}}$

(2) Is there a statistically significant difference in the ability to gas metal arc weld between students who were taught how to oxyfuel weld without filler versus those students who were not taught to oxyfuel weld?

Statistical Hypothesis 2

Ho: $\mu_{\text{OFW - filler}} = \mu_{\text{GMAW}}$

Ha: $\mu_{\text{OFW - filler}} \neq \mu_{\text{GMAW}}$

Methodology

Population and Sample

The research was conducted in three sections of an introductory materials processing course (ITEC 130: Production Materials and Processes) in the Department of Industry and Technology at Millersville University in the spring 2006 semester. The population for this study is industrial technology students with a focus on four-year technical management programs. Each section of the course meets for a total of four hours and 10 minutes of contact time per week. The entire experiment was conducted over two class periods. During this time, each class was given lecture, manipulative/practice time, and a final gas metal arc welding test. Given that this is all the time that is allotted to welding during other semesters at Millersville University (and sometimes less), it provides an opportunity to perform the experiment in a normal semester setting. Students are given lab time each week, outside the normal course schedule, to practice their skills (not just welding skills) and complete projects, if they choose to do so.

Statistical Design

The research is set up as a two-stage experiment. Stage one is a one-way analysis of variance (ANOVA) with three treatment groups and one factor of interest.

Table 1

Experimental setup of three groups

Group/Class	Treatment Groups	Total
1	OFW w/ Filler + GMAW	24 Students
2	OFW w/out Filler + GMAW	20 Student
3	GMAW + GMAW	24 Students

On day one of the study, each group was taught and practiced only one type of welding (oxyfuel with filler, oxyfuel without filler, or gas metal arc welding) but all groups tested on gas metal arc welding. On day two, each class practiced gas metal arc welding and was immediately tested on gas metal arc welding. Each weld was independently evaluated by two welding instructors for seven pre-defined characteristics on a one to ten scale[5]. The two

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[5] Points allotted indicated competency as a percentage of the overall weld. For example, if only about 30% of the weld had correct height (sequentially or sporadically), then a 3 was assigned; if 90% of the weld was correct, then a 9 was assigned.

evaluators' scores were averaged for each of the seven scores, and those seven averaged scores were used to compute an overall mean score per student.

Stage two of the experiment is an evaluation of how students performed on specific parts of the weld. More specifically, it evaluated whether teaching oxyfuel welding prior to gas metal arc welding significantly improves any gas metal arc welding test characteristics. An analysis of variance with a narrower alpha level (0.01) was used for each individual test. A narrower alpha level (called a Bonferroni correction) for each of the seven tests is used to ensure at least a standard confidence level overall (Agresti & Finlay, 1997) also known as Bonferroni's inequalities (Snedecor & Cochran, 1989).

The researcher utilized lectures previously given to ITEC 130 students in the Spring 2004 semester when he was an instructor at Millersville University. The lecture material follows the curriculum guide of the American Welding Society (for gas metal arc welding only).

Practice

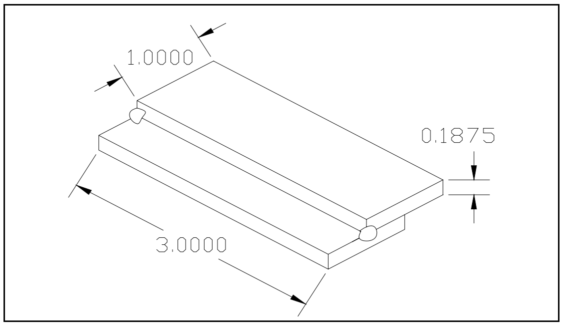
As previously mentioned, the experiment spanned two class periods. Day one was largely devoted to introduction of welding and practicing the weld process assigned to that particular class. Day two included instruction with a shorter practice time and the actual welding experiment on the gas metal arc welding process. The following procedures describe what the researcher taught and demonstrated in each class, respectively. Given that there were only two oxygen and acetylene torch outfits and one gas metal arc welder, practice time was limited to two minutes per student. During the oxyfuel practice times, the researcher demonstrated lighting and flame adjustment and handed a torch to the student. The researcher had an assistant whose only job was to help the student start the puddle, relight the torch, and/or adjust the flame if the researcher was helping the other student. The researcher gave the only instruction during practice of oxyfuel welding. Each student practiced for a total of two minutes. For the class that was taught how to add filler material into the weld puddle, practice time was divided into two parts. One minute was given for puddle creation and moving the puddle, and one minute was given for practicing puddle creation, adding filler material, and then moving the puddle. Those students who did not have any oxyfuel training practiced for two minutes on gas metal arc welding.

Testing

On the second day of the experiment, each group was given the same practice/testing sequence on gas metal arc welding. Every student practiced for one minute on an unmarked lap joint with the researcher's guidance. Immediately following the one minute of practice, the student welded the test specimen lap joint to the best of their ability. There was no guidance from the instructor during the final welding test. An example of the lap joint test specimen is shown in Figure 1 below. Each student was randomly called to perform the test.

Figure 1

Lap joint test specimen



An Airco Dip-Pak 250 welder was used for practice and testing of all participants. The welder was set to the recommended short-circuiting arc voltage and wire feed for 0.1875 inch thick mild steel with 0.035 inch diameter wire using 75% Argon – 25% Carbon Dioxide shielding gas. The welder was set to "1" on the medium voltage range and "4" for the wire feed speed. Although the Dip-Pak 250 is no longer manufactured and the researcher could not find any manuals for the welder, the actual voltage and wire feed speed can be estimated using the Typical Conditions for the Gas Metal Arc Welding of Carbon and Low-Alloy Steels in the Flat Position (Short-Circuiting Transfer) of the American Welding Society Welding Handbook; they are: 20 Volts and 265 inches per minute of wire feed (AWS, 2004, p. 186).

Inspection

Two welding instructors from the Lancaster County Career and Technology Center, Lancaster, Pennsylvania, inspected each test specimen on each of the following seven quality characteristics: 1) Test 1 - weld height, 2) Test 2 - weld width, 3) Test 3 - undercut, 4) Test 4 - uniformity of weld, 5) Test 5 - proper contour, 6) Test 6 - surface contaminants/porosity, and 7) Test 7 - penetration at top. This rubric was developed jointly by the researcher and the welding instructors to identify areas the instructors look at for their beginning students. At this level of competency and practice time, that is, with only a few minutes of practice time, it was not deemed appropriate to perform mechanical testing. Visual inspections determine whether or not the students understand the basic concept of creating and moving a molten weld puddle.

Results

The data table for all seven tests are presented below.

Table 2

Data table and overall mean scores

Group	n	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Overall Mean	s
OFW+F	24	3.52	2.53	7.40	3.42	2.85	7.19	5.23	4.59	1.95
OFW-F	20	2.83	2.90	7.18	3.23	1.63	6.50	6.25	4.36	1.54
GMAW	24	4.92	3.73	6.54	4.46	3.25	7.90	6.56	5.33	1.83
Overall	68	3.81	3.06	7.03	3.73	2.63	7.24	6.00	4.79	

The one-way analysis of variance of the overall mean scores between oxyfuel welding with filler, oxyfuel welding without filler, and gas metal arc welding indicated no significant differences at the 0.05 alpha level (p = 0.168).

Table 3

Analysis of Variance for the three individual groups

Source	df	F	p
Instructional Method	2	1.835	0.1678
Error	65		

Subsequent separate analyses comparing oxyfuel welding with filler versus gas metal arc welding and an analysis comparing oxyfuel welding without filler versus gas metal arc welding were conducted. The findings of these two analyses are presented in Table 4 and Table 5 below, respectively.

Table 4

Analysis of Variance for oxyfuel with filler versus gas metal arc welding

Source	df	F	p
Instructional Method	1	1.864	0.1788
Error	46		

Table 5

Analysis of Variance for oxyfuel without filler versus gas metal arc welding

Source	df	F	p
Instructional Method	1	3.5704	0.0657
Error	42		

Given that the overall mean scores are made up of the seven individual test scores, a one-way analysis of variance was performed on each test to assess whether any of the seven welding characteristics tested were significantly different between the oxyfuel and gas metal arc welding groups. Each of the seven tests was performed on the weld specimens thereby making each test dependant on the other six tests. An adjustment was made for simultaneous confidence intervals with alpha = 0.01 for each individual test[6] for an approximate total margin of error equal to 0.05. The analysis of variance results for oxyfuel with filler versus gas metal arc welding for each test are presented in Table 6 below.

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[6] This is an approximation for a Bonferroni correction (0.05/7 = 0.00714)

Table 6

Analysis of Variance for each Individual Test (alpha = 0.01)

Oxyfuel welding with filler versus gas metal arc welding

Source	df	F	p
Test 1	1	3.6325	0.0629
Test 2	1	2.7372	0.1048
Test 3	1	2.8273	0.0995
Test 4	1	2.7756	0.1025
Test 5	1	.4812	0.4914
Test 6	1	.9790	0.3276
Test 7	1	2.6656	0.1094
Error	46	*Error term applies to each test*	

Of the seven weld characteristics evaluated, none were found to be statistically different when oxyfuel welding versus gas metal arc welding were compared.

The analysis of variance results for oxyfuel with filler versus gas metal arc welding for each test are presented in Table 7 below.

Table 7

Analysis of Variance for each Individual Test (alpha =0.01)

Oxyfuel welding without filler versus gas metal arc welding

Source	df	F	p
Test 1	1	8.5312	0.0056
Test 2	1	1.2536	0.2692
Test 3	1	1.5177	0.2248
Test 4	1	4.1070	0.0491
Test 5	1	10.0042	0.0029
Test 6	1	4.2411	0.0457
Test 7	1	0.1985	0.6582
Error	42	*Error term applies to each test*	

Only Test 1 and Test 5 were found to be significant at the 0.01 alpha level (p = 0.0056 and p = 0.0029, respectively) when comparing oxyfuel without filler versus gas metal arc welding. The line graphs of the individual weld test comparisons are presented in the following line graphs.

Figure 2

Line graph of the seven tests by 3 treatment groups

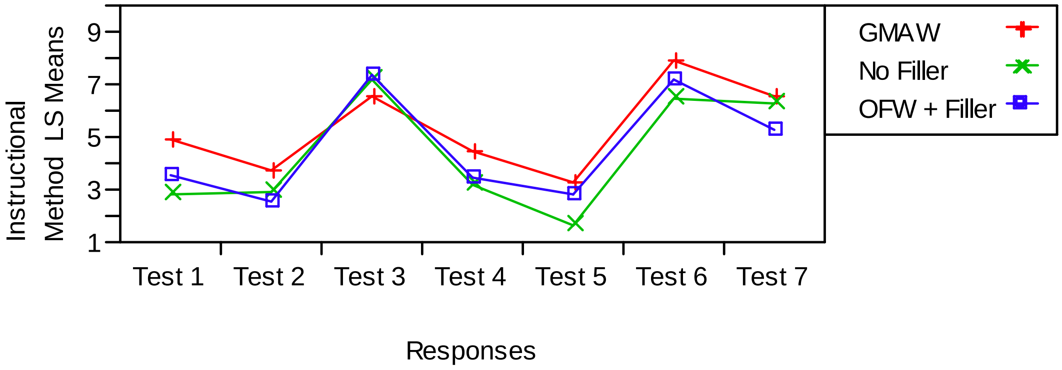


Figure 3

Line graph of the seven weld tests by OFW(+ Filler) versus GMAW

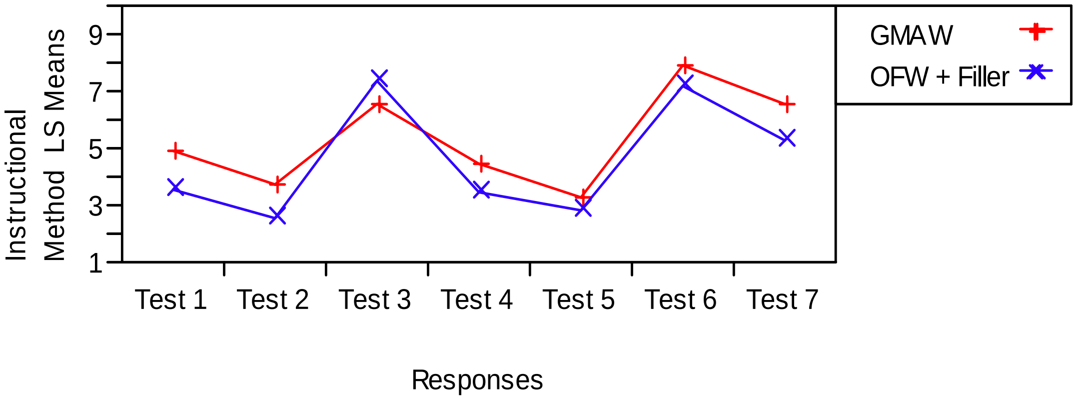
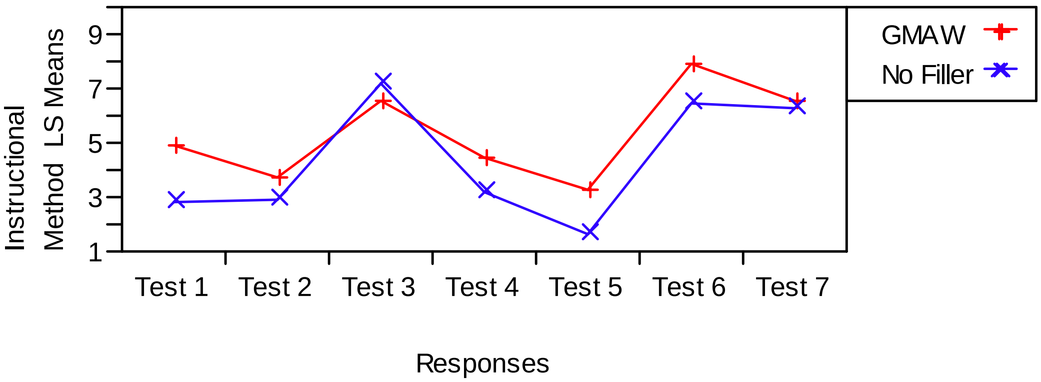


Figure 4

Line graph of the seven weld tests by OFW (No Filler) versus GMAW



The graphs illustrate that on average, students tend to weld better on certain tests than they do in others regardless of their initial welding instruction. Only Test 1 and Test 5 were found to be significant at the 0.01 alpha level when comparing oxyfuel without filler versus gas metal arc welding. Those who were taught only gas metal arc welding performed better than those who were taught to oxyfuel weld without filler.

Discussion

The results of this research revealed that there is no statistically significant difference in the average arc welding skills between those students who were first taught to oxyfuel weld with filler versus those who were not taught to oxyfuel weld. Nor were there any significant differences between those students who were first taught to oxyfuel weld without filler versus those who were not taught to oxyfuel weld. However, those students who were not taught to oxyfuel weld performed better on weld height (Test 1) and overall weld contour (Test 5) compared to those who were taught to oxyfuel weld without filler. Under the conditions of this research, the outcomes did not suggest, as Sosnin (1982) did that students will learn to weld other processes better and faster if they were first taught to oxyfuel. To that end, recommendations are presented in support of an industrial technology welding curriculum without the use of oxyfuel welding when time is a critical factor. It should be noted that these recommendations are for industrial technology programs whose main focus is technology management, not welding. The outcome of the research does not impact or impede the importance of learning oxyfuel welding when gas tungsten arc welding or oxyfuel welding and cutting will be a significant skill set the student will learn for his or her profession.

The literature pointed to a global increase in gas metal arc welding solid wire consumption (Pekkari, 2000). This was further warranted by the U. S. Department of Commerce's (2002) findings that welding expenditures make up a substantial contribution to our economy, especially the labor portion, as well as a recent Wall Street Journal Online Edition (2006) citing the present welding labor shortages. These economic indicators, coupled with the time a student can spend learning arc welding skills, call for efficient and effective instructional methodologies when time is limited.

One can argue that oxyfuel welding equipment is significantly less expensive, but the cost of the equipment versus the time students spend creating and moving puddles is generally ignored. Based on the material thickness and travel speed time figures found in welding books, a student using gas metal arc welding can weld over seven times the amount of linear distance than a student oxyfuel welding (Althouse, et al. 2003; AWS, 2004). These numbers are conservative given that they do not include learning curves for understanding how to properly light and adjust a torch, notwithstanding the coordination required to add filler material with a second hand. Generally speaking, welding schools no longer teach oxyfuel welding as a major welding component, but rather incorporate it into a cutting and brazing program.

From surveys given before the experiment, over half of the students had no previous welding experience. Some students indicated some experience in either oxyfuel welding, shielded metal arc welding, gas metal arc welding, and/or gas tungsten arc welding. Although it makes sense to account for experience statistically (those with more experience scored significantly higher), it is typically not practical to separate those in an industrial technology class into those with and without experience. Additionally, sample sizes of experience, especially specific experience in any of the aforementioned categories, were reason for concern and were not controlled for in these analyses.

Future research in welding education is recommended to better understand where the true differences in learning each type of welding exist. This study indicated that those who were taught to gas metal arc weld only performed better on welding height and contour versus those students who were taught to oxyfuel weld without filler material. This difference was not found in those students who were taught to oxyfuel weld with filler, but why? Subsequent studies should focus on longer practice time for both types of welding whereby true welding skills are developed and then tested using both destructive test methods, such as tensile tests or bend tests, as well as nondestructive and visual tests. Experiments should be set up to effectively evaluate different aspects of the weld (height, undercut, porosity, etc) as well as strength and penetration. One suggestion to validate the findings of this research would be to increase the sample size of the groups and perform multiple tests on students as more practice is given to improve their skills. In doing so, researchers can better understand where beginning welders are typically stronger or where better teaching methods are required. Understanding where students struggle can be a powerful mechanism for streamlining the initial learning of welding. Industrial technology could benefit in terms of time and program effectiveness by teaching welding more efficiently within the time constraints of the curriculum.

Finally, an article written by Litowitz (2002) entitled, When Did Shop Become a Four-letter Word, describes events in the 20th century that led society away from vocational careers, trivializing shop and the industrial arts. He writes:

> Given the limited time students have in school, the resources that schools have available, society's perception of the level at which career preparation should occur, and the literacy it will take to function today, shop does not appear to be part of the solution (Litowitz, 2002, p. 13).

Amid these comments, we have manufactures desperately looking for skilled workers (Brat, 2006), the growing gas metal arc welding industrial sector (Pekkari 2000, U. S. Department of Commerce, 2002), and shop classes that have become more about hobbies rather than industry (Litowitz, 2002). Technology programs, in particular those with welding, must have students and industry in mind. Gas metal arc welding must be a critical component of the industrial technology curriculum.

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CHAPTER 4. TRANFERABILITY OF OXYFUEL SKILLS TO GAS METAL ARC SKILLS

A paper submitted to *The Welding Journal*

Sergio D. Sgro

Abstract

A study was conducted to test whether there are statistically significant differences in gas metal arc welding skills between students who were taught to oxyfuel weld with filler and students who were taught to weld without filler. Although not universally taught as a separate welding skill apart from cutting, brazing, and soldering, oxygen-acetylene welding remains a popular first-time welding skill to teach at the technical management/university level. To that end, the hypothesis that arc welding skills, particularly gas metal arc welding, are affected by the use of filler material is tested in this research. Although the primary objective of the research is for technical managers of welding technologies (entry to mid-level management positions), the methodology is well-suited for further investigation of welding education. Understanding where students struggle or do poorly can be a powerful mechanism for streamlining the initial learning of welding.

Introduction

A study was conducted to determine whether or not teaching students in technical management programs oxyfuel welding with or without filler material has any effect on gas metal arc welding skills. The research is part of a larger study evaluating whether teaching oxyfuel welding prior to arc welding affects gas metal arc welding skills. Of particular interest is whether teaching students to add filler material to the weld puddle positively affects the skills of gas metal arc welding. The research focuses on technical management degrees where welding is a technical competency rather than a focus; however, the methodology of the study is also well suited for primary welding programs as it examines strengths and weaknesses of beginner welders.

The emphasis over the past decades to pursue a less physically demanding career has resulted in profound labor shortages throughout most industries. These shortages have made it increasingly more difficult to attract and retain skilled welders (Ref. 1). This article delves into welding education, examining if two different teaching methods of oxyfuel welding are beneficial to students in becoming more proficient in arc welding. In particular, the researcher has chosen oxyacetylene welding, referred to here as oxyfuel welding, and gas metal arc welding as the two test vehicles. Oxyfuel welding is the oldest fusion welding process (Ref. 2), burning oxygen and acetylene in a flame to melt base metals into a single structure. Oxyfuel welding requires two coordinated activities to properly weld. The first is to create and move a molten weld puddle. The other is to insert a solid metal rod, called filler material, into the molten weld puddle where it coalesces with the base metal(s) to increase the weld strength. Given that oxyfuel welding requires a great deal of coordination and practice, it is important to understand how it affects arc welding skills. This research examines whether or not teaching students to add and manipulate filler material into the molten puddle has any positive influence on arc welding skills.

Gas metal arc welding was chosen as the assessment tool because it continues to grow globally (Ref. 3) and is used extensively in industrial and manufacturing sectors (Ref. 2). Gas metal arc welding, also known as Metal Inert Gas “MIG” welding, uses an electric power source, rather than a flame, to produce an arc that melts metal. Today's manual welding industry is largely dependent on arc welding technology (Ref. 2) and despite the technological growth of robotic arc welding equipment, there remains a growing need for skilled welders (Ref. 4, Ref. 1).

Experimental Procedure

Research Question

Is there a statistically significant difference in GMAW skills between those students who were taught to oxyfuel weld with filler versus those students who were taught to oxyfuel weld without filler?

Statistical Hypothesis 1

Ho: $\mu_{\text{(OFW+filler)}} = \mu_{\text{(OFW-filler)}}$

Ha: $\mu_{\text{(OFW+filler)}} \neq \mu_{\text{(OFW-filler)}}$

Population and Sample

The research was conducted in three sections of an introductory materials processing course (ITEC 130: Production Materials and Processes) in the Department of Industry and Technology at Millersville University in the Spring 2006 semester. The population for this study encompasses first year industrial technology students with a focus on four-year technical management programs. Each section of the course met for a total of four hours and 10 minutes of contact time per week or two classes periods of 125 minutes each. During this time, each class was given lecture, practice time (two minutes per student), and a final gas metal arc welding test (on the test day only). Given that this is all the time that is allotted to welding during other semesters at Millersville University (and sometimes less), it provides an opportunity to perform the experiment in a normal semester setting. Furthermore, students are typically given lab time each week, outside the normal course schedule, to practice their skills (not just welding skills) and complete projects, if they choose to do so. There was no indication that any of the students came in to practice above and beyond the time allotted for this study.

Prior to the experiment, a survey was administered to each student to collect information pertaining to any prior welding experience. The survey gathered information about any previous welding experience (Table 1). When a student indicated prior welding experience, the student indicated which welding process they had previously learned. When a student indicated prior welding experience, he or she was asked to specify between (1) oxyacetylene welding (not oxyacetylene cutting), (2) shielded metal arc welding, (3) gas metal arc welding, (4) gas tungsten arc welding, or (5) some other type not identified above. In addition, those students who indicated prior welding experience were asked to complete how much welding time was spent on the specified welding experience. Three choices were available for each welding process selection, they were: (1) greater than zero but less then two hours of experience, (2) two to twenty hours of welding experience, or (3) greater than 20 hours of experience. The sample sizes for gas metal arc welding are presented in Table 2 below.

Table 1 – Sample sizes for those with and without experience

Group/Class	No Experience (No)	Experience (Yes)	Total
$\text{OFW}_{+\text{Filler}}$	13	11	24
$\text{OFW}_{-\text{Filler}}$	11	9	20

Table 2 – Sample sizes for different levels of gas metal arc welding experience

Group/Class	No GMAW	up to 2 hours	2 – 20 hours	> 20 hours	Total
OFW $_{+\text{Filler}}$	17	1	4	2	24
OFW $_{-\text{Filler}}$	12	3	1	4	20

Equipment Used

Two oxyfuel welding outfits were utilized for all students. Oxygen and acetylene regulators were set to 5 pound(s) per square inch gauge (psig) for a neutral gas welding mixture. A leftward welding technique was utilized with a number 3 torch tip on a 0.1875 inch plate (4.76 mm).

An Airco Dip-Pak 250 welder was used for practice and testing of all participants. The welder was set to the manufacture's recommended short-circuiting arc voltage and wire feed for 0.1875 inch thick mild steel with 0.035 inch (0.889 mm) diameter wire using 75% Argon – 25% Carbon Dioxide shielding gas. The welder was set to "1" on the medium voltage range and "4" for the wire feed speed. Although the Dip-Pak 250 is no longer manufactured and the researcher could not find any manuals for the welder, the actual voltage and wire feed speed can be estimated using the Typical Conditions for the Gas Metal Arc Welding of Carbon and Low-Alloy Steels in the Flat Position (Short-Circuiting Transfer) of the American Welding Society Welding Handbook; they are: 20 Volts and 265 inches per minute of wire feed (Ref. 2).

Statistical Design and Analysis

The study is a one-factor experiment with two treatment groups, OFW w/Filler and OFW w/out Filler.

Table 3 - Experimental setup of three groups

Group/Class	Treatment Groups	Total
1	OFW w/ Filler + GMAW	24 Students
2	OFW w/out Filler + GMAW	20 Student

On day one of the study, each group, or class section, was taught and practiced only one type of welding (oxyfuel with filler or oxyfuel without filler). Each weld was independently evaluated by two welding instructors for seven pre-defined characteristics on a one to ten scale[7]. The two evaluators' scores were averaged for each of the seven scores, and those seven averaged scores were used to compute an overall mean score per student.

The first stage of the analysis involves a one-way analysis of variance (ANOVA) of the overall weld score. Stage two of the analysis looks at how students performed on specific parts of the weld. More specifically, it investigates whether teaching oxyfuel welding with filler or oxyfuel welding without filler prior to gas metal arc welding significantly improves any of the seven gas metal arc welding test characteristic scores. An analysis of variance with a smaller alpha level (0.01) was used for each individual test. A smaller alpha level for each of the seven tests is used to ensure a higher confidence level overall approaching a Bonferroni correction (Ref. 5).

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[7] Points allotted indicated competency as a percentage of the overall weld. For example, if only about 30% of the weld had correct height (sequentially or sporadically), then a 3 was assigned.

Stage three of the analysis includes prior welding experience. The experience covariate is included in two ways. First, the two treatment groups are compared while accounting for welding experience (yes or no, see Table 1). Second, the two treatment groups are compared while accounting for the four levels of experience in the study. Those levels are: no gas metal arc welding experience, up to two hours of gas metal arc welding experience, two to 20 hours of gas metal arc welding experience, or greater than 20 hours of gas metal arc welding experience (see Table 2).

Practice

The study was conducted over two class periods. Day one was largely devoted to introduction of welding and practicing the weld process assigned to that particular class. Day two included instruction with a shorter practice time and the actual welding test using the gas metal arc welding process. The following procedures describe what the researcher taught and demonstrated in each class, respectively. Given that there were only two oxygen acetylene torch outfits and one gas metal arc welder, practice time was limited to two minutes per student after lecture time. During the oxyfuel practice times, the researcher demonstrated lighting and flame adjustment and handed a torch to the student. The researcher had an assistant whose only job was to help the student start the puddle, relight the torch, and/or adjust the flame if the researcher was helping the other student. The researcher gave the only instruction during practice of oxyfuel welding. Each student practiced for a total of two minutes. For the class that was taught how to add filler material into the weld puddle, practice time was divided into two parts. One minute was given for puddle creation and moving, and one minute was given for practicing puddle creation, adding filler material, and then moving the puddle.

Testing

On the second day of the study, each group was given the same practice/testing sequence on gas metal arc welding. Every student practiced for one minute on an unmarked lap joint with the researcher's guidance. Immediately following the one minute of practice, the student welded the test specimen lap joint to the best of her/his ability. There was no guidance from the instructor during the final gas metal arc welding test. An example of the lap joint test specimen is shown in Figure 1. The order of students performing the gas metal arc welding test was random.

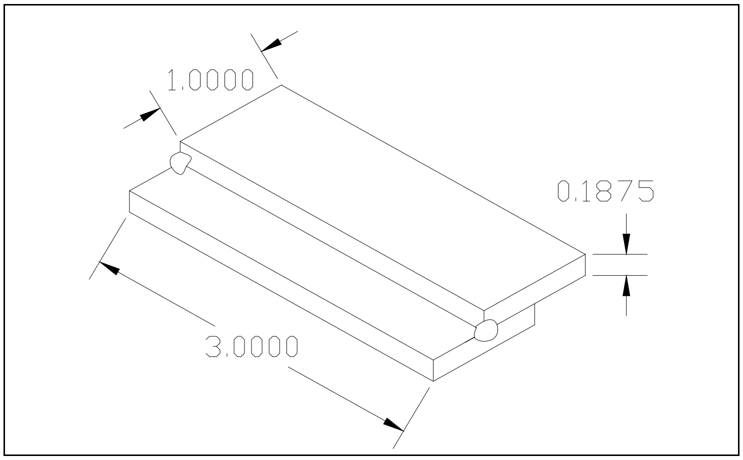

Fig. 1 - Lap joint test specimen

Inspection

Two welding instructors from the Lancaster County Career and Technology Center, Lancaster, Pennsylvania, inspected each test specimen on each of the following seven quality characteristics: (1) Weld height, (2) Weld width, (3) Undercut, (4) Uniformity of weld, (5) Proper contour, (6) Surface contaminants/porosity, (7) Penetration at top. A rubric was developed jointly by the researcher and the welding instructors to identify areas the instructors evaluate for their beginning students. At this level of competency and practice time, that is, with only a few minutes of practice time, it was not deemed appropriate to perform mechanical testing. Visual inspections determine whether or not the students understand the basic concept of creating and moving a molten weld puddle.

Results

The results were compiled and analyzed using JMP 6.0 (Ref. 6). A graph of the mean scores for each of the seven tests is shown in Figure 2.

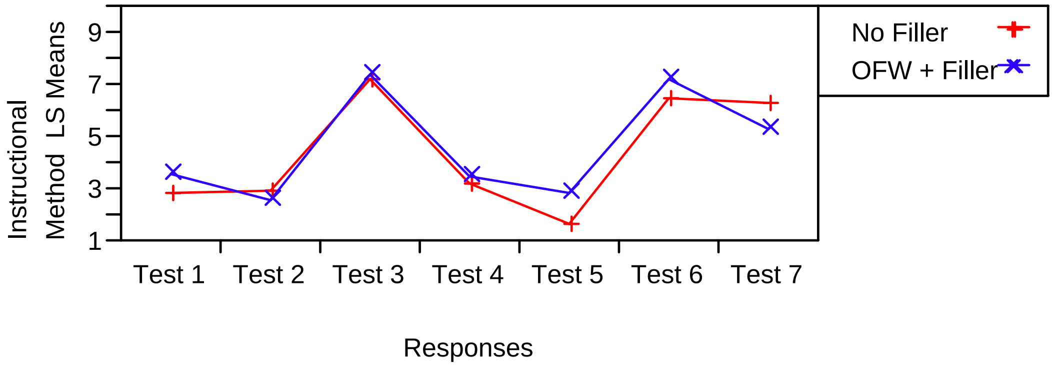

Fig. 2 – Graph of each of the seven tests

The graph illustrates that on average, students tend to weld better in certain areas (Tests 3, 6, and 7) than they do in others regardless of their initial welding instruction.

The data table for all seven tests are presented in Table 4.

Table 4 - Data table and overall mean scores

		Weld Height	Weld Width	Under-cut	Uni-formity	Proper Contour	Contam. Porosity	Pene-tration	Overall	
Group	n	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Mean	s
OFW+F	24	3.52	2.53	7.40	3.42	2.85	7.19	5.23	4.59	1.95
OFW-F	20	2.83	2.90	7.18	3.23	1.63	6.50	6.25	4.36	1.54
Overall	44	3.20	2.70	7.30	3.33	2.30	6.88	5.70	4.46	

The one-way analysis of variance of the overall mean scores between oxyfuel welding with filler and oxyfuel welding without filler indicated no significant differences at the 0.05 alpha level (p = 0.6658) (see Table 5).

Table 5 - Analysis of Variance for the two individual groups

Source	df	F	p
Instructional Method	1	0.1892	0.6658
Error	42		

Given that the overall mean scores are made up of the seven individual test scores, a second stage of analysis was performed to assess whether any of the seven welding characteristics tested were significantly different between the oxyfuel groups. Each of the seven tests was performed on the weld specimens thereby making each test dependant on the other six tests. An adjustment was made for simultaneous confidence intervals with alpha = 0.01 for each individual test[8] for an approximate total margin of error equal to 0.05. The

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[8] This is an approximation for a Bonferroni correction (0.05/7 = 0.00714)

analysis of variance results for oxyfuel with filler versus gas metal arc welding for each test are presented in Table 6 .

Table 6 - Analysis of variance for each Individual Test (alpha = .01): Oxyfuel welding with filler versus oxyfuel welding without filler

Source	df	F	p
Test 1	1	0.8520	0.3613
Test 2	1	0.2483	0.6209
Test 3	1	0.1984	0.6583
Test 4	1	0.0865	0.7701
Test 5	1	4.8518	0.0332
Test 6	1	0.8009	0.3759
Test 7	1	1.4328	0.2380
Error	42	*Error term for each individual test*	

Of the seven weld characteristics evaluated, none were found to be statistically different when oxyfuel with and without filler were compared. Stage three of the analysis took into account prior welding experience to compare the overall welding scores between the two groups. First, experience is characterized as either no prior welding experience whatsoever or some type of welding experience, regardless of which process or how much time was spent on that welding process (Yes/No results). Second, prior gas metal arc welding experience is characterized as falling into one of the four aforementioned categories. Tables 7 and 8 are the results of those analyses.

Table 7 – Level 1 Analysis of Variance with Yes/No experience covariate

Source	df	F	p
Instructional Method	1	0.3923	0.5347
Experience	1	8.6164	0.0055
Instructional Method*Experience	1	3.2260	0.0800
Error	40		

The results found in Table 7 indicate that although experience is statistically significant at the 0.05 alpha level (p = 0.0055), there was insufficient evidence to suggest that instructional method is statistically significant at the 0.05 alpha level (p = 0.5347). The interaction term of Instructional Method*Experience was not found to be statistically significant at the 0.05 alpha level (p = 0.08). This means that the relationship between overall weld test performance and experience is the same regardless of which instructional method was used.

In order to account for the four experience categories, three experience covariates are constructed. Experience1 is “1” if up to 2 hours experience of gas metal arc welding and “0” otherwise. Experience2 is “1” if from 2 to 20 hours of gas metal arc welding experience and “0” otherwise. Experience3 is “1” if over 20 hours gas metal arc welding experience and “0” otherwise.

Table 8 – Level 2 Analysis of Variance with 3 experience covariates

Source	df	F	p
Instructional Method	1	0.8281	0.3689
Experience1 (up to 2 hours)	1	0.7038	0.4071
Experience2 (2-20 hours)	1	0.3296	0.5695
Experience3 (>20 hours)	1	5.2604	0.0278
Experience1*Instructional Method	1	0.0397	0.8431
Experience2*Instructional Method	1	3.7624	0.0603
Experience3*Instructional Method	1	0.2539	0.6174
Error	36		

The results of Table 8 indicate that only Experience3 (>20 hours) was significant at the 0.05 alpha level (p = 0.0278). There is insufficient evidence to suggest that there is a statistically significant difference in instructional method between those students who were first taught to oxyfuel weld with filler versus those students who were first taught to oxyfuel weld without filler material at the 0.05 alpha level (p = 0.3689). None of the interaction terms were found to be statistically significant at the 0.05 alpha level.

Discussion

The results of this study revealed that there is no statistically significant difference in gas metal arc welding skills between those students who were first taught to oxyfuel weld with filler versus those who were first taught to oxyfuel weld without filler. Seven weld characteristics were individually tested. There was insufficient evidence to suggest that the two groups differed significantly on any of the seven weld tests.

The experience covariate was incorporated into the study in two ways. The first way examined the collective experience of the participants, while the second way looked specifically at three levels of gas metal arc welding experience. Although there was insufficient evidence to suggest any statistically significant difference between the two oxyfuel groups of the study when accounting for experience, there was evidence to suggest a statistically significant effect of having over 20 hours of experience at the 0.05 alpha level. This is neither surprising nor unexpected; one would expect a welder with over 20 hours of gas metal arc welding experience to weld better than a person without 20 hours of experience.

The literature pointed to a global increase in gas metal arc welding solid wire consumption (Ref. 3). Additionally, this claim is supported by the U.S. Department of Commerce's (Ref. 7) findings that welding expenditures make up a substantial contribution to our economy, especially the labor portion, as well as a recent Wall Street Journal Online Edition (Ref. 1) citing the present welding labor shortages. These economic indicators should guide welding educators with programs that bolster the overall effectiveness of their welding programs, especially when time is critical and industry needs welders. Welding instructors are left with the responsibility to fill this void, and they are expected to do so as quickly as possible. Understanding where students struggle the most as beginners is key to streamlining the learning process.

The study revealed that although there are no significant differences between students who are taught to add filler material versus those who are not taught to add filler material, the average score of both groups on certain individual tests 3, 6, and 7—i.e., amount of undercut, number of contaminants, and visual penetration at top of weld, respectively—was much higher ($\mu = 6.62$, $s = 1.77$) than the average score of both groups on the remaining four tests ($\mu = 2.88$, $s = 2.02$). One possible reason for the difference between average scores on these specific tests is that the results from tests 3, 6, and 7 are largely dependant on correct machine setup. Given that the study was intentionally set within very tight time constraints, it allowed the researcher to evaluate very specific welding skills. Subsequent testing should incorporate an overall understanding of fusion welding by allowing students to setup their own equipment and then test.

It was noted that the study was limited to technical management students who are to have a basic understanding of arc welding. Future research in welding education for technical managers is recommended to better understand where the true differences lie when teaching different types of welding. Although this study has limited implications for welding schools (those that are preparing certified welders), the methodology of the study is well suited for future welding research. Subsequent studies of this nature should focus on longer practice times for both types of welding (oxyfuel and gas metal arc) whereby students can develop better skills and are then tested using destructive test methods, such as tensile tests or bend tests, as well as nondestructive and visual tests. Studies should be set up to effectively evaluate different aspects of the weld (height, undercut, porosity, etc) as well as strength and penetration. In doing so, researchers can better understand where beginning welders are typically stronger or where better teaching methods are required. Understanding where students struggle or do poorly can be a powerful mechanism for streamlining the initial learning of welding. As welding continues to grow both nationally and globally (Ref. 7) and more individuals choose less physically demanding jobs (Ref. 1), welding schools must be ready to teach welding in the most effective and efficient manner.

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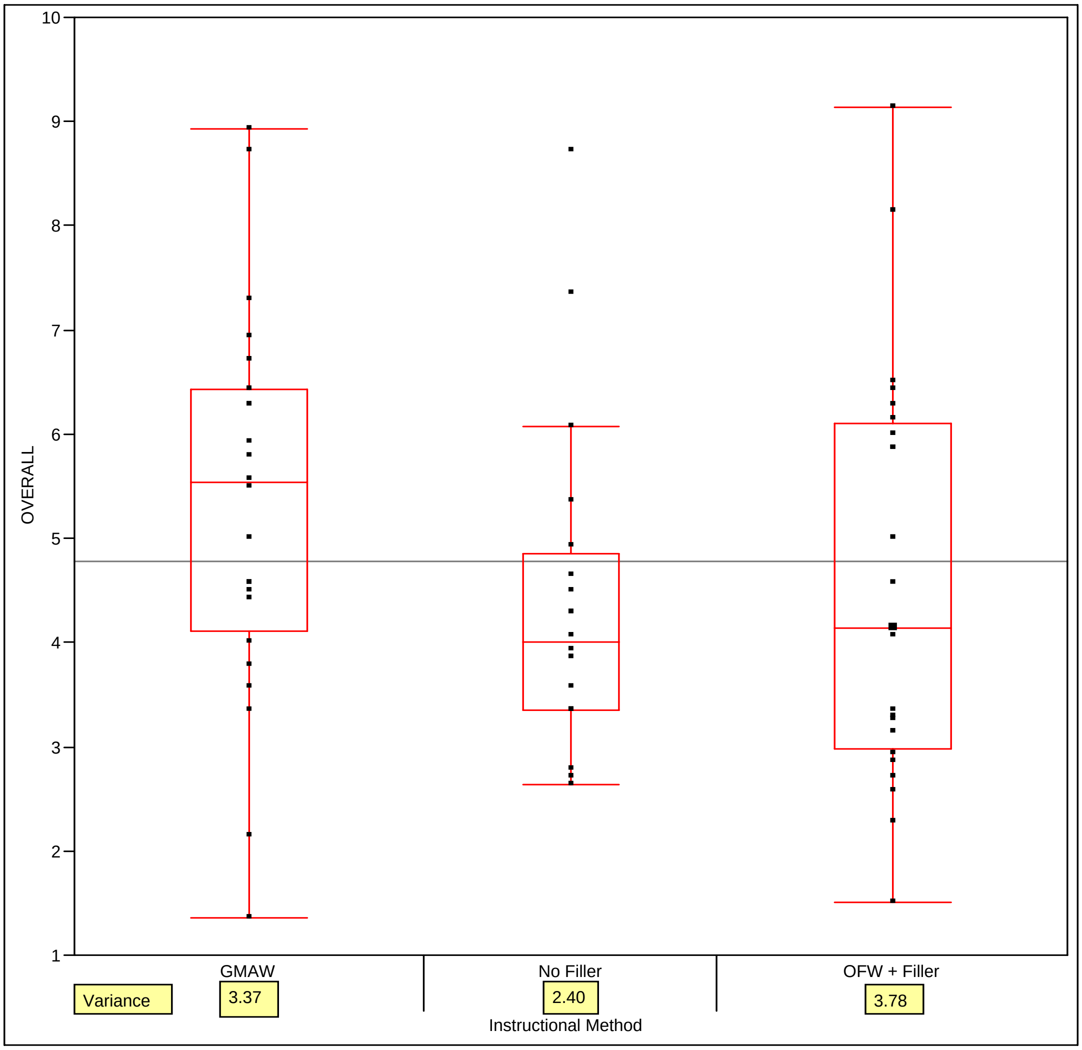
CHAPTER 5: GENERAL CONCLUSIONS

Confirmatory Data Analysis

It is useful at this time to perform confirmatory data analysis to verify the efficacy of the statistical analysis. Graphical data analyses are utilized to check for normality and equal variances of the data analyzed. Normal plots, or Normal Quantile Plots as they are called by JMP 6.0 (SAS Institute, 2005) incorporate a diagonal reference line that approximates the predicted residuals (Cobb, 1998) as well as confidence limits for those residuals (SAS Institute, 2005). Normally distributed populations will fall along a straight line. The closer the residuals fall to the straight line, the stronger the evidence of a normally distributed population. Interpretation for normality will be assumed if the residuals fall within the calculated confidence limits. Additionally, equal variance assumptions between the three groups are tested based on Johnson and Wichern's (1998) variance test of equality for unequal sample sizes. The test is that variances outside four times larger than the other should be considered serious (Johnson and Wichern, 1998). Figure 1 below is a distribution of the entire data set.

Figure 1

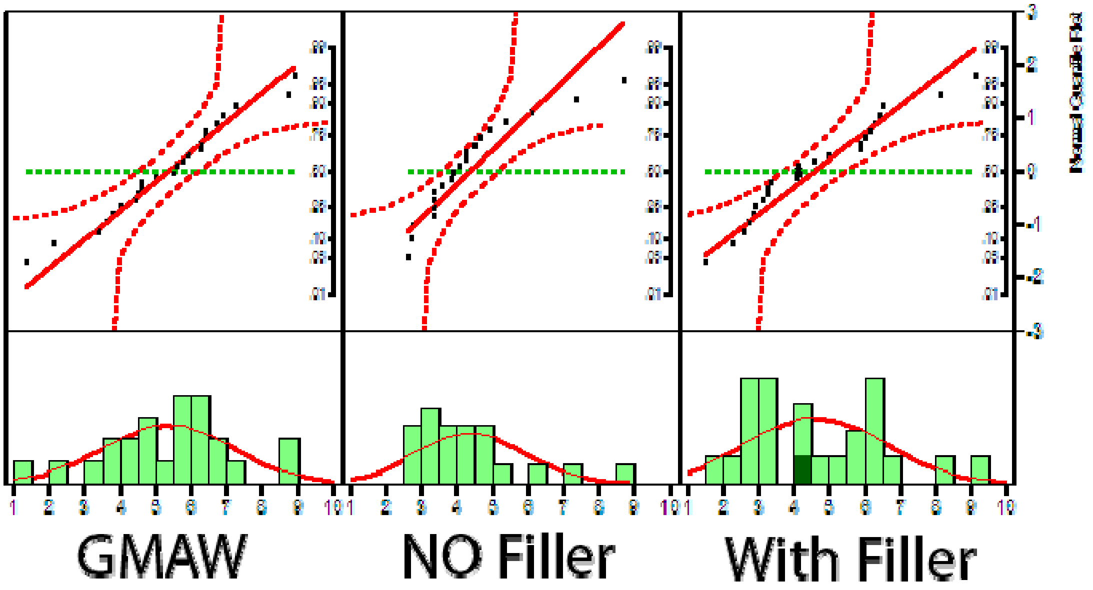
Quantile Box Plots for the three groups



Given that none of the variances are more than four times larger than the others, it is reasonable to conclude that the equal variance assumption is satisfied (Johnson and Wichern, 1998). Figure 2 below is the data distribution for the three groups with the residuals plotted for each group.

Figure 2

Histograms and normal quantile plots for the three groups



If one starts from the premise that these data are normally distributed and examines the probability plots as described above, there would be insufficient evidence to suggest that these data are not normally distributed. However, the oxyfuel group without filler appears to have a curved line of fit even though the data points remain within the confidence limits of the quantile plot. A Shapiro-Wilk W [Goodness of Fit] test for samples sizes less than 2000 (SAS Institute, 2005) was run on the “NO Filler” histogram that indicated a potential curvilinear fit of the data at the 0.05 alpha level ($p = 0.0068$). The Shapiro-Wilk W test was then run again with the highest extreme point in the “NO Filler” excluded from the analysis. Without the highest extreme point, there was insufficient evidence to suggest data with a nonnormal distribution at the 0.05 alpha level ($p = 0.0721$). A closer look at the individual data point (JMP data table row 32 – See **APPENDIX D – RAW DATA**) revealed that the individual had over twenty hours of experience in gas metal arc welding with the most recent experience being three or four months before the experiment. Given that each group had one or two individuals with the same experience and high scores, the decision was made to keep all the data.

Conclusions

The research questions posed by this study were:

Research Question 1

Does teaching the manipulative skills of oxyfuel welding with filler enhance beginning gas metal arc welding skills?

There was no statistically significant difference (alpha = 0.05) between those students who were taught to oxyfuel weld with filler versus those students who were not taught to oxyfuel weld. Additionally, there was no statistically significant difference (alpha = 0.01) in the seven individual weld characteristic tests between the two groups.

Research Question 2

Does teaching the manipulative skills of oxyfuel welding without filler enhance beginning gas metal arc welding skills?

There was no statistically significant differences (alpha = 0.05) between those students who were taught to oxyfuel weld with filler versus those students who were not taught to oxyfuel weld. There was evidence to suggest that individual weld characteristic Test 1 (weld height) and Test 5 (contour) were significant at the 0.01 alpha level ($p = 0.0056$ and $p = 0.0029$, respectively). That is, students who were not taught any oxyfuel welding performed better on Test 1 and Test 5 versus those students who were taught to oxyfuel weld without filler.

Research Question 3

Is there a statistically significant difference in gas metal arc welding skills between those students who were taught to oxyfuel weld with filler versus those students who were taught to oxyfuel weld without filler?

There was no statistically significant difference (alpha = 0.05) between those students who were taught to oxyfuel weld with filler versus those students who were taught to oxyfuel weld without filler. Additionally, there was no statistically significant differences (alpha = 0.01) in the seven individual weld characteristic tests between the two groups.

Further consideration of the experience covariate revealed that although experience is significant (at the 0.05 alpha level), instructional method is not significant at the 0.05 alpha level.

Research Question 4

Is there a statistically significant difference in gas metal arc welding skills between students who were taught how to oxyfuel weld (with or without filler) versus those students who were not taught any oxyfuel welding?

There was no statistically significant difference (alpha = 0.05) between those students who were taught to oxyfuel weld (with or without filler) versus those students who were not taught to oxyfuel weld. There was evidence to suggest that the individual weld characteristic Test 1 (weld height) was significant at the 0.01 alpha level ($p = 0.008$). That is, students who were not taught any oxyfuel welding performed better on Test 1 versus those students who were taught to oxyfuel weld.

Research Question 5

Is there a difference in the aggregate economic factors between oxyacetylene and gas metal arc welding that would lend one a preferred teaching selection over the other by industrial technology four-year programs?

The cost of equipment for both oxyfuel and gas metal arc welding was reviewed. One can argue that oxyfuel welding equipment is significantly less expensive, but the cost of the equipment versus the time students spend creating and moving puddles is generally ignored. Based on the material thickness and travel speed time figures presented in the literature review, a student using gas metal arc welding can weld over seven times the amount of linear distance than a student oxyfuel welding (Althouse, et al, 2003; AWS, 2004). These numbers are conservative given that they do not include learning curves for understanding how to properly light and adjust a torch, notwithstanding the coordination required to add filler material with a second hand. Generally speaking, welding schools no longer teach oxyfuel welding as an individual welding component, but rather incorporate it into a cutting and brazing program.

The results of this research revealed that there is no statistically significant difference in arc welding skills between those students who were first taught to oxyfuel weld versus those who were not taught to oxyfuel weld. There was evidence to suggest that several individual tests were significant at the 0.01 alpha level. This significance was found only when comparing students who were taught to oxyfuel weld without filler versus those students who were not taught to oxyfuel weld (students who were only taught gas metal arc welding). There was not enough evidence to suggest that students who were taught to oxyfuel weld with filler material performed significantly different than those who were not taught to oxyfuel weld (students who were only taught gas metal arc welding).

The study suggests that teaching oxyfuel with filler material has a positive effect on certain welding skills. Weld height and contour (Tests 1 and 5, respectively) were found to be significantly different (alpha = 0.01) when the oxyfuel groups were separated. One potential reason is that students who were taught to incorporate with filler material, even at a limited amount of welding time, had more of a weld puddle to work with, however, this is only speculation.

The line graph of the mean overall scores of all three groups showed better performance, on average, on certain tests. For instance, students performed better on Test 3, Test 6, and Test 7 (amount of undercut, number of contaminants, and visual penetration at top of weld, respectively) than they did on the remainder of the four tests. One possible reason for these specific tests being better is that they are largely dependant on correct machine setup. Given that the experiment was intentionally set within very tight time constraints, it allowed the researcher to evaluate very specific welding skills. Subsequent testing should incorporate an overall understanding of fusion welding by allowing students to set up their own equipment and then test.

Under the conditions of this research, the outcomes did not support Sosnin's (1982) assertion that students will learn to weld other processes better and faster if they were first taught to oxyfuel. To that end, recommendations are presented in support of an industrial technology welding curriculum without the use of oxyfuel welding when time is a critical factor. It should be noted that these recommendations are for industrial technology programs whose main focus is technology management, not welding. Further research is needed to extrapolate the results of this research to other programs. The outcome of the research does not impede and should not impact the importance of learning oxyfuel welding when gas tungsten arc welding or oxyfuel welding and cutting will be a significant skill set the student will learn for his or her profession.

The literature pointed to a global increase in gas metal arc welding solid wire consumption (Pekkari, 2000). This was further supported by the U. S. Department of Commerce's (2002) findings that welding expenditures make up a substantial contribution to our economy, especially the labor portion, as well as a recent Wall Street Journal Online Edition (2006) citing the present welding labor shortages. These economic indicators, coupled with the time a student can spend learning arc welding skills, call for efficient and effective instructional methodologies when time is limited.

Future research in welding education is recommended to better understand where the true differences in learning each type of welding exist. This study indicated that those who were taught to gas metal arc weld only performed better on welding height, but why? Subsequent studies should focus on longer practice time for both types of welding whereby true welding skills are developed and then tested using both destructive test methods, such as tensile tests or bend tests, as well as nondestructive and visual tests. Destructive testing in combination with nondestructive testing, such as x-ray or magnetic particle testing, could improve teaching methods of welding instructors by pointing them to general weakness areas of beginner students. Experiments should be set up to effectively evaluate different aspects of the weld (height, undercut, porosity, etc) as well as strength and penetration. One suggestion to validate the findings of this research would be to increase the sample size of the groups and perform multiple tests on students as more practice is given to improve their skills. The research should also include other industrial technology schools. In doing so, researchers can better understand where beginning welders are typically stronger or where better teaching methods are required. Understanding where students struggle can be a powerful mechanism for streamlining the initial learning of welding. Industrial technology could benefit in terms of time and program effectiveness by teaching welding more efficiently within the time constraints of teaching industrial technology students.

Finally, an article written by Litowitz (2002) entitled, When Did Shop Become a Four-letter Word, describes events in the 20th century that led society away from vocational careers, trivializing shop and the industrial arts. He writes:

> Given the limited time students have in school, the resources that schools have available, society's perception of the level at which career preparation should occur, and the literacy it will take to function today, shop does not appear to be part of the solution (Litowitz, 2002, p. 13).

Amid these comments, manufacturers are desperately looking for skilled workers (Brat, 2006), the gas metal arc welding industry continues to expand (Pekkari 2000; U. S. Department of Commerce, 2002), and shop classes have become more about hobbies rather than industry (Litowitz, 2002). Technology programs, in particular those with welding, must have students and industry in mind – this means that gas metal arc welding is a critical component of the industrial technology curriculum.

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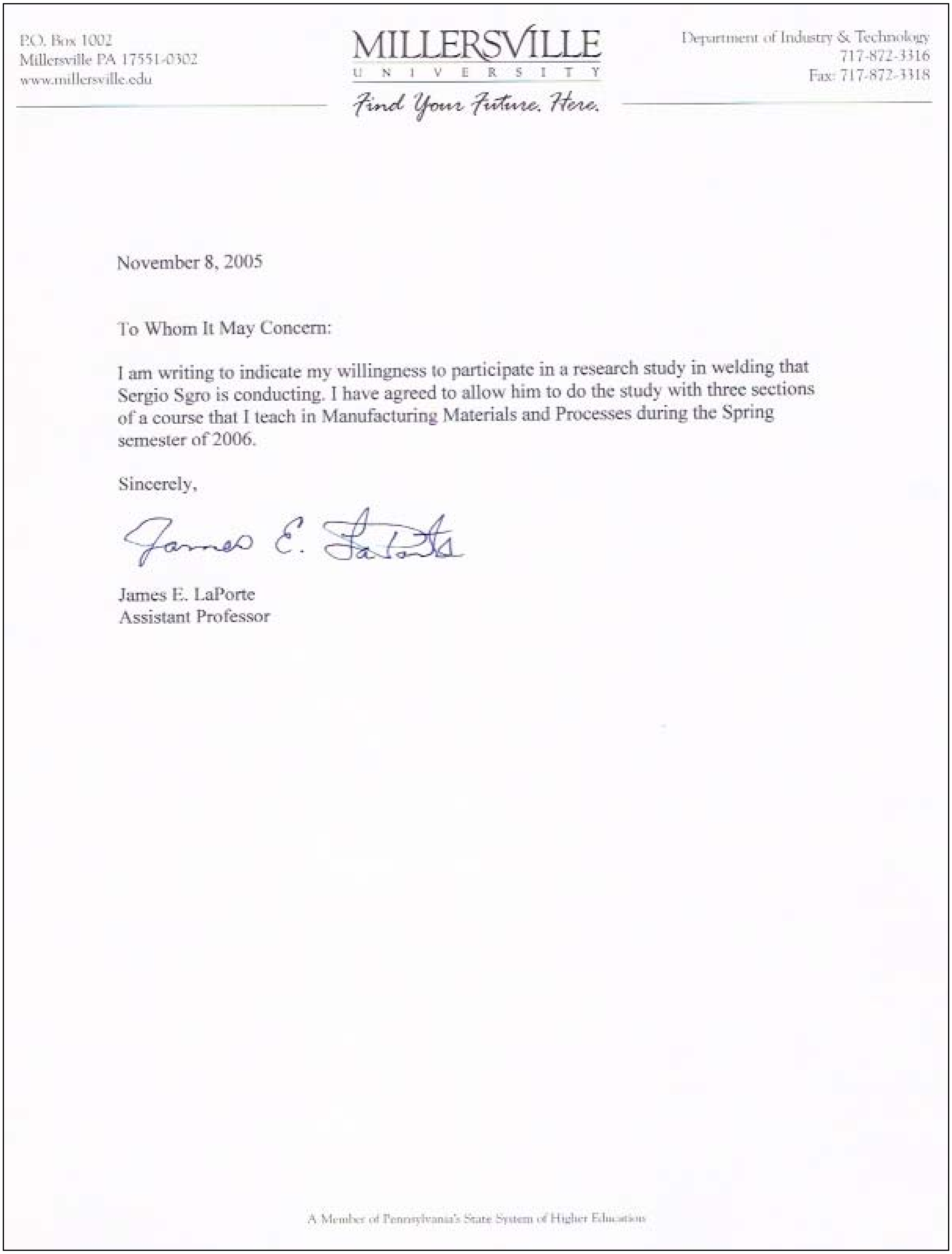
APPENDIX A: MILLERSVILLE UNIVERSITY CONSENT FORM



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November 8, 2005

To Whom It May Concern:

I am writing to indicate my willingness to participate in a research study in welding that Sergio Sgro is conducting. I have agreed to allow him to do the study with three sections of a course that I teach in Manufacturing Materials and Processes during the Spring semester of 2006.

Sincerely,

James E. LaPorte

James E. LaPorte
Assistant Professor

A Member of Pennsylvania's State System of Higher Education

APPENDIX B: DEMOGRAPHIC SURVEY

ITEC 130 - Welding Research Questionnaire

1 Class Rank Freshman Sophomore Junior Senior Graduate

2 Gender: Male Female

3 Do you have any experience in welding whatsoever? Yes No
(If not, you are finished with this questionnaire and may submit it at this time.)

4 What type of welding have you previously performed and for how long? (Circle all that apply)

Oxyacetylene Welding (Not cutting)	Less than 2 hours	2-20 hours	Greater than 20 hours
Shielded Metal Arc Welding - "Stick Welding"	Less than 2 hours	2-20 hours	Greater than 20 hours
Gas Metal Arc Welding - "MIG Welding"	Less than 2 hours	2-20 hours	Greater than 20 hours
Gas Tungsten Arc Welding - "TIG Welding"	Less than 2 hours	2-20 hours	Greater than 20 hours
Other (Please Specify)______________________	Less than 2 hours	2-20 hours	Greater than 20 hours

5 Where did you learn and/or have experience welding? (Circle all that apply)

High School
Trade School
Community College
Another University
Farm/Family Farm
On the Job
Home/Garage
Other (Please Specify) ______________________________

6 How long has it been since the last time you welded? (# of days/weeks/years/etc)______________________________

-End of Questionnaire-

APPENDIX C: VISUAL INSPECTION RUBRIC

Visual Inspection Rubric

Points allotted should indicate competency as a percentage of the overall weld. For example, if only about 30% of the weld has correct height (sequentially or sporadically), than a 3 should be assigned.

1) Size – Weld Height

1 2 3 4 5 6 7 8 9 10

(Poor: 0-10% OK) - - - - - - (50% OK) - - - - - - - - - - - - - - (Excellent - > 90 % proficiency)

2) Size – Weld Width

1 2 3 4 5 6 7 8 9 10

(Poor: 0-10% OK) - - - - - - (50% OK) - - - - - - - - - - - - - -(Excellent - > 90 % proficiency)

3) Undercut

1 2 3 4 5 6 7 8 9 10

(Poor: 0-10% OK) - - - - - - (50% OK) - - - - - - - - - - - - - -(Excellent - > 90 % proficiency)

4) Uniformity of weld

1 2 3 4 5 6 7 8 9 10

(Poor: 0-10% OK) - - - - - - (50% OK) - - - - - - - - - - - - - -(Excellent - > 90 % proficiency)

5) Proper Contour

1 2 3 4 5 6 7 8 9 10

(Poor: 0-10% OK) - - - - - - (50% OK) - - - - - - - - - - - - - -(Excellent - > 90 % proficiency)

6) Surface contaminants (1 indicates a lot of contaminant, 10 is no contaminants)

1 2 3 4 5 6 7 8 9 10

(Poor: 0-10% OK) - - - - - - (50% OK) - - - - - - - - - - - - - -(Excellent - > 90 % proficiency)

7) Penetration at top

1 2 3 4 5 6 7 8 9 10

(Poor: 0-10% OK) - - - - - - (50% OK) - - - - - - - - - - - - - -(Excellent - > 90 % proficiency)

APPENDIX D: RAW DATA

Instructional Method	WeldingType	ID	Run Order	Class Rank	Gender	Experience
OFW + Filler	OFW	A	17	Junior	Male	Yes
OFW + Filler	OFW	B	6	Sophomore	Male	Yes
OFW + Filler	OFW	D	4	Freshman	Male	No
OFW + Filler	OFW	E	7	Freshman	Male	No
OFW + Filler	OFW	F	16	Freshman	Male	No
OFW + Filler	OFW	G	10	Junior	Male	Yes
OFW + Filler	OFW	H	19	Junior	Male	No
OFW + Filler	OFW	I	23	Freshman	Male	No
OFW + Filler	OFW	J	22	Freshman	Female	Yes
OFW + Filler	OFW	K	11	Junior	Male	No
OFW + Filler	OFW	L	12	Junior	Male	No
OFW + Filler	OFW	M	20	Freshman	Male	Yes
OFW + Filler	OFW	N	1	Junior	Male	No
OFW + Filler	OFW	O	2	Junior	Male	No
OFW + Filler	OFW	P	13	Junior	Male	Yes
OFW + Filler	OFW	Q	14	Freshman	Male	Yes
OFW + Filler	OFW	R	18	Freshman	Male	No
OFW + Filler	OFW	S	8	Freshman	Male	Yes
OFW + Filler	OFW	T	25	Freshman	Male	No
OFW + Filler	OFW	U	3	Freshman	Male	No
OFW + Filler	OFW	V	9	Sophomore	Male	Yes
OFW + Filler	OFW	W	21	Junior	Female	No
OFW + Filler	OFW	X	15	Sophomore	Male	Yes
OFW + Filler	OFW	Y	5	Freshman	Male	Yes
No Filler	OFW	A	9	Freshman	Male	Yes
No Filler	OFW	B	18	Freshman	Male	No
No Filler	OFW	C	4	Senior	Male	No
No Filler	OFW	D	6	Sophomore	Female	No
No Filler	OFW	E	8	Freshman	Male	Yes
No Filler	OFW	F	10	Freshman	Male	Yes
No Filler	OFW	I	20	Freshman	Male	No
No Filler	OFW	J	11	Freshman	Male	Yes
No Filler	OFW	K	3	Freshman	Male	Yes
No Filler	OFW	L	5	Freshman	Male	Yes
No Filler	OFW	M	14	Sophomore	Male	Yes
No Filler	OFW	N	7	Junior	Male	Yes
No Filler	OFW	O	15	Freshman	Male	No
No Filler	OFW	P	16	Freshman	Male	No
No Filler	OFW	R	13	Freshman	Male	No
No Filler	OFW	S	12	Sophomore	Male	No
No Filler	OFW	T	23	Sophomore	Male	No
No Filler	OFW	U	21	Freshman	Male	Yes
No Filler	OFW	V	17	Sophomore	Male	No
No Filler	OFW	W	2	Junior	Male	No
GMAW	GMAW	A	16	Freshman	Male	No
GMAW	GMAW	B	14	Freshman	Male	No
GMAW	GMAW	C	9	Sophomre	Male	Yes
GMAW	GMAW	D	6	Senior	Female	No
GMAW	GMAW	E	8	Freshman	Male	No
GMAW	GMAW	F	12	Junior	Male	Yes
GMAW	GMAW	G	15	Freshman	Male	No
GMAW	GMAW	H	21	Freshman	Male	Yes
GMAW	GMAW	I	17	Sophomore	Male	No
GMAW	GMAW	J	4	Freshman	Male	Yes
GMAW	GMAW	K	7	Freshman	Male	Yes
GMAW	GMAW	L	20	Freshman	Male	No
GMAW	GMAW	M	2	Freshman	Male	Yes
GMAW	GMAW	N	18	Freshman	Male	Yes
GMAW	GMAW	O	3	Freshman	Male	No
GMAW	GMAW	P	22	Junior	Male	No
GMAW	GMAW	Q	13	Junior	Male	No
GMAW	GMAW	R	10	Graduate	Male	Yes
GMAW	GMAW	S	23	Freshman	Male	Yes
GMAW	GMAW	T	25	Freshman	Male	No
GMAW	GMAW	U	11	Freshman	Male	No
GMAW	GMAW	V	5	Junior	Male	No
GMAW	GMAW	W	19	Freshman	Male	No
GMAW	GMAW	Y	1	Freshman	Male	No

Experience-numeric	OFW	SMAW	GMAW	Experience1	Experience2	Experience3	GTAW
1	2	2	2	0	1	0	1
1	2	2	3	0	0	1	2
0			0	0	0	0	
0			0	0	0	0	
0			0	0	0	0	
1	0	0	1	1	0	0	0
0			0	0	0	0	
0			0	0	0	0	
1	0	1	0	0	0	0	0
0			0	0	0	0	
0			0	0	0	0	
1	0	0	0	0	0	0	0
0			0	0	0	0	
0			0	0	0	0	
1	1	2	3	0	0	1	1
1	0	0	2	0	1	0	0
0			0	0	0	0	
1	2	2	2	0	1	0	1
0			0	0	0	0	
0			0	0	0	0	
1	0	2	2	0	1	0	0
0			0	0	0	0	
1	2	2	0	0	0	0	0
1	0	2	0	0	0	0	0
1	0	1	0	0	0	0	1
0			0	0	0	0	
0			0	0	0	0	
0			0	0	0	0	
1	1	0	1	1	0	0	0
1	1	2	1	1	0	0	0
0			0	0	0	0	
1	2	2	3	0	0	1	1
1	1	0	2	0	1	0	0
1	1	2	3	0	0	1	2
1	2	3	3	0	0	1	3
1	0	0	1	1	0	0	0
0			0	0	0	0	
0			0	0	0	0	
0			0	0	0	0	
0			0	0	0	0	
0			0	0	0	0	
1	0	3	3	0	0	1	3
0			0	0	0	0	
0			0	0	0	0	
0			0	0	0	0	
0			0	0	0	0	
1	1	2	1	1	0	0	1
0			0	0	0	0	
0			0	0	0	0	
1	1	2	0	0	0	0	0
0			0	0	0	0	
1	2	1	1	1	0	0	1
0			0	0	0	0	
1	0	0	2	0	1	0	0
1	0	1	1	1	0	0	1
0			0	0	0	0	
1	2	2	2	0	1	0	1
1	0	0	2	0	1	0	0
0			0	0	0	0	
0			0	0	0	0	
0			0	0	0	0	
1	1	0	0	0	0	0	0
1	1	3	3	0	0	1	3
0			0	0	0	0	
0			0	0	0	0	
0			0	0	0	0	
0			0	0	0	0	
0			0	0	0	0	

Other Welding	Where	Time Since Last	Eval1_1	Eval1_2	Eval1_3	Eval1_4	Eval1_5
1	High School	4 years	1	1	3	2	2
0	Various	6 weeks	5	5	7	5	5
			3	2.62	5	3	1
			1	1	9	2	1
			1	1	9	1	1
0	Home/Gar	3 years	1	1	9	8	4
			8	4	9	9	8
			1	1	5	1	2
0	Home/Gar	Not sure	1	1	8	1	1
			1	1	1	1	1
			7	1	8	7	6
1	High School		8	8	8	7	7
			1	1	9	7	1
			5	4	8	1	1
0	Home/Gar	3 weeks	10	9	9	8	7
0	High School	1 year	8	1	9	8	8
			3	1	8	5	1
0	High School	1 year	1	10	10	8	5
			9	1	5	7	6
			2	1	9	1	1
0	Various	1 year	8	10	9	9	9
			1	1	1	1	1
0	Various	2 years	8	1	10	6	7
0	Various	2 years	10	8	2	8	8
0	Various	2 years	2	2	1	2	1
			1	1	6	7	2
			2	5	5	2	1
			3	3	7	5	1
0	Various	4 years	3	5	8	7	2
0	High School	1 year	2	1	4	5	1
			7	7	8	4	1
0	Various	3 months	9	10	9	9	7
0	High School	2 years	2	2	7	2	1
1	High School	1 year	2	1	9	2	2
0	Various	1 year	9	1	9	7	1
0	Home/Gar	8 months	7	7	9	8	2
			1	1	1	2	1
			10	10	10	10	1
			1	1	1	2	1
			2	4	5	4	2
			1	1	7	3	1
0	Various	1.5 years	2	7	7	3	1
			1	1	1	1	1
			3	2	3	4	1
			5	5	3	4	4
			6	4	4	3	5
0	High School	2.5 years	9	4	7	4	4
			2	1	1	3	3
			3	3	3	3	3
0	On the job	4 months	1	3	6	4	2
			5	8	9	8	7
0	Various	7 months	2	1	8	7	3
			7	2	10	9	2
0	Home/Gar	3 months	7	8	9	8	5
0	High School	1 year	7	1	8	6	4
			5	6	6	6	5
0	Various	1 year	8	8	8	7	3
0	Home/Gar	1 week	10	9	8	9	5
			1	1	1	1	1
			8	9	8	8	5
			8	8	9	8	4
0	On the job	3 months	10	1	4	7	3
0	Various	1 day	9	10	9	9	9
			2	2	8	2	1
			7	7	6	5	3
			1	1	1	1	1
			2	1	6	5	2
			3	3	6	6	5

Eval1_6	Eval1_7	Eval2_1	Eval2_2	Eval2_3	Eval2_4	Eval2_5	Eval2_6	Eval2_7
10	9	1	1	8	1	2	9	8
5	4	3	2	5	1	2	5	4
7	2	1	1	8	1	1	8	2
9	8	2	1	8	1	1	9	4
9	1	1	1	9	1	1	2	2
9	9	1	1	8	1	1	9	8
9	7	4	2	8	1	2	9	8
9	1	1	1	5	1	1	8	1
2	2	1	1	5	1	1	10	1
1	1	1	1	8	1	1	1	1
4	6	4	2	7	1	1	5	5
9	8	5	3	8	1	1	9	8
6	1	1	1	8	1	1	5	1
4	1	1	1	5	1	1	5	3
10	10	7	6	10	5	4	10	9
10	9	5	1	9	4	1	9	9
8	3	2	1	7	1	1	1	5
10	1	3	3	9	5	3	9	5
8	9	5	1	9	5	3	5	9
1	2	1	1	8	1	1	1	2
10	8	9	9	9	9	9	10	10
10	5	2	1	7	1	1	9	5
10	9	2	1	9	2	2	9	8
9	9	2	3	8	1	1	9	8
6	6	1	1	9	1	1	5	9
6	7	1	1	9	1	1	8	9
3	2	1	1	8	1	1	1	4
8	7	1	2	8	1	1	8	8
8	3	3	2	8	2	1	8	5
3	8	1	1	9	1	1	1	9
9	8	2	2	9	1	1	8	8
10	9	8	8	9	8	8	9	9
6	3	1	1	8	1	1	1	2
8	2	5	4	9	5	2	7	2
9	9	1	1	8	2	1	5	6
9	7	5	5	9	3	4	5	5
7	9	1	1	8	1	1	5	8
10	10	5	5	9	4	3	9	7
5	1	1	1	9	1	1	5	9
8	2	2	3	8	2	2	8	5
9	7	1	1	8	1	1	8	6
5	7	1	2	8	2	1	2	6
8	8	1	1	9	1	1	8	8
4	2	1	1	8	1	1	8	8
9	7	5	5	8	3	3	8	8
9	8	5	3	7	5	3	8	8
9	7	5	3	8	5	5	10	8
4	5	9	1	6	5	3	2	8
8	7	3	2	6	3	1	9	8
9	2	2	2	8	2	3	7	5
9	8	5	4	5	2	3	9	8
9	2	5	1	5	3	3	10	5
9	8	5	2	9	5	1	10	9
9	8	5	3	8	2	2	9	7
7	7	2	1	8	1	1	9	8
9	7	5	1	5	1	1	1	5
9	8	7	5	8	5	3	10	5
10	10	9	8	9	8	8	10	9
5	2	1	1	8	1	1	5	1
9	9	5	5	9	5	5	8	9
9	9	5	5	8	3	3	10	8
9	10	5	3	6	5	2	10	8
10	9	9	8	8	8	9	9	9
7	7	1	1	5	1	1	7	5
7	7	2	2	5	1	1	6	5
2	2	1	1	4	1	1	1	1
8	2	1	1	5	1	1	9	3
9	6	6	5	8	5	3	8	8

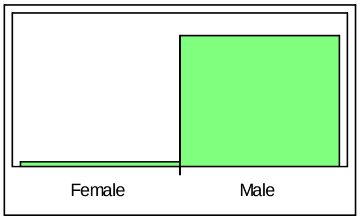
Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Eval1-Mean	Eval2-Mean
1	1	5.5	1.5	2	9.5	8.5	4.00	4.29
4	3.5	6	3	3.5	5	4	5.14	3.14
2	1.81	6.5	2	1	7.5	2	3.37	3.14
1.5	1	8.5	1.5	1	9	6	4.43	3.71
1	1	9	1	1	5.5	1.5	3.29	2.43
1	1	8.5	4.5	2.5	9	8.5	5.86	4.14
6	3	8.5	5	5	9	7.5	7.71	4.86
1	1	5	1	1.5	8.5	1	2.86	2.57
1	1	6.5	1	1	6	1.5	2.29	2.86
1	1	4.5	1	1	1	1	1.00	2.00
5.5	1.5	7.5	4	3.5	4.5	5.5	5.57	3.57
6.5	5.5	8	4	4	9	8	7.86	5.00
1	1	8.5	4	1	5.5	1	3.71	2.57
3	2.5	6.5	1	1	4.5	2	3.43	2.43
8.5	7.5	9.5	6.5	5.5	10	9.5	9.00	7.29
6.5	1	9	6	4.5	9.5	9	7.57	5.43
2.5	1	7.5	3	1	4.5	4	4.14	2.57
2	6.5	9.5	6.5	4	9.5	3	6.43	5.29
7	1	7	6	4.5	6.5	9	6.43	5.29
1.5	1	8.5	1	1	1	2	2.43	2.14
8.5	9.5	9	9	9	10	9	9.00	9.29
1.5	1	4	1	1	9.5	5	2.86	3.71
5	1	9.5	4	4.5	9.5	8.5	7.29	4.71
6	5.5	5	4.5	4.5	9	8.5	7.71	4.57
1.5	1.5	5	1.5	1	5.5	7.5	2.86	3.86
1	1	7.5	4	1.5	7	8	4.29	4.29
1.5	3	6.5	1.5	1	2	3	2.86	2.43
2	2.5	7.5	3	1	8	7.5	4.86	4.14
3	3.5	8	4.5	1.5	8	4	5.14	4.14
1.5	1	6.5	3	1	2	8.5	3.43	3.29
4.5	4.5	8.5	2.5	1	8.5	8	6.29	4.43
8.5	9	9	8.5	7.5	9.5	9	9.00	8.43
1.5	1.5	7.5	1.5	1	3.5	2.5	3.29	2.14
3.5	2.5	9	3.5	2	7.5	2	3.71	4.86
5	1	8.5	4.5	1	7	7.5	6.43	3.43
6	6	9	5.5	3	7	6	7.00	5.14
1	1	4.5	1.5	1	6	8.5	3.14	3.57
7.5	7.5	9.5	7	2	9.5	8.5	8.71	6.00
1	1	5	1.5	1	5	5	1.71	3.86
2	3.5	6.5	3	2	8	3.5	3.86	4.29
1	1	7.5	2	1	8.5	6.5	4.14	3.71
1.5	4.5	7.5	2.5	1	3.5	6.5	4.57	3.14
1	1	5	1	1	8	8	3.00	4.14
2	1.5	5.5	2.5	1	6	5	2.71	4.00
5	5	5.5	3.5	3.5	8.5	7.5	5.29	5.71
5.5	3.5	5.5	4	4	8.5	8	5.57	5.57
7	3.5	7.5	4.5	4.5	9.5	7.5	6.29	6.29
5.5	1	3.5	4	3	3	6.5	2.71	4.86
3	2.5	4.5	3	2	8.5	7.5	4.29	4.57
1.5	2.5	7	3	2.5	8	3.5	3.86	4.14
5	6	7	5	5	9	8	7.71	5.14
3.5	1	6.5	5	3	9.5	3.5	4.57	4.57
6	2	9.5	7	1.5	9.5	8.5	6.71	5.86
6	5.5	8.5	5	3.5	9	7.5	7.71	5.14
4.5	1	8	3.5	2.5	8	7.5	5.71	4.29
5	3.5	5.5	3.5	3	5	6	6.29	2.71
7.5	6.5	8	6	3	9.5	6.5	7.29	6.14
9.5	8.5	8.5	8.5	6.5	10	9.5	8.71	8.71
1	1	4.5	1	1	5	1.5	1.71	2.57
6.5	7	8.5	6.5	5	8.5	9	8.00	6.57
6.5	6.5	8.5	5.5	3.5	9.5	8.5	7.86	6.00
7.5	2	5	6	2.5	9.5	9	6.29	5.57
9	9	8.5	8.5	9	9.5	9	9.29	8.57
1.5	1.5	6.5	1.5	1	7	6	4.14	3.00
4.5	4.5	5.5	3	2	6.5	6	6.00	3.14
1	1	2.5	1	1	1.5	1.5	1.29	1.43
1.5	1	5.5	3	1.5	8.5	2.5	3.71	3.00
4.5	4	7	5.5	4	8.5	7	5.43	6.14

Evaluator Range	OVERALL	Residuals Test 1	Total Score	TotalYrsExperience
-0.29	4.14	-3.76	29	8
2.00	4.14	-0.76	29	9
0.23	3.26	-1.10	22.81	
0.71	4.07	-1.60	28.5	
0.86	2.86	-2.10	20	
1.71	5.00	-3.76	35	1
2.86	6.29	2.90	44	
0.29	2.71	-2.10	19	
-0.57	2.57	-3.76	18	1
-1.00	1.50	-2.10	10.5	
2.00	4.57	2.40	32	
2.86	6.43	1.74	45	1
1.14	3.14	-2.10	22	
1.00	2.93	-0.10	20.5	
1.71	8.14	3.74	57	7
2.14	6.50	1.74	45.5	2
1.57	3.36	-0.60	23.5	
1.14	5.86	-2.76	41	7
1.14	5.86	3.90	41	
0.29	2.29	-1.60	16	
-0.29	9.14	3.74	64	4
-0.86	3.29	-1.60	23	
2.57	6.00	0.24	42	4
3.14	6.14	1.24	43	2
-1.00	3.36	-3.26	23.5	2
0.00	4.29	-2.10	30	
0.43	2.64	-1.60	18.5	
0.71	4.50	-1.10	31.5	
1.00	4.64	-1.76	32.5	2
0.14	3.36	-3.26	23.5	4
1.86	5.36	1.40	37.5	
0.57	8.71	3.74	61	8
1.14	2.71	-3.26	19	3
-1.14	4.29	-1.26	30	9
3.00	4.93	0.24	34.5	11
1.86	6.07	1.24	42.5	1
-0.43	3.36	-2.10	23.5	
2.71	7.36	4.40	51.5	
-2.14	2.79	-2.10	19.5	
-0.43	4.07	-1.10	28.5	
0.43	3.93	-2.10	27.5	
1.43	3.86	-3.26	27	9
-1.14	3.57	-2.10	25	
-1.29	3.36	-1.10	23.5	
-0.43	5.50	1.90	38.5	
0.00	5.57	2.40	39	
0.00	6.29	2.24	44	5
-2.14	3.79	2.40	26.5	
-0.29	4.43	-0.10	31	
-0.29	4.00	-3.26	28	3
2.57	6.43	1.90	45	
0.00	4.57	-1.26	32	5
0.86	6.29	2.90	44	
2.57	6.43	1.24	45	2
1.43	5.00	-0.26	35	3
3.57	4.50	1.90	31.5	
1.14	6.71	2.74	47	7
0.00	8.71	4.74	61	2
-0.86	2.14	-2.10	15	
1.43	7.29	3.40	51	
1.86	6.93	3.40	48.5	
0.71	5.93	2.74	41.5	1
0.71	8.93	4.24	62.5	10
1.14	3.57	-1.60	25	
2.86	4.57	1.40	32	
-0.14	1.36	-2.10	9.5	
0.71	3.36	-1.60	23.5	
-0.71	5.79	1.40	40.5	

APPENDIX E: JMP OUTPUT

Distributions Instructional Method=GMAW

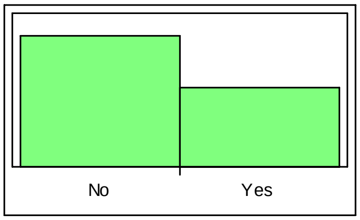
Gender



Frequencies

```
Level       Count     Prob
Female          1  0.04167
Male           23  0.95833
Total          24  1.00000
N Missing       0
     2 Levels
```

Experience

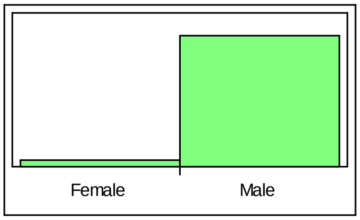


Frequencies

```
Level       Count     Prob
No             15  0.62500
Yes             9  0.37500
Total          24  1.00000
N Missing       0
     2 Levels
```

Distributions Instructional Method=No Filler

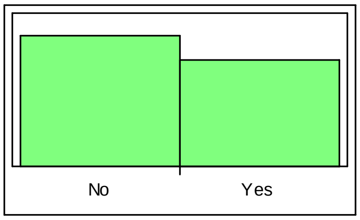
Gender



Frequencies

```
Level       Count     Prob
Female          1  0.05000
Male           19  0.95000
Total          20  1.00000
N Missing       0
     2 Levels
```

Experience

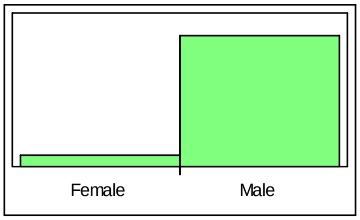


Frequencies

```
Level       Count     Prob
No             11  0.55000
Yes             9  0.45000
Total          20  1.00000
N Missing       0
     2 Levels
```

Distributions Instructional Method=OFW + Filler

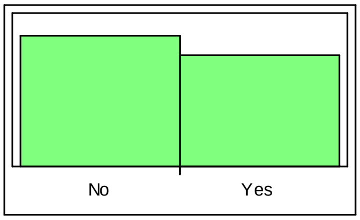
Gender



Frequencies

```
Level       Count     Prob
Female          2  0.08333
Male           22  0.91667
Total          24  1.00000
N Missing       0
     2 Levels
```

Experience



Frequencies

```
Level       Count     Prob
No             13  0.54167
Yes            11  0.45833
Total          24  1.00000
N Missing       0
     2 Levels
```

Manova Fit Experience=No

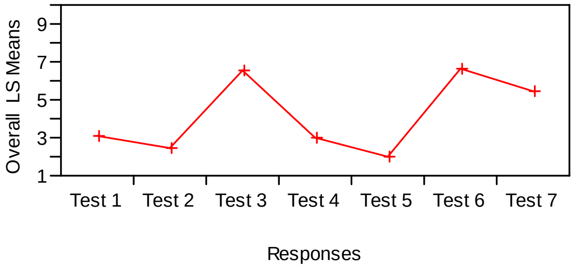
N	39
DFE	36

Parameter Estimates

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
Intercept	3.0048174	2.40111111	6.56231546	2.96829837	1.92276612	6.65749806	5.47350427
Instructional Method[GMAW]	1.12851593	0.93222222	-0.5956488	0.83170163	0.81056721	0.47583528	0.79316239
Instructional Method[No Filler]	-0.7775447	0.09888889	0.11950272	-0.2864802	-0.6954934	0.2970474	1.02649573

Least Squares Means

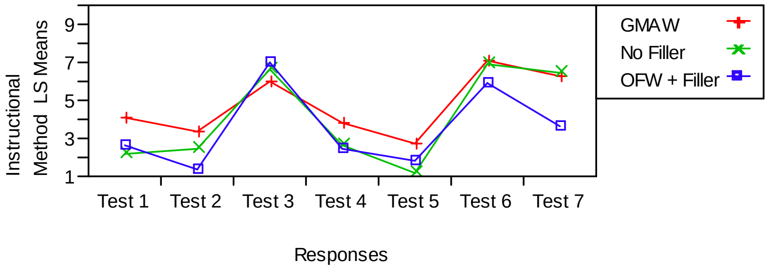
Overall Means



Overall Means

Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
3.1025641	2.44384615	6.52564103	3.02564103	2	6.66666667	5.46153846

Instructional Method



Instructional Method

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
GMAW	4.13333333	3.33333333	5.96666667	3.8	2.73333333	7.13333333	6.26666667
No Filler	2.22727273	2.5	6.68181818	2.68181818	1.22727273	6.95454545	6.5
OFW + Filler	2.65384615	1.37	7.03846154	2.42307692	1.80769231	5.88461538	3.65384615

Manova Fit Experience=Yes

Response Specification

To construct the linear combinations across responses,

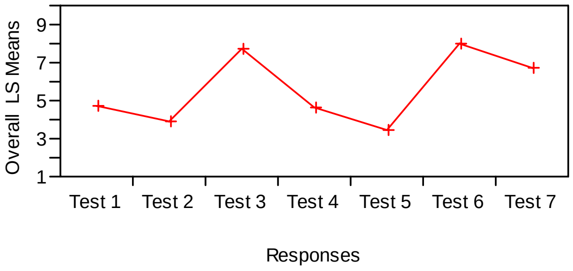
☐ Univariate Tests Also

☐ Test Each Column Separately Also

N	29
DFE	26

Least Squares Means

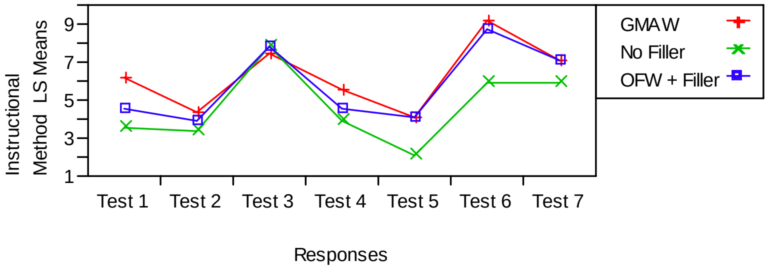
Overall Means



Overall Means

Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
4.75862069	3.89655172	7.70689655	4.67241379	3.48275862	8	6.72413793

Instructional Method



Instructional Method

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
GMAW	6.22222222	4.38888889	7.5	5.55555556	4.11111111	9.16666667	7.05555556
No Filler	3.55555556	3.38888889	7.77777778	3.88888889	2.11111111	5.94444444	5.94444444
OFW + Filler	4.54545455	3.90909091	7.81818182	4.59090909	4.09090909	8.72727273	7.09090909

Manova Fit Experience1=0, Experience2=0, Experience3=0

Response Specification

To construct the linear combinations across responses,

☐ Univariate Tests Also

☐ Test Each Column Separately Also

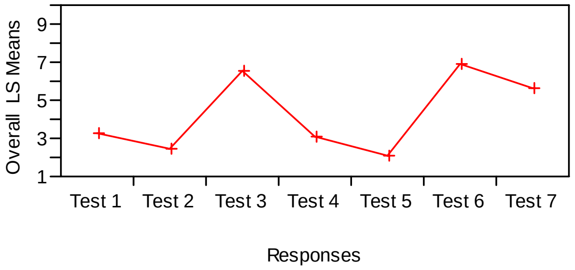
N	46
DFE	43

Parameter Estimates

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
Intercept	3.15359477	2.47830065	6.53349673	3.0375817	2.04003268	6.87581699	5.73366013
Instructional Method[GMAW]	1.02287582	0.7275817	-0.5629085	0.84477124	0.66584967	0.44771242	0.53104575
Instructional Method[No Filler]	-0.9869281	-0.061634	0.00816993	-0.4542484	-0.8316993	-0.0424837	0.8496732

Least Squares Means

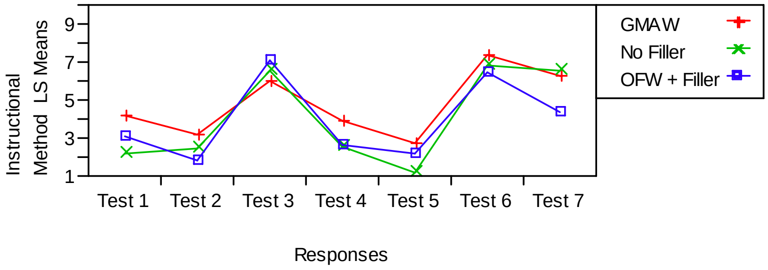
Overall Means



Overall Means

Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
3.26086957	2.485	6.5326087	3.08695652	2.13043478	6.88043478	5.64130435

Instructional Method



Instructional Method

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
GMAW	4.17647059	3.20588235	5.97058824	3.88235294	2.70588235	7.32352941	6.26470588
No Filler	2.16666667	2.41666667	6.54166667	2.58333333	1.20833333	6.83333333	6.58333333
OFW + Filler	3.11764706	1.81235294	7.08823529	2.64705882	2.20588235	6.47058824	4.35294118

Manova Fit Experience1=1, Experience2=0, Experience3=0

Response Specification

To construct the linear combinations across responses,

☐ Univariate Tests Also

☐ Test Each Column Separately Also

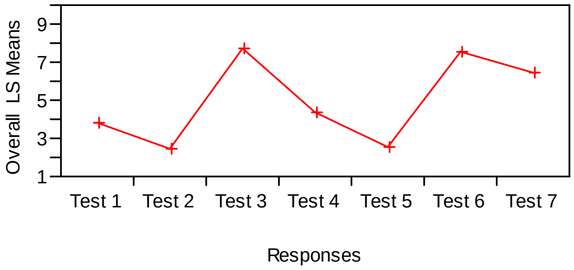
N	7
DFE	4

Parameter Estimates

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
Intercept	3.16666667	2.11111111	7.88888889	4.38888889	2.55555556	7.88888889	6.94444444
Instructional Method[GMAW]	1.83333333	-0.2777778	-0.5555556	-0.0555556	0.77777778	1.11111111	-0.7777778
Instructional Method[No Filler]	0.33333333	1.38888889	-0.0555556	-0.0555556	-0.7222222	-2.2222222	-0.7777778

Least Squares Means

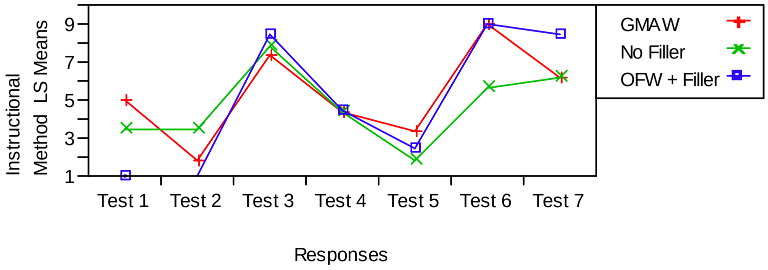
Overall Means



Overall Means

Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
3.78571429	2.42857143	7.71428571	4.35714286	2.57142857	7.57142857	6.5

Instructional Method



Instructional Method

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
GMAW	5	1.83333333	7.33333333	4.33333333	3.33333333	9	6.16666667
No Filler	3.5	3.5	7.83333333	4.33333333	1.83333333	5.66666667	6.16666667
OFW + Filler	1	1	8.5	4.5	2.5	9	8.5

Manova Fit Experience1=0, Experience2=1, Experience3=0

Response Specification

To construct the linear combinations across responses,
☐ Univariate Tests Also
☐ Test Each Column Separately Also

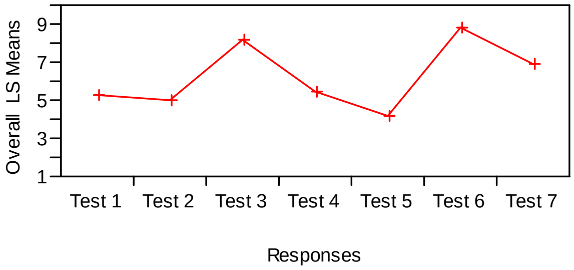
N	8
DFE	5

Parameter Estimates

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
Intercept	4.55555556	4.27777778	8.02777778	4.58333333	3.40277778	7.54166667	5.90277778
Instructional Method[GMAW]	3.11111111	2.55555556	0.30555556	1.91666667	0.93055556	1.95833333	1.93055556
Instructional Method[No Filler]	-3.0555556	-2.7777778	-0.5277778	-3.0833333	-2.4027778	-4.0416667	-3.4027778

Least Squares Means

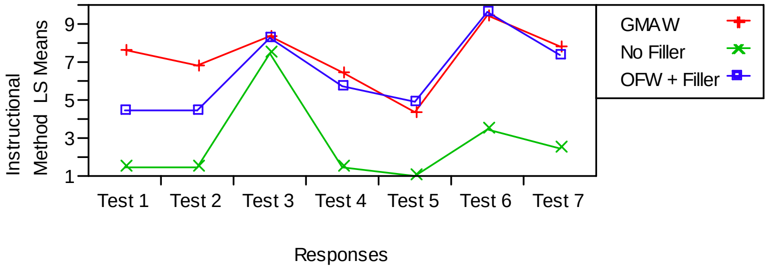
Overall Means



Overall Means

Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
5.3125	5	8.1875	5.5	4.1875	8.8125	6.9375

Instructional Method



Instructional Method

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
GMAW	7.66666667	6.83333333	8.33333333	6.5	4.33333333	9.5	7.83333333
No Filler	1.5	1.5	7.5	1.5	1	3.5	2.5
OFW + Filler	4.5	4.5	8.25	5.75	4.875	9.625	7.375

Manova Fit Experience1=0, Experience2=0, Experience3=1

Response Specification

To construct the linear combinations across responses,
☐ Univariate Tests Also
☐ Test Each Column Separately Also

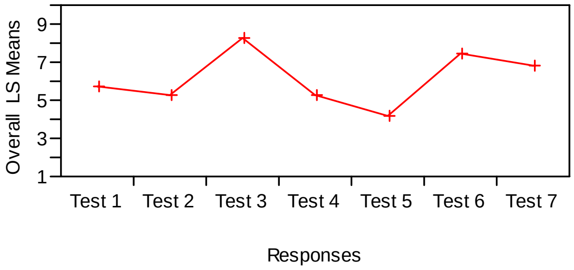
N	7
DFE	4

Parameter Estimates

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
Intercept	6.625	6.25	8.25	6	5.45833333	7.95833333	7.33333333
Instructional Method[GMAW]	2.375	2.75	0.25	2.5	3.54166667	1.54166667	1.66666667
Instructional Method[No Filler]	-2	-2	0.25	-1.25	-2.5833333	-1.0833333	-1.0833333

Least Squares Means

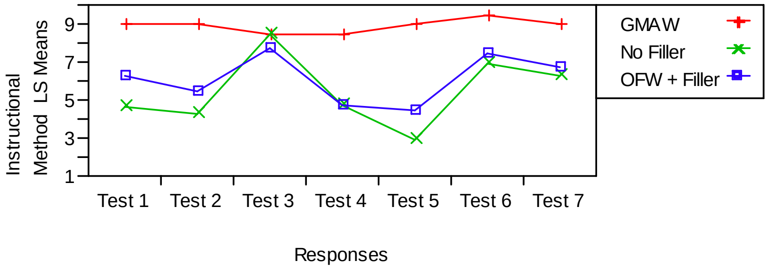
Overall Means



Overall Means

Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
5.71428571	5.28571429	8.28571429	5.28571429	4.21428571	7.42857143	6.78571429

Instructional Method



Instructional Method

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
GMAW	9	9	8.5	8.5	9	9.5	9
No Filler	4.625	4.25	8.5	4.75	2.875	6.875	6.25
OFW + Filler	6.25	5.5	7.75	4.75	4.5	7.5	6.75

Manova Fit

Response Specification

To construct the linear combinations across responses,

☐ Univariate Tests Also

☐ Test Each Column Separately Also

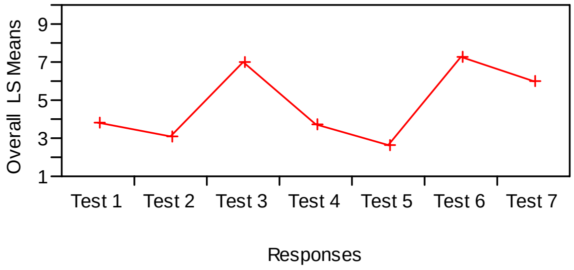
N	68
DFE	66

Parameter Estimates

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
Intercept	4.06060606	3.21469697	6.91856061	3.89393939	2.77272727	7.38541667	6.12784091
WeldingType[GMAW]	0.85606061	0.5144697	-0.3768939	0.56439394	0.47727273	0.51041667	0.43465909

Least Squares Means

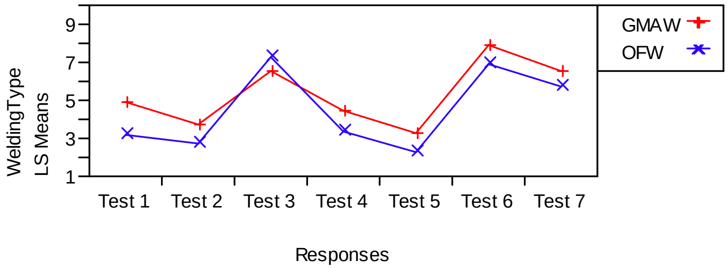
Overall Means



Overall Means

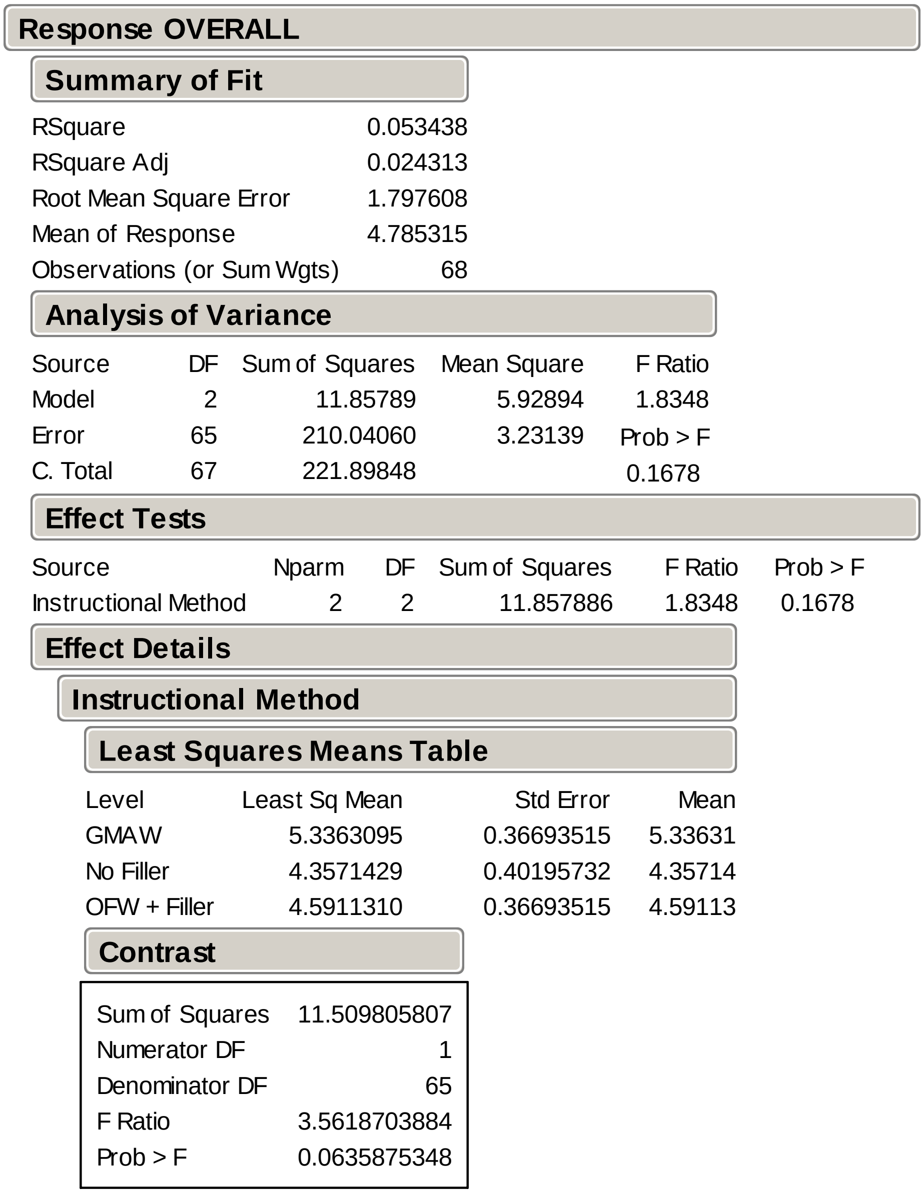
Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
3.80882353	3.06338235	7.02941176	3.72794118	2.63235294	7.23529412	6

WeldingType

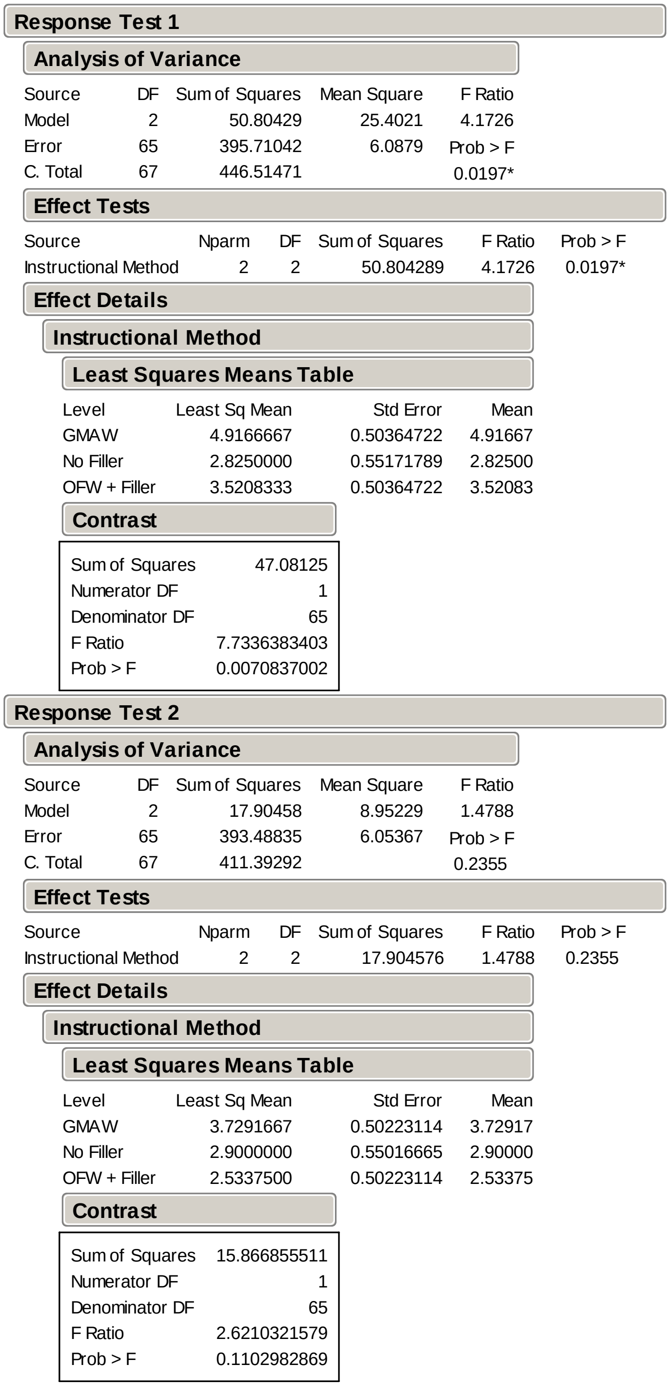


WeldingType

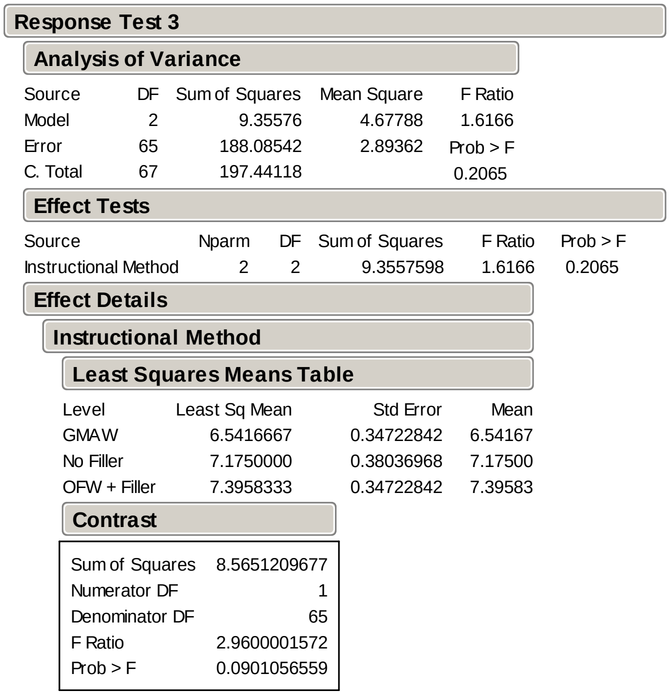
	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
GMAW	4.91666667	3.72916667	6.54166667	4.45833333	3.25	7.89583333	6.5625
OFW	3.20454545	2.70022727	7.29545455	3.32954545	2.29545455	6.875	5.69318182



```
Response OVERALL
  Summary of Fit
  RSquare                          0.053438
  RSquare Adj                      0.024313
  Root Mean Square Error           1.797608
  Mean of Response                 4.785315
  Observations (or Sum Wgts)             68
  Analysis of Variance
  Source      DF  Sum of Squares  Mean Square   F Ratio
  Model        2        11.85789      5.92894    1.8348
  Error       65       210.04060      3.23139  Prob > F
  C. Total    67       221.89848                 0.1678
  Effect Tests
  Source               Nparm   DF  Sum of Squares    F Ratio   Prob > F
  Instructional Method     2    2       11.857886     1.8348     0.1678
  Effect Details
    Instructional Method
      Least Squares Means Table
      Level         Least Sq Mean        Std Error      Mean
      GMAW              5.3363095       0.36693515   5.33631
      No Filler         4.3571429       0.40195732   4.35714
      OFW + Filler      4.5911310       0.36693515   4.59113
      Contrast
      Sum of Squares    11.509805807
      Numerator DF                 1
      Denominator DF              65
      F Ratio           3.5618703884
      Prob > F          0.0635875348
```



```
Response Test 1
  Analysis of Variance
  Source       DF   Sum of Squares   Mean Square    F Ratio
  Model         2         50.80429       25.4021     4.1726
  Error        65        395.71042        6.0879   Prob > F
  C. Total     67        446.51471                  0.0197*
  Effect Tests
  Source               Nparm   DF   Sum of Squares    F Ratio   Prob > F
  Instructional Method     2    2        50.804289     4.1726    0.0197*
  Effect Details
    Instructional Method
      Least Squares Means Table
      Level          Least Sq Mean       Std Error      Mean
      GMAW               4.9166667      0.50364722   4.91667
      No Filler          2.8250000      0.55171789   2.82500
      OFW + Filler       3.5208333      0.50364722   3.52083
      Contrast
      Sum of Squares        47.08125
      Numerator DF                 1
      Denominator DF              65
      F Ratio           7.7336383403
      Prob > F          0.0070837002
Response Test 2
  Analysis of Variance
  Source       DF   Sum of Squares   Mean Square    F Ratio
  Model         2         17.90458       8.95229     1.4788
  Error        65        393.48835       6.05367   Prob > F
  C. Total     67        411.39292                   0.2355
  Effect Tests
  Source               Nparm   DF   Sum of Squares    F Ratio   Prob > F
  Instructional Method     2    2        17.904576     1.4788     0.2355
  Effect Details
    Instructional Method
      Least Squares Means Table
      Level          Least Sq Mean       Std Error      Mean
      GMAW               3.7291667      0.50223114   3.72917
      No Filler          2.9000000      0.55016665   2.90000
      OFW + Filler       2.5337500      0.50223114   2.53375
      Contrast
      Sum of Squares    15.866855511
      Numerator DF                 1
      Denominator DF              65
      F Ratio           2.6210321579
      Prob > F          0.1102982869
```



Response Test 3

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	9.35576	4.67788	1.6166
Error	65	188.08542	2.89362	Prob > F
C. Total	67	197.44118		0.2065

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Instructional Method	2	2	9.3557598	1.6166	0.2065

Effect Details

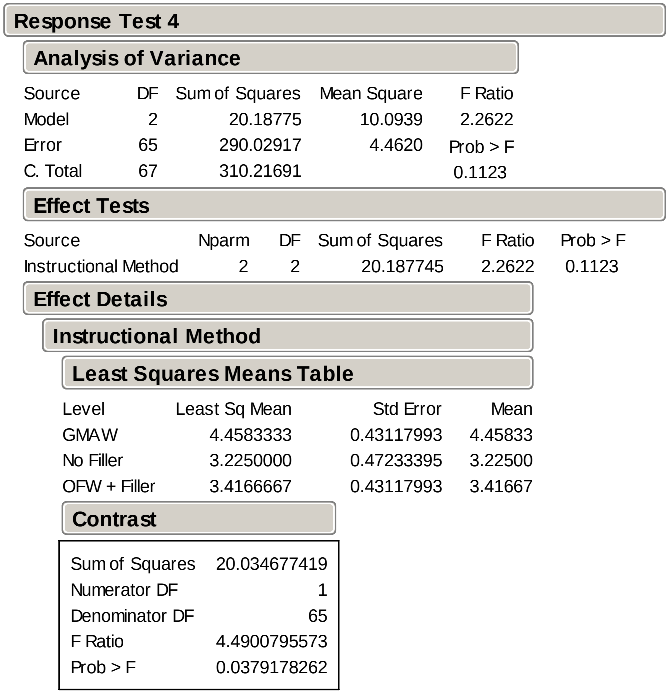
Instructional Method

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
GMAW	6.5416667	0.34722842	6.54167
No Filler	7.1750000	0.38036968	7.17500
OFW + Filler	7.3958333	0.34722842	7.39583

Contrast

Sum of Squares	8.5651209677
Numerator DF	1
Denominator DF	65
F Ratio	2.9600001572
Prob > F	0.0901056559



Response Test 4

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	20.18775	10.0939	2.2622
Error	65	290.02917	4.4620	Prob > F
C. Total	67	310.21691		0.1123

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Instructional Method	2	2	20.187745	2.2622	0.1123

Effect Details

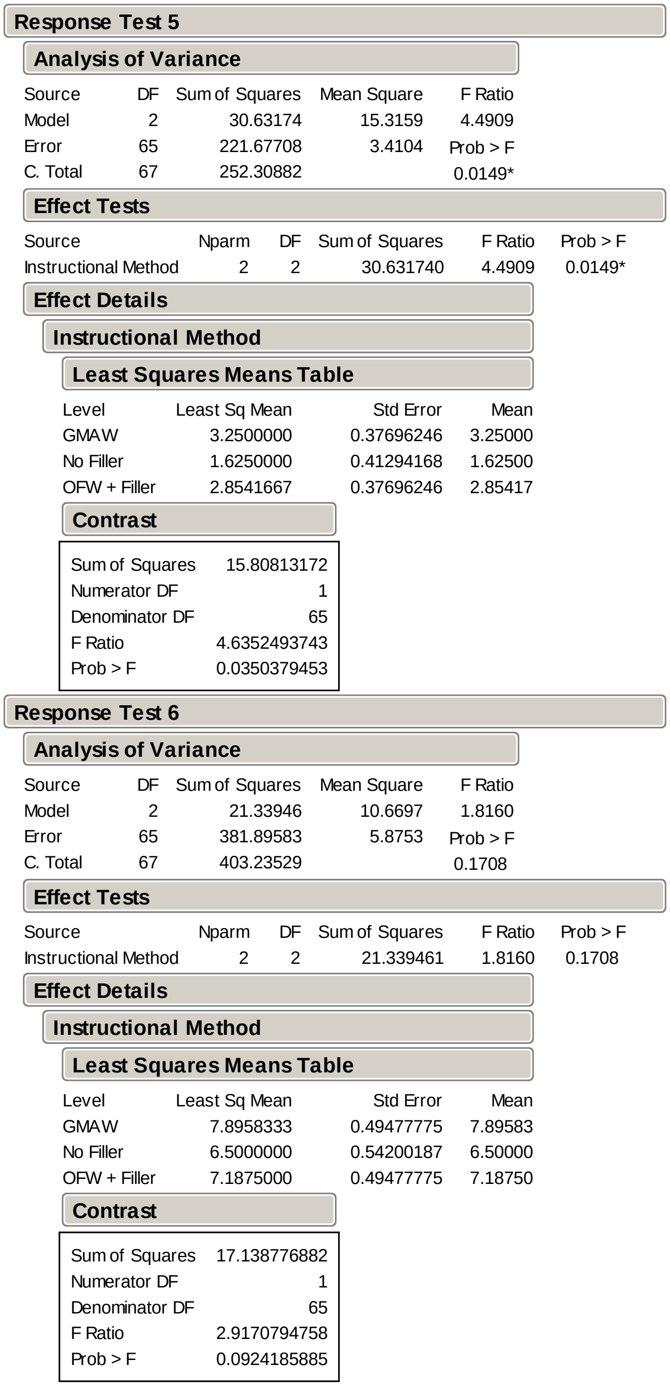
Instructional Method

Least Squares Means Table

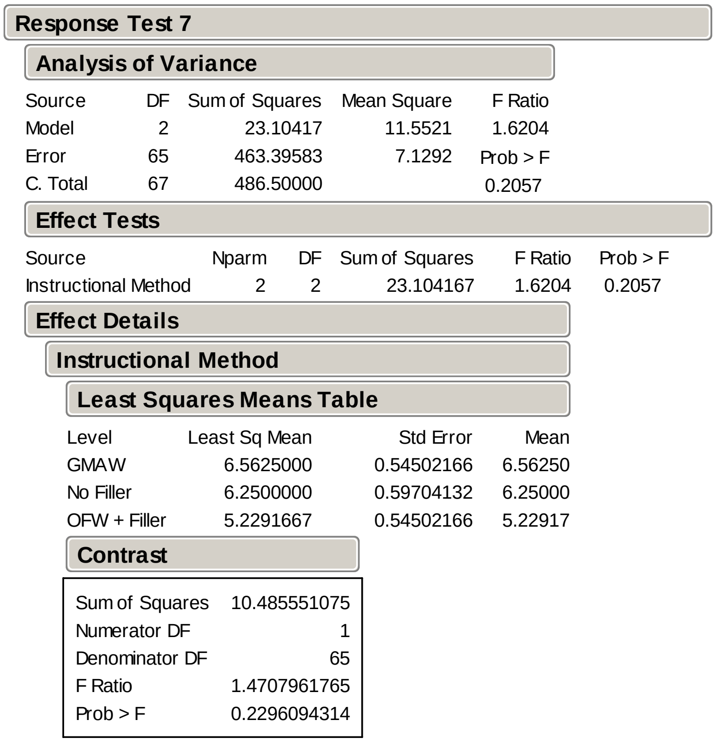
Level	Least Sq Mean	Std Error	Mean
GMAW	4.4583333	0.43117993	4.45833
No Filler	3.2250000	0.47233395	3.22500
OFW + Filler	3.4166667	0.43117993	3.41667

Contrast

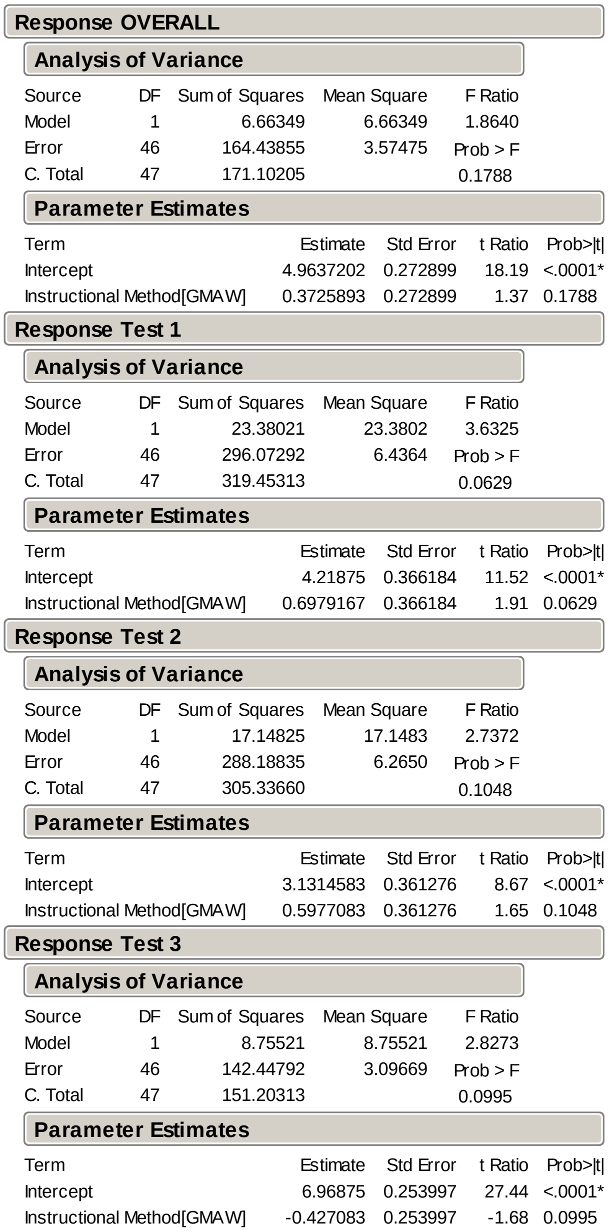
Sum of Squares	20.034677419
Numerator DF	1
Denominator DF	65
F Ratio	4.4900795573
Prob > F	0.0379178262



```
Response Test 5
  Analysis of Variance
  Source      DF  Sum of Squares  Mean Square   F Ratio
  Model        2        30.63174      15.3159    4.4909
  Error       65       221.67708       3.4104  Prob > F
  C. Total    67       252.30882                0.0149*
  Effect Tests
  Source                Nparm   DF  Sum of Squares   F Ratio   Prob > F
  Instructional Method      2    2       30.631740    4.4909    0.0149*
  Effect Details
    Instructional Method
      Least Squares Means Table
      Level          Least Sq Mean      Std Error      Mean
      GMAW               3.2500000     0.37696246   3.25000
      No Filler          1.6250000     0.41294168   1.62500
      OFW + Filler       2.8541667     0.37696246   2.85417
      Contrast
      Sum of Squares   15.80813172
      Numerator DF               1
      Denominator DF            65
      F Ratio         4.6352493743
      Prob > F        0.0350379453
Response Test 6
  Analysis of Variance
  Source      DF  Sum of Squares  Mean Square   F Ratio
  Model        2        21.33946      10.6697    1.8160
  Error       65       381.89583       5.8753  Prob > F
  C. Total    67       403.23529                 0.1708
  Effect Tests
  Source                Nparm   DF  Sum of Squares   F Ratio   Prob > F
  Instructional Method      2    2       21.339461    1.8160     0.1708
  Effect Details
    Instructional Method
      Least Squares Means Table
      Level          Least Sq Mean      Std Error      Mean
      GMAW               7.8958333     0.49477775   7.89583
      No Filler          6.5000000     0.54200187   6.50000
      OFW + Filler       7.1875000     0.49477775   7.18750
      Contrast
      Sum of Squares  17.138776882
      Numerator DF               1
      Denominator DF            65
      F Ratio         2.9170794758
      Prob > F        0.0924185885
```



```
Response Test 7
  Analysis of Variance
  Source        DF  Sum of Squares  Mean Square   F Ratio
  Model          2        23.10417      11.5521    1.6204
  Error         65       463.39583       7.1292  Prob > F
  C. Total      67       486.50000                 0.2057
  Effect Tests
  Source                Nparm    DF  Sum of Squares    F Ratio   Prob > F
  Instructional Method      2     2       23.104167     1.6204     0.2057
  Effect Details
    Instructional Method
      Least Squares Means Table
      Level          Least Sq Mean         Std Error      Mean
      GMAW               6.5625000        0.54502166   6.56250
      No Filler          6.2500000        0.59704132   6.25000
      OFW + Filler       5.2291667        0.54502166   5.22917
      Contrast
      Sum of Squares     10.485551075
      Numerator DF                  1
      Denominator DF               65
      F Ratio            1.4707961765
      Prob > F           0.2296094314
```



```
Response OVERALL
  Analysis of Variance
  Source      DF   Sum of Squares   Mean Square    F Ratio
  Model        1          6.66349       6.66349     1.8640
  Error       46        164.43855       3.57475   Prob > F
  C. Total    47        171.10205                   0.1788
  Parameter Estimates
  Term                                Estimate   Std Error   t Ratio   Prob>|t|
  Intercept                          4.9637202    0.272899     18.19   <.0001*
  Instructional Method[GMAW]         0.3725893    0.272899      1.37    0.1788
Response Test 1
  Analysis of Variance
  Source      DF   Sum of Squares   Mean Square    F Ratio
  Model        1         23.38021       23.3802     3.6325
  Error       46        296.07292        6.4364   Prob > F
  C. Total    47        319.45313                   0.0629
  Parameter Estimates
  Term                                Estimate   Std Error   t Ratio   Prob>|t|
  Intercept                            4.21875    0.366184     11.52   <.0001*
  Instructional Method[GMAW]         0.6979167    0.366184      1.91    0.0629
Response Test 2
  Analysis of Variance
  Source      DF   Sum of Squares   Mean Square    F Ratio
  Model        1         17.14825       17.1483     2.7372
  Error       46        288.18835        6.2650   Prob > F
  C. Total    47        305.33660                   0.1048
  Parameter Estimates
  Term                                Estimate   Std Error   t Ratio   Prob>|t|
  Intercept                          3.1314583    0.361276      8.67   <.0001*
  Instructional Method[GMAW]         0.5977083    0.361276      1.65    0.1048
Response Test 3
  Analysis of Variance
  Source      DF   Sum of Squares   Mean Square    F Ratio
  Model        1          8.75521       8.75521     2.8273
  Error       46        142.44792       3.09669   Prob > F
  C. Total    47        151.20313                   0.0995
  Parameter Estimates
  Term                                Estimate   Std Error   t Ratio   Prob>|t|
  Intercept                            6.96875    0.253997     27.44   <.0001*
  Instructional Method[GMAW]         -0.427083    0.253997     -1.68    0.0995
```

Response Test 4

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	13.02083	13.0208	2.7756
Error	46	215.79167	4.6911	Prob > F
C. Total	47	228.81250		0.1025

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	3.9375	0.312621	12.60	<.0001*
Instructional Method[GMAW]	0.5208333	0.312621	1.67	0.1025

Response Test 5

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	1.88021	1.88021	0.4812
Error	46	179.73958	3.90738	Prob > F
C. Total	47	181.61979		0.4914

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	3.0520833	0.285314	10.70	<.0001*
Instructional Method[GMAW]	0.1979167	0.285314	0.69	0.4914

Response Test 6

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	6.02083	6.02083	0.9790
Error	46	282.89583	6.14991	Prob > F
C. Total	47	288.91667		0.3276

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	7.5416667	0.357943	21.07	<.0001*
Instructional Method[GMAW]	0.3541667	0.357943	0.99	0.3276

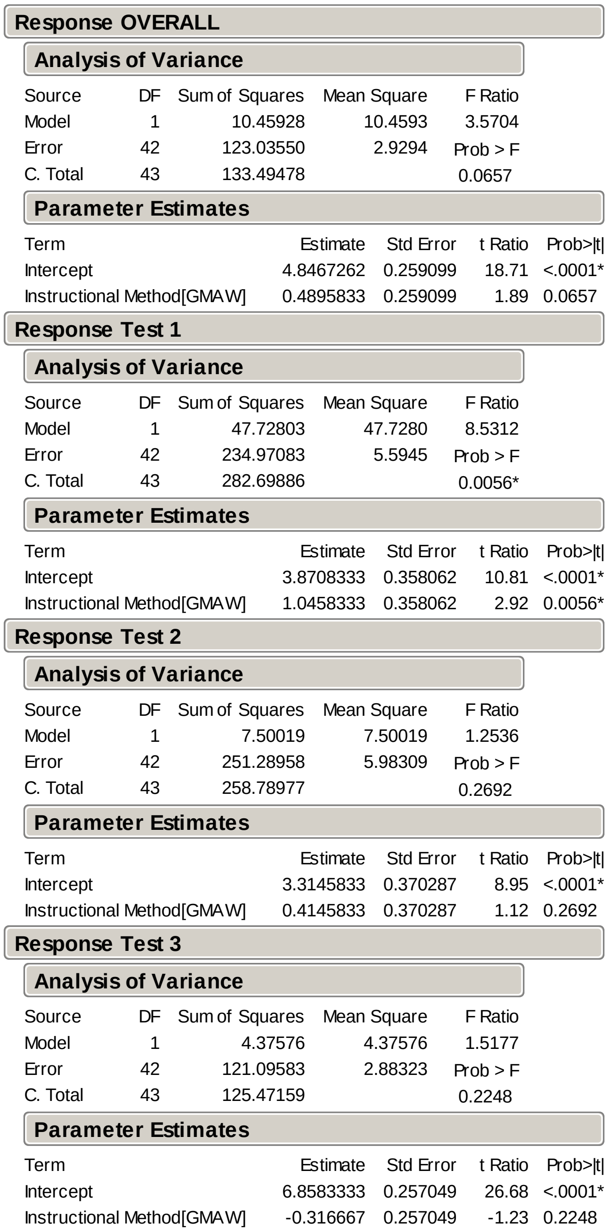
Response Test 7

Analysis of Variance

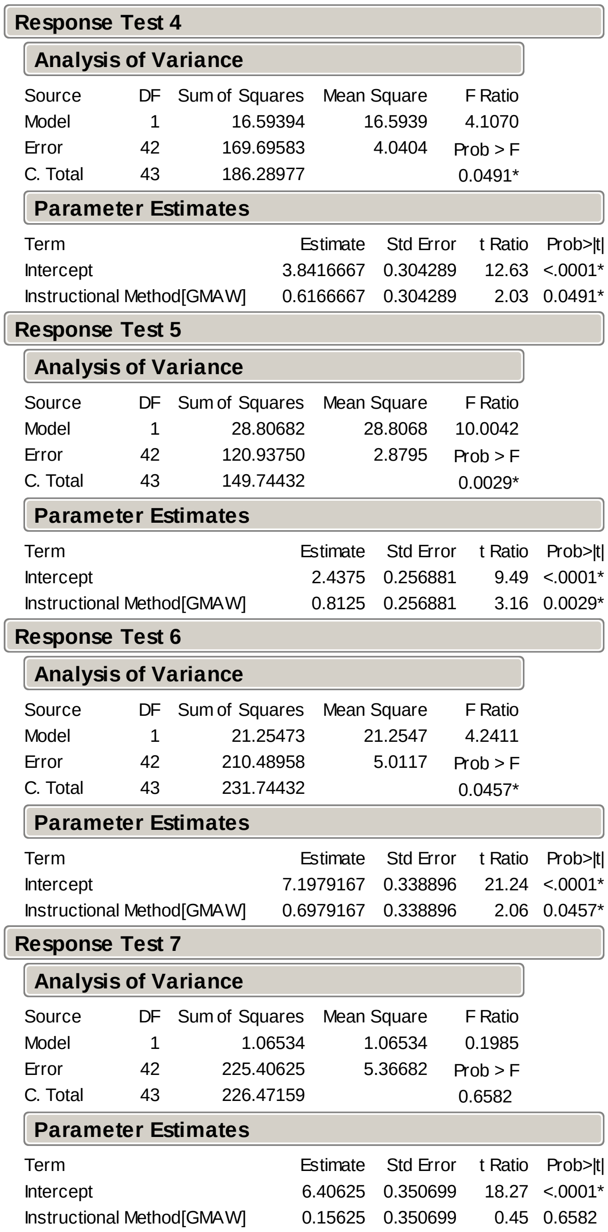
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	21.33333	21.3333	2.6656
Error	46	368.14583	8.0032	Prob > F
C. Total	47	389.47917		0.1094

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	5.8958333	0.408329	14.44	<.0001*
Instructional Method[GMAW]	0.6666667	0.408329	1.63	0.1094



```
Response OVERALL
  Analysis of Variance
  Source        DF   Sum of Squares   Mean Square    F Ratio
  Model          1         10.45928       10.4593     3.5704
  Error         42        123.03550        2.9294   Prob > F
  C. Total      43        133.49478                   0.0657
  Parameter Estimates
  Term                             Estimate   Std Error   t Ratio   Prob>|t|
  Intercept                       4.8467262    0.259099     18.71   <.0001*
  Instructional Method[GMAW]      0.4895833    0.259099      1.89   0.0657
Response Test 1
  Analysis of Variance
  Source        DF   Sum of Squares   Mean Square    F Ratio
  Model          1         47.72803       47.7280     8.5312
  Error         42        234.97083        5.5945   Prob > F
  C. Total      43        282.69886                   0.0056*
  Parameter Estimates
  Term                             Estimate   Std Error   t Ratio   Prob>|t|
  Intercept                       3.8708333    0.358062     10.81   <.0001*
  Instructional Method[GMAW]      1.0458333    0.358062      2.92   0.0056*
Response Test 2
  Analysis of Variance
  Source        DF   Sum of Squares   Mean Square    F Ratio
  Model          1          7.50019       7.50019     1.2536
  Error         42        251.28958       5.98309   Prob > F
  C. Total      43        258.78977                   0.2692
  Parameter Estimates
  Term                             Estimate   Std Error   t Ratio   Prob>|t|
  Intercept                       3.3145833    0.370287      8.95   <.0001*
  Instructional Method[GMAW]      0.4145833    0.370287      1.12   0.2692
Response Test 3
  Analysis of Variance
  Source        DF   Sum of Squares   Mean Square    F Ratio
  Model          1          4.37576       4.37576     1.5177
  Error         42        121.09583       2.88323   Prob > F
  C. Total      43        125.47159                   0.2248
  Parameter Estimates
  Term                             Estimate   Std Error   t Ratio   Prob>|t|
  Intercept                       6.8583333    0.257049     26.68   <.0001*
  Instructional Method[GMAW]      -0.316667    0.257049     -1.23   0.2248
```



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Response Test 4
  Analysis of Variance
  Source      DF   Sum of Squares   Mean Square    F Ratio
  Model        1         16.59394       16.5939     4.1070
  Error       42        169.69583        4.0404   Prob > F
  C. Total    43        186.28977                  0.0491*
  Parameter Estimates
  Term                               Estimate   Std Error   t Ratio   Prob>|t|
  Intercept                         3.8416667    0.304289     12.63   <.0001*
  Instructional Method[GMAW]        0.6166667    0.304289      2.03   0.0491*
Response Test 5
  Analysis of Variance
  Source      DF   Sum of Squares   Mean Square    F Ratio
  Model        1         28.80682       28.8068    10.0042
  Error       42        120.93750        2.8795   Prob > F
  C. Total    43        149.74432                  0.0029*
  Parameter Estimates
  Term                               Estimate   Std Error   t Ratio   Prob>|t|
  Intercept                            2.4375    0.256881      9.49   <.0001*
  Instructional Method[GMAW]           0.8125    0.256881      3.16   0.0029*
Response Test 6
  Analysis of Variance
  Source      DF   Sum of Squares   Mean Square    F Ratio
  Model        1         21.25473       21.2547     4.2411
  Error       42        210.48958        5.0117   Prob > F
  C. Total    43        231.74432                  0.0457*
  Parameter Estimates
  Term                               Estimate   Std Error   t Ratio   Prob>|t|
  Intercept                         7.1979167    0.338896     21.24   <.0001*
  Instructional Method[GMAW]        0.6979167    0.338896      2.06   0.0457*
Response Test 7
  Analysis of Variance
  Source      DF   Sum of Squares   Mean Square    F Ratio
  Model        1          1.06534       1.06534     0.1985
  Error       42        225.40625       5.36682   Prob > F
  C. Total    43        226.47159                   0.6582
  Parameter Estimates
  Term                               Estimate   Std Error   t Ratio   Prob>|t|
  Intercept                           6.40625    0.350699     18.27   <.0001*
  Instructional Method[GMAW]          0.15625    0.350699      0.45   0.6582
```

Manova Fit

Response Specification

To construct the linear combinations across responses,

☐ Univariate Tests Also

☐ Test Each Column Separately Also

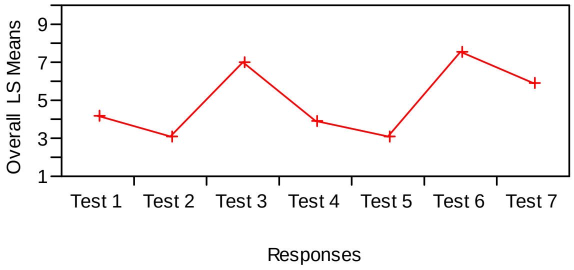
N	48
DFE	46

Parameter Estimates

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
Intercept	4.21875	3.13145833	6.96875	3.9375	3.05208333	7.54166667	5.89583333
Instructional Method[GMAW]	0.69791667	0.59770833	-0.4270833	0.52083333	0.19791667	0.35416667	0.66666667

Least Squares Means

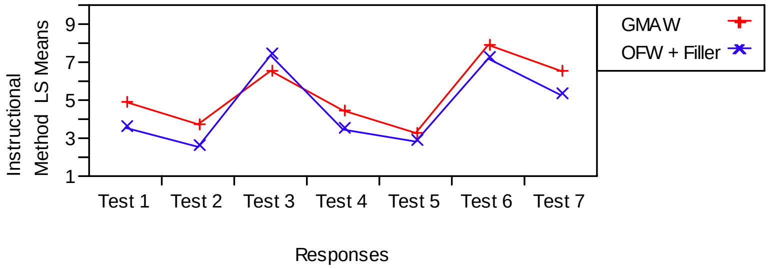
Overall Means



Overall Means

Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
4.21875	3.13145833	6.96875	3.9375	3.05208333	7.54166667	5.89583333

Instructional Method



Instructional Method

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
GMAW	4.91666667	3.72916667	6.54166667	4.45833333	3.25	7.89583333	6.5625
OFW + Filler	3.52083333	2.53375	7.39583333	3.41666667	2.85416667	7.1875	5.22916667

Manova Fit

Response Specification

To construct the linear combinations across responses,
☐ Univariate Tests Also
☐ Test Each Column Separately Also

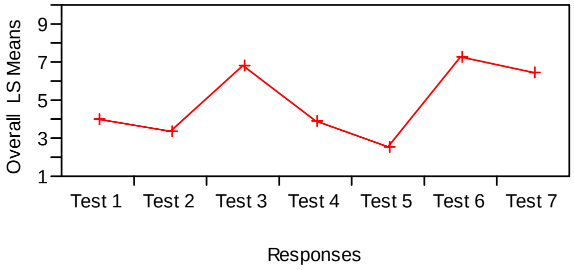
N	44
DFE	42

Parameter Estimates

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
Intercept	3.87083333	3.31458333	6.85833333	3.84166667	2.4375	7.19791667	6.40625
Instructional Method[GMAW]	1.04583333	0.41458333	-0.3166667	0.61666667	0.8125	0.69791667	0.15625

Least Squares Means

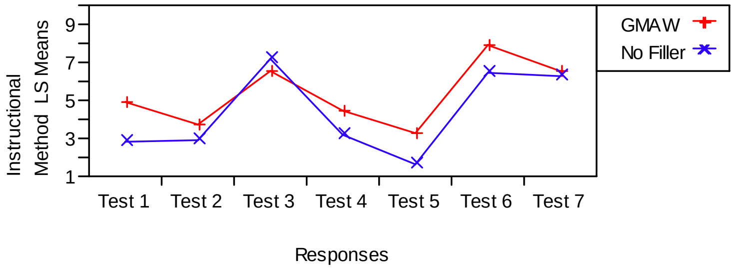
Overall Means



Overall Means

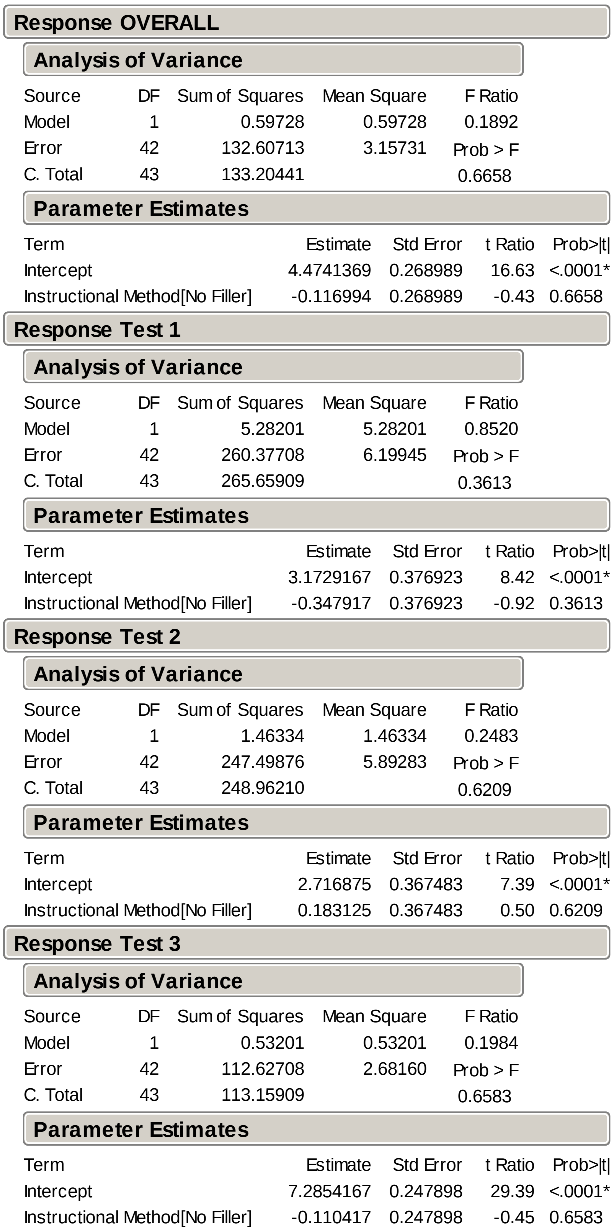
Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
3.96590909	3.35227273	6.82954545	3.89772727	2.51136364	7.26136364	6.42045455

Instructional Method



Instructional Method

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
GMAW	4.91666667	3.72916667	6.54166667	4.45833333	3.25	7.89583333	6.5625
No Filler	2.825	2.9	7.175	3.225	1.625	6.5	6.25



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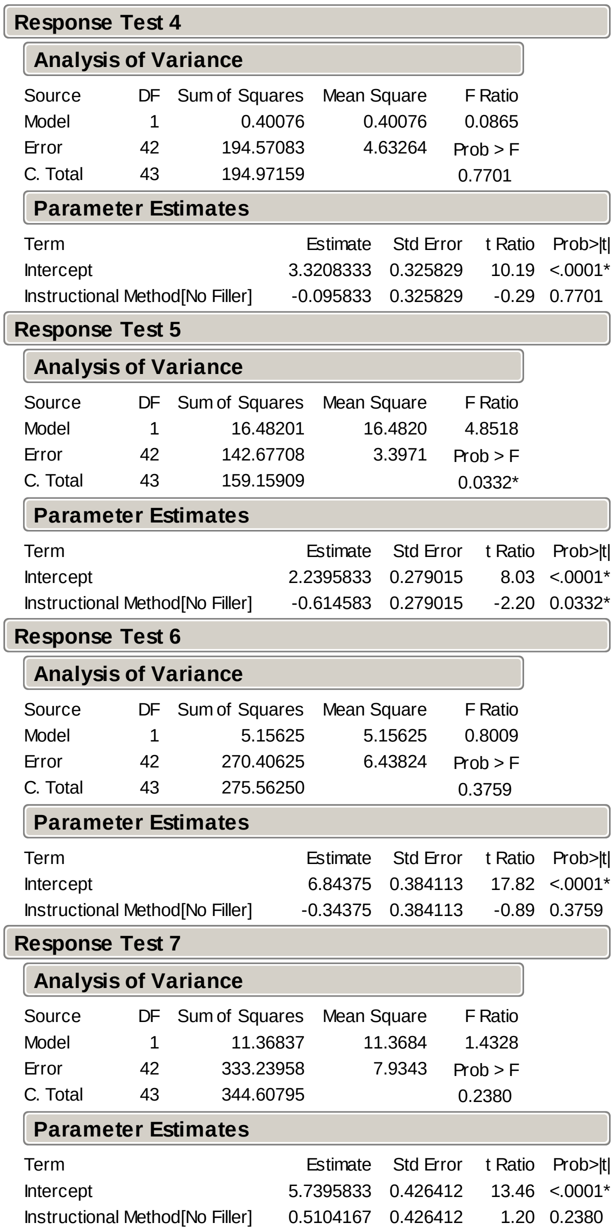
Response OVERALL
  Analysis of Variance
  Source      DF   Sum of Squares   Mean Square    F Ratio
  Model        1          0.59728       0.59728     0.1892
  Error       42        132.60713       3.15731   Prob > F
  C. Total    43        133.20441                   0.6658
  Parameter Estimates
  Term                               Estimate   Std Error   t Ratio   Prob>|t|
  Intercept                         4.4741369    0.268989     16.63   <.0001*
  Instructional Method[No Filler]   -0.116994    0.268989     -0.43   0.6658
Response Test 1
  Analysis of Variance
  Source      DF   Sum of Squares   Mean Square    F Ratio
  Model        1          5.28201       5.28201     0.8520
  Error       42        260.37708       6.19945   Prob > F
  C. Total    43        265.65909                   0.3613
  Parameter Estimates
  Term                               Estimate   Std Error   t Ratio   Prob>|t|
  Intercept                         3.1729167    0.376923      8.42   <.0001*
  Instructional Method[No Filler]   -0.347917    0.376923     -0.92   0.3613
Response Test 2
  Analysis of Variance
  Source      DF   Sum of Squares   Mean Square    F Ratio
  Model        1          1.46334       1.46334     0.2483
  Error       42        247.49876       5.89283   Prob > F
  C. Total    43        248.96210                   0.6209
  Parameter Estimates
  Term                               Estimate   Std Error   t Ratio   Prob>|t|
  Intercept                          2.716875    0.367483      7.39   <.0001*
  Instructional Method[No Filler]    0.183125    0.367483      0.50   0.6209
Response Test 3
  Analysis of Variance
  Source      DF   Sum of Squares   Mean Square    F Ratio
  Model        1          0.53201       0.53201     0.1984
  Error       42        112.62708       2.68160   Prob > F
  C. Total    43        113.15909                   0.6583
  Parameter Estimates
  Term                               Estimate   Std Error   t Ratio   Prob>|t|
  Intercept                         7.2854167    0.247898     29.39   <.0001*
  Instructional Method[No Filler]   -0.110417    0.247898     -0.45   0.6583
```



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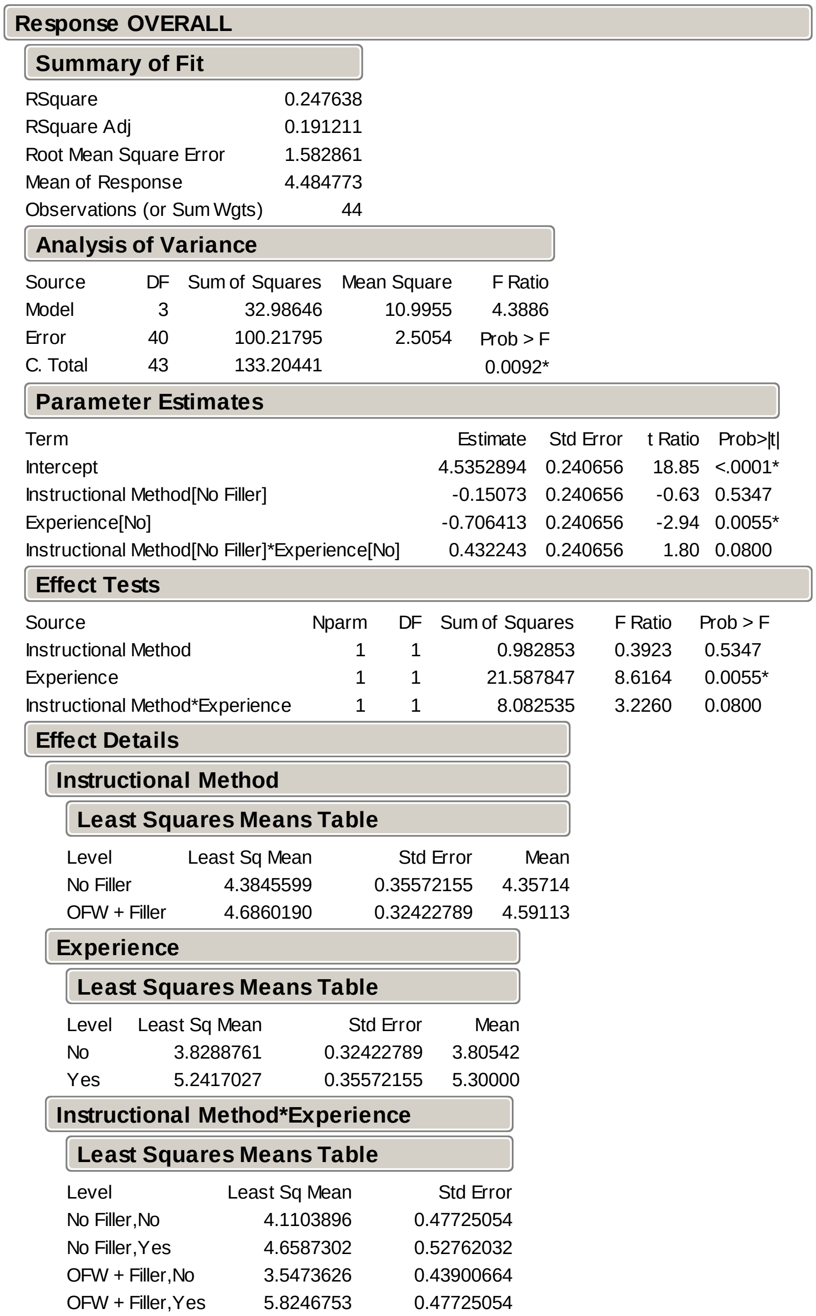
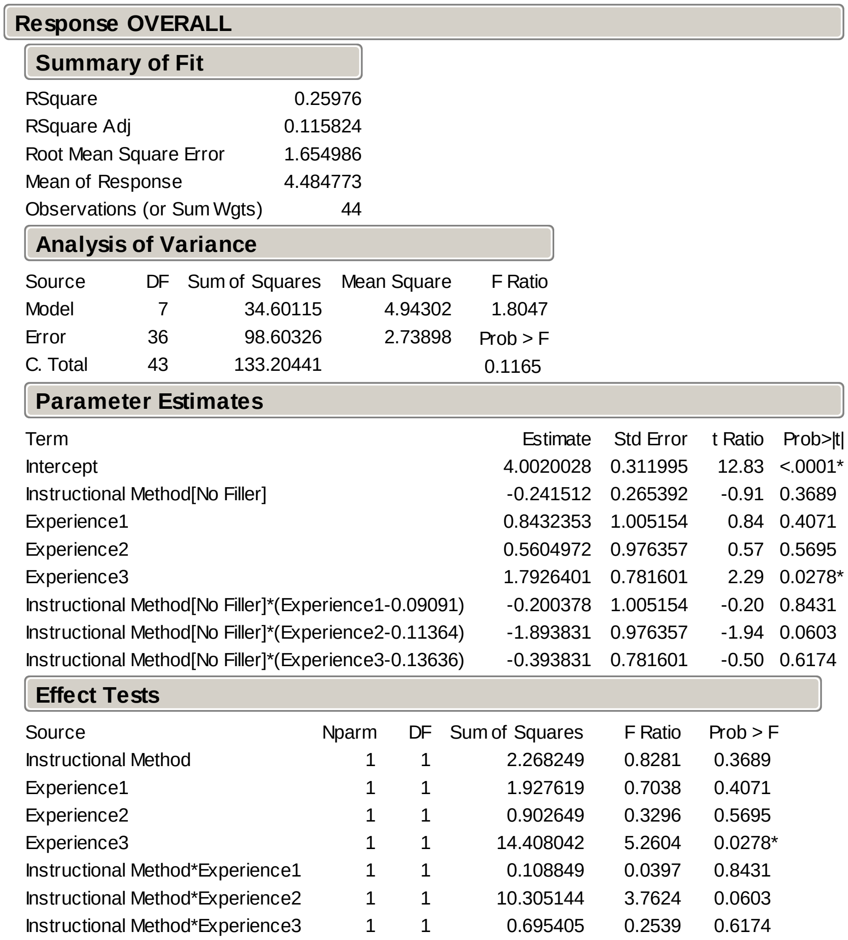
Response Test 4
  Analysis of Variance
  Source     DF   Sum of Squares   Mean Square    F Ratio
  Model       1          0.40076       0.40076     0.0865
  Error      42        194.57083       4.63264   Prob > F
  C. Total   43        194.97159                   0.7701
  Parameter Estimates
  Term                              Estimate   Std Error   t Ratio   Prob>|t|
  Intercept                        3.3208333    0.325829     10.19   <.0001*
  Instructional Method[No Filler] -0.095833    0.325829     -0.29   0.7701
Response Test 5
  Analysis of Variance
  Source     DF   Sum of Squares   Mean Square    F Ratio
  Model       1         16.48201       16.4820     4.8518
  Error      42        142.67708        3.3971   Prob > F
  C. Total   43        159.15909                   0.0332*
  Parameter Estimates
  Term                              Estimate   Std Error   t Ratio   Prob>|t|
  Intercept                        2.2395833    0.279015      8.03   <.0001*
  Instructional Method[No Filler] -0.614583    0.279015     -2.20   0.0332*
Response Test 6
  Analysis of Variance
  Source     DF   Sum of Squares   Mean Square    F Ratio
  Model       1          5.15625       5.15625     0.8009
  Error      42        270.40625       6.43824   Prob > F
  C. Total   43        275.56250                   0.3759
  Parameter Estimates
  Term                              Estimate   Std Error   t Ratio   Prob>|t|
  Intercept                          6.84375    0.384113     17.82   <.0001*
  Instructional Method[No Filler]   -0.34375    0.384113     -0.89   0.3759
Response Test 7
  Analysis of Variance
  Source     DF   Sum of Squares   Mean Square    F Ratio
  Model       1         11.36837       11.3684     1.4328
  Error      42        333.23958        7.9343   Prob > F
  C. Total   43        344.60795                   0.2380
  Parameter Estimates
  Term                              Estimate   Std Error   t Ratio   Prob>|t|
  Intercept                        5.7395833    0.426412     13.46   <.0001*
  Instructional Method[No Filler]  0.5104167    0.426412      1.20   0.2380
```



```
Response OVERALL
  Summary of Fit
  RSquare                        0.247638
  RSquare Adj                    0.191211
  Root Mean Square Error         1.582861
  Mean of Response               4.484773
  Observations (or Sum Wgts)           44
  Analysis of Variance
  Source       DF  Sum of Squares  Mean Square    F Ratio
  Model         3        32.98646      10.9955     4.3886
  Error        40       100.21795       2.5054   Prob > F
  C. Total     43       133.20441                 0.0092*
  Parameter Estimates
  Term                                           Estimate  Std Error  t Ratio  Prob>|t|
  Intercept                                     4.5352894   0.240656    18.85  <.0001*
  Instructional Method[No Filler]                -0.15073   0.240656    -0.63  0.5347
  Experience[No]                                -0.706413   0.240656    -2.94  0.0055*
  Instructional Method[No Filler]*Experience[No] 0.432243   0.240656     1.80  0.0800
  Effect Tests
  Source                          Nparm  DF  Sum of Squares  F Ratio  Prob > F
  Instructional Method                1   1        0.982853   0.3923   0.5347
  Experience                          1   1       21.587847   8.6164   0.0055*
  Instructional Method*Experience     1   1        8.082535   3.2260   0.0800
  Effect Details
    Instructional Method
      Least Squares Means Table
      Level         Least Sq Mean     Std Error      Mean
      No Filler         4.3845599    0.35572155   4.35714
      OFW + Filler      4.6860190    0.32422789   4.59113
    Experience
      Least Squares Means Table
      Level  Least Sq Mean     Std Error      Mean
      No         3.8288761    0.32422789   3.80542
      Yes        5.2417027    0.35572155   5.30000
    Instructional Method*Experience
      Least Squares Means Table
      Level               Least Sq Mean     Std Error
      No Filler,No            4.1103896    0.47725054
      No Filler,Yes           4.6587302    0.52762032
      OFW + Filler,No         3.5473626    0.43900664
      OFW + Filler,Yes        5.8246753    0.47725054
```



Response OVERALL

Summary of Fit

RSquare	0.25976
RSquare Adj	0.115824
Root Mean Square Error	1.654986
Mean of Response	4.484773
Observations (or Sum Wgts)	44

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	34.60115	4.94302	1.8047
Error	36	98.60326	2.73898	Prob > F
C. Total	43	133.20441		0.1165

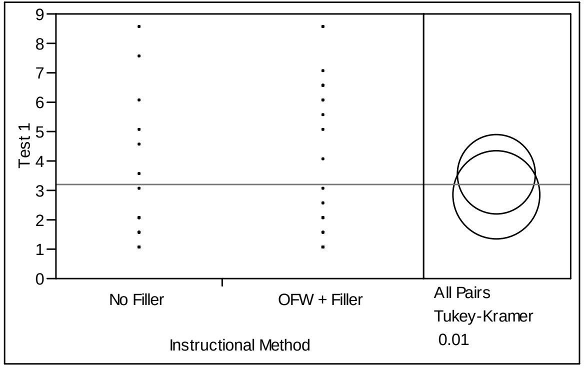
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	4.0020028	0.311995	12.83	<.0001*
Instructional Method[No Filler]	-0.241512	0.265392	-0.91	0.3689
Experience1	0.8432353	1.005154	0.84	0.4071
Experience2	0.5604972	0.976357	0.57	0.5695
Experience3	1.7926401	0.781601	2.29	0.0278*
Instructional Method[No Filler]*(Experience1-0.09091)	-0.200378	1.005154	-0.20	0.8431
Instructional Method[No Filler]*(Experience2-0.11364)	-1.893831	0.976357	-1.94	0.0603
Instructional Method[No Filler]*(Experience3-0.13636)	-0.393831	0.781601	-0.50	0.6174

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Instructional Method	1	1	2.268249	0.8281	0.3689
Experience1	1	1	1.927619	0.7038	0.4071
Experience2	1	1	0.902649	0.3296	0.5695
Experience3	1	1	14.408042	5.2604	0.0278*
Instructional Method*Experience1	1	1	0.108849	0.0397	0.8431
Instructional Method*Experience2	1	1	10.305144	3.7624	0.0603
Instructional Method*Experience3	1	1	0.695405	0.2539	0.6174

Oneway Analysis of Test 1 By Instructional Method



Excluded Rows 24

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

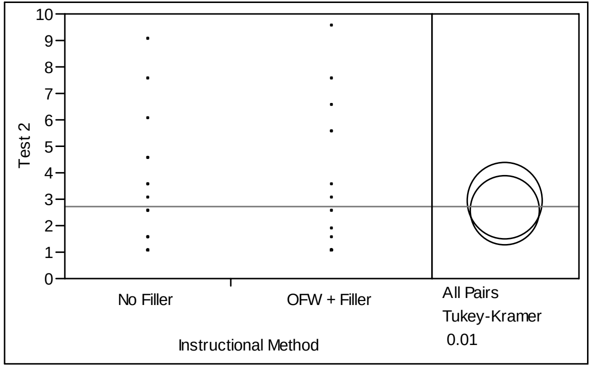
q*	Alpha
2.69807	0.01

Abs(Dif)-LSD

	OFW + Filler	No Filler
OFW + Filler	-1.9393	-1.3381
No Filler	-1.3381	-2.1244

Positive values show pairs of means that are significantly different.

Oneway Analysis of Test 2 By Instructional Method



Excluded Rows 24

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

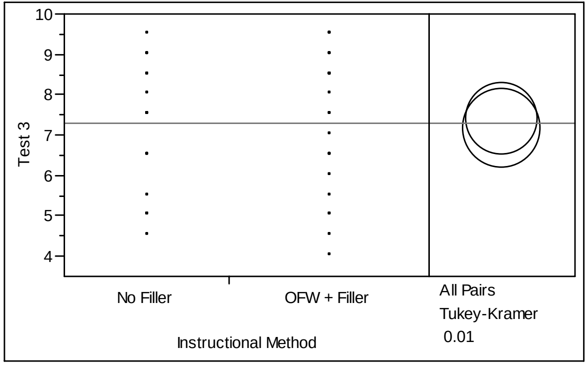
q*	Alpha
2.69807	0.01

Abs(Dif)-LSD

	No Filler	OFW + Filler
No Filler	-2.0712	-1.6167
OFW + Filler	-1.6167	-1.8907

Positive values show pairs of means that are significantly different.

Oneway Analysis of Test 3 By Instructional Method



Excluded Rows 24

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

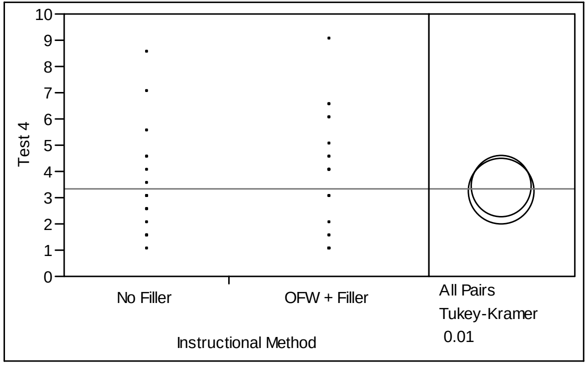
q*	Alpha
2.69807	0.01

Abs(Dif)-LSD

	OFW + Filler	No Filler
OFW + Filler	-1.2754	-1.1169
No Filler	-1.1169	-1.3972

Positive values show pairs of means that are significantly different.

Oneway Analysis of Test 4 By Instructional Method



Excluded Rows 24

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

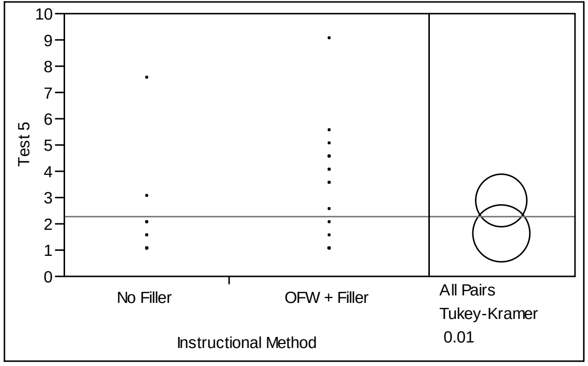
q*	Alpha
2.69807	0.01

Abs(Dif)-LSD

	OFW + Filler	No Filler
OFW + Filler	-1.6764	-1.5666
No Filler	-1.5666	-1.8364

Positive values show pairs of means that are significantly different.

Oneway Analysis of Test 5 By Instructional Method



Excluded Rows 24

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

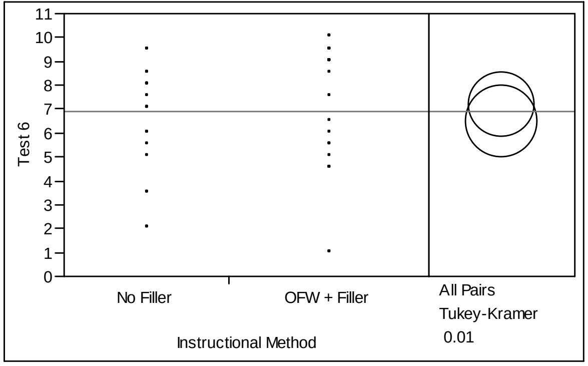
q*	Alpha
2.69807	0.01

Abs(Dif)-LSD

	OFW + Filler	No Filler
OFW + Filler	-1.4355	-0.2764
No Filler	-0.2764	-1.5726

Positive values show pairs of means that are significantly different.

Oneway Analysis of Test 6 By Instructional Method



Excluded Rows 24

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

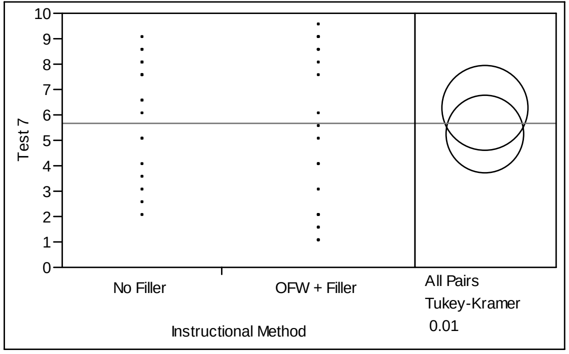
q*	Alpha
2.69807	0.01

Abs(Dif)-LSD

	OFW + Filler	No Filler
OFW + Filler	-1.9763	-1.3852
No Filler	-1.3852	-2.1649

Positive values show pairs of means that are significantly different.

Oneway Analysis of Test 7 By Instructional Method



Excluded Rows 24

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.69807	0.01

Abs(Dif)-LSD

	No Filler	OFW + Filler
No Filler	-2.4033	-1.2801
OFW + Filler	-1.2801	-2.1939

Positive values show pairs of means that are significantly different.