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A Comparison of Instructional Strategies for Teaching

Entry-Level Welding at the High School Level

Jared Paul Massic

A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Science

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School of Technology

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ABSTRACT

A Comparison of Instructional Strategies for Teaching
Entry-Level Welding at the High School Level

Jared Paul Massic
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Master of Science

The traditional method of teaching welding has remained unchanged for decades. In this model, an instructor gives demonstrations to a class of students and then helps them individually as they practice the techniques of welding. This traditional instructional method has been effective but is time consuming. Due to a significant increase in the demand for skilled welders within the United States, efforts have been made to develop more efficient methods of providing welding instruction. Various electronic welding guidance systems and virtual welding systems have recently been developed. In this study, the researcher addressed two questions 1) Does the use of an electronic welding guidance system improve the pass rate that entry-level high school students receive on basic gas metal arc weld tests? 2) Will entry-level high school students who learn gas metal arc welding with a guided welding training system learn how to weld faster and/or more proficiently than those taught using the traditional training method?

A study was performed in an entry-level high school welding class to determine the effectiveness of a guided welding instruction system in comparison to the traditional method of teaching welding. The results of the study indicated that the traditional method of teaching welding and the use of a guided welding system yielded similar results, both in quality and efficiency, in student ability to produce basic GMAW welds.

Keywords: Jared Massic, welding, education, welding education, vocational, industrial education, virtual reality, training, high school, gas metal arc welding

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I would like to thank Dr. W. Richard Polanin of Weld-Ed for giving me the initial guidance for this topic. I would like to also thank Jamey McIntosh from RealityWorks® who helped me acquire the guided welding systems for me to collect the data. I would like to thank Dr. Dennis Eggett, he verified the data was analyzed correctly. Thanks to Greg Smith and Gordon Reynolds for helping with the visual inspection of the welding tests. Thank you, Dr. Kip Christensen for being my chair, confidant and guide through this whole process. Finally, my wife Khristen Massic, for her patience and encouragement in helping me finish this goal.

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1 INTRODUCTION

1.1 Nature of the Problem

For decades, students have learned how to weld through attending a trade school and being taught by an instructor. In this teaching method, the instructor gives students examples of quality welds and demonstrates proper welding techniques. As an instructor makes his or her rounds to each welding station, he or she will give feedback on the welds that will satisfy the students' needs and help them progress. This is called the traditional welding method (TW). As a student goes through this method, it often takes many hours to complete.

With a class load of upwards of 30 students there is typically one, or on occasion, two instructors. In large classes, students may lose valuable time waiting for the opportunity to get feedback from the instructor. Oftentimes, much of this critique is letting the student know if his or her technique needs correction, i.e. are they moving too fast or slow across the plate or is the angle of approach too steep or shallow. If a student could have this feedback given immediately, his or her progress through a welding program might accelerate.

Researchers at The National Center for Welding Education and Training indicate that upwards of 300,000 jobs will be available in the welding industry by 2019 (Ondov, 2009). In order for students and educators to keep up with this demand, new teaching aides may be necessary to expedite the training process. There are a few options on the market for commercially produced welding training equipment. These options include virtual reality welding simulation systems (VW) and welding guidance systems (GW).

VW has been around in the welding industry since the early 2000's (Journal, 2004). Either by wearing a head set that will fully immerse a persons' vision in a welding environment or by looking at a monitor, VW allows a user to guide welding equipment in a simulated environment. A computer will track several types of movement from the user and calculate discrepancies. Depending on how accurate the user was in the system, a score is generated and feedback is given on ways for improvement. The student can look at the computer generated image of the weld and quickly see his or her progress.

GW is a hybrid of VW and TW. The student has the capability to run a live arc on weld, with regular welding machines, while a computer system monitors his or her movement. These GW systems can also be operated in a simulation mode to do a "test" run without arcing the welding machine and the computer will still track the student's movements with the welding equipment. Afterward, the student will get a score based on how accurate he or she welded the joint, and can see where the areas for improvement are by looking at both a real weld and the feedback on the GW monitor.

These equipment options range in price from a few thousand dollars to tens of thousands of dollars for one machine. However, with the help of these modern training aides, a student can receive this feedback almost instantaneously and not have to wait for an instructor every time improvements needed to be made.

In summary, "…welders [are] retiring at twice the pace of new welders coming into the field" (Shook, 2009) and students are not learning some of the aspects of welding well enough or fast enough to meet the demand created by people retiring from the welding profession. Welding training equipment (VW, GW) could quite possibly help students learn to weld more efficiently and, in turn, fill welding positions as they become open.

A review of literature was conducted, and the amount of research reported to date on the effectiveness of VW is minimal. Only one researcher was found using training aids and tracked the results against traditional welding (Stone, 2013; Stone, 2011; Stone, 2011). This study was limited in the sample size and referenced only an adult population. No research on this topic has been conducted with high school students. Additional research is needed to determine how effective VW and GW welding trainers are in training new welders for the profession and how effective VW and GW welders may be in training high school students in particular.

1.2 Purpose of the Research

The purpose of this research is to determine whether high school students in entry-level welding classes can learn how to weld proficiently and quickly through the use of welding training equipment (GW) as compared to students using the traditional method of learning to weld (TW).

1.3 Research Questions

Question 1: Does a welding guidance system (GW) improve an entry-level high school student's ability to learn to weld? This question was answered by addressing two more specific questions: (a) does the guided system improve final test scores compared to the traditional method on the three final welds completed by the students; and (b) does the guided system improve a student's probability of receiving a passing score on the three welds completed?

Question 2: Does a welding guidance system (GW) impact the efficiency with which students learn to weld? To answer this general question, the data must be analyzed to answer two more specific questions: (1) Does the guided system increase the number of passing welds per hour; and (2) Does the guided system improve materials usage efficiency?

2 REVIEW OF LITERATURE

2.1 Review of Literature

Ondov, Smith, and Visdos (Ondov, 2009) addressed in their writings that the United States is short of welding operators, and skilled workers are needed to take the jobs that are available. Dr. Ondovs' paper helped the author think of ways to focus his own research on the need to speed up the training of skilled welding operators. The Advanced Technological Education Centers are educational institutions across the U.S. that have partnered with the National Science Foundation to help prepare students of all levels to be ready for potential welding careers. Dr. Ondov's paper also provided important contacts/groups in industry, such as Weld-Ed, that could be used as references in the future. Weld-Ed has a three-fold mission, (a) Increase the number of welding technicians to meet the ongoing workforce needs; (b) Impact recruitment of women, minorities, and special needs workers; (c) Foster and enhance faculty professional development and continuing education for welding educators.

Ondov, et al went on to explain that the National Science Foundation grant for Weld-Ed was to help establish career pathways from high school through community colleges and universities; assist in the recruitment and preparation of welders, welding technicians, welding engineers; address immediate workforce needs; and to provide long-term guidance to the entire welding industry. Individuals at Weld-Ed would also explored ways to expand apprentice opportunities, and developed an outreach program to encourage more youth and/or job seekers to consider educational credentials and degrees specific to the high-demand welding and materials joining industry. Lastly, they have took on the responsibility to continually gather information and provide a true snapshot of today's needs leading to a "demand-driven" response through education, training, workforce, and economic development.

Stone, Watts, and Zhong conducted studies at the University of Iowa (Stone, 2013; Stone, 2011; Stone, 2011) using virtual welding (VW) simulators to teach entry-level students how to weld. The first paper published (Stone, 2011) mainly focused on the cognitive and physical impacts of learning how to weld using the integrated 50 percent VW/50 percent TW compared to 100 percent TW.   For the study conducted at ISU two welding labs were set up. One lab was outfitted with traditional welding equipment, welding booths, and supplies. The other lab was set up with virtual welding systems, welding booths and supplies. The study included twenty-two adult students in total. Half of the adults were taught at a time for two weeks each. One group received instruction with TW the whole time, and the other group was taught half time on VW and then half time on TW. These adults practiced four weld types ranging in difficulty from easy to moderate.

The results showed that the VW integrated group performed as well as, and in some cases significantly outperformed, the TW group. The study also showed the physical ability of these trainees by hooking up medical electrodes to specific muscle groups and tracking proper muscle contraction as welds were performed. Expert welders were also tested with these electrodes as they welded and the results were then compared with how the new trainees preformed. It was concluded that learning on the VW systems teaches comparable motor skills to that of TW.

Next, Dr. Stone published his findings on evaluating the training potential, team learning, material consumption, and cost implications of learning how to weld using integrated 50 percent

VW/50 percent TW compared to 100 percent TW (Stone, 2011). Using the same scenario as in their first study, the research team looked at the data in a different way. All the adults practiced the same four welds, over the same two-week period. Teams of two were developed when they started using the VW systems. It was observed that when the teams were operating TW equipment, they seemed to have less team interaction with each other. On the other hand, as the groups entered the VW section of the study, they began to communicate more with each other and had an increased desire to help each other to pass off the welding assignments.

As the adults went through the course of study for two weeks, the research team looked very closely at the number of metal plates used, the amount of welding electrodes used, and the time spent on each assignment. This was information was considered in terms of real world usage and virtual world usage. In relation to real world usage, researchers looked at both TW and the integrated VW groups, and the amount of metal and electrodes that were used. Being that the VW group only welded on physical material for one of the two weeks, they used less of the real material. However, when Dr. Stone looked at the amount of virtual material used by the VW group and combined it with their real-world use, it exceeded the use from the TW group. It was observed that in the VW system, the users would not be afraid to re-run a weld if the system said it was bad, and they also would not have to wait to have the material cut and tacked together. Also not having to track down the instructor to get their welds examined, they received immediate feedback and continued to practice and correct their actions. When the cost of materials consumed in VW instruction was compared with material used in TW, it was concluded that there was significant monetary savings with the integrated VW group.

Lastly, Dr. Stone and his team reported on the effectiveness of a 100 percent VW program compared to one that only used VW 50 percent of the time and TW the remaining 50 percent

(Stone, 2013). They looked specifically at the use of overlays in the VW system, performance, and physical impact. As the same for their first study, they used medical electrodes to track the muscle usage of their participants. This showed how well the 100 percent VW group learned proper muscle technique compared to the set of expert welders and those who learned how to weld with 50 percent VW. Between the two instructional methods, there was no significant difference in the pass rate of three out of the four welds practiced. The most difficult weld was a 3G vertical up test, and the students had a lower success rate, but they still had a high pass rate. In regard to performance, the research team discovered that 100 percent VW did just as well as the 50 percent VW group except for the most difficult weld. Dr. Stone concluded that using 100 percent VW for easy welds is a viable way for welding operators to be taught.

Overlays in the VW system were also looked at by Dr. Stone. Most VW systems have some sort of visual graphs that are available to be placed over the screen to give cues on ways to correct the operator, such as electrode angle, travel speed, etc. Multiple cues can be used individually, or the user can pick and choose multiple overlays that can help the user. These overlays can help with arc length, work angle, and travel angle to name a few. Dr. Stone was curious to see if any of these particular overlays were used and correlated to a better pass rate of assignments and welding tests. It was concluded that one or two overlays were more effective than others, and a few seemed to decrease the pass rate. A single overlay used by itself was also deemed more effective than multiple overlays used in one attempt. They called this the tipping point where a user could get distracted by trying to look at too many overlays at one time and their success would diminish.

In all, these papers that Dr. Stone wrote are beneficial in explaining how research could be conducted using different methods to teach welding. Dr. Stone's studies gave this researcher a direction in which to take this study, in comparing how effective different methods of welder training can be.

The benefits of using virtual reality welding machines (VW) to quickly and efficiently train new welding operators were discussed by White, Prachyabrued, and Chambers (White, 2011). These benefits included being able to train multiple welders at one time without having to hire a plethora of instructors; ease the burden of instructors; lower cost of the students' tuition and lastly; present the students with additional information both during and after their weld attempts can speed up their progress.

Dr. White's team concluded that to expeditiously fill the need for highly qualified welders, many of these VW systems are now needed in training centers. The problem is the VW systems are expensive. Most training systems range in price from $30-$70+ thousand dollars each. Dr. White related how he built a welding simulator for about $5,500 dollars. He included the list of materials and broke down the cost for each item. Dr. White also described how he received proper acoustics to simulate the sound of a real weld, as well as get an optimal graphic representation of a weld. Though this is good to know, Dr. White did not provide instructions on how to build such a machine. Furthermore, the typical welding teacher would not have the time or knowledge to make such a complex system. This study showed, however, that the VW systems are good at what they are designed to do but are overpriced for the market they are shooting for.

The researchers noted above indicate that VW welding training systems can decrease the amount of time needed to learn fundamental welding techniques. The research on VW is altogether minimal, and it's practically nonexistent with high school students. The proposed research examined the effectiveness of VW and GW in teaching high school students how to weld.

3 METHODOLOGY

3.1 Methodology

This study was conducted using three sections of an entry level welding course. The population consisted of 76 students; 48 students were fifteen years old, 18 students were sixteen years old, 9 students were seventeen years old, and 1 student was eighteen years old. One female student, and 75 male students were involved. Fifty-eight were sophomores, nine were juniors, and nine were seniors. Students were randomly assigned to one of the following methods of welding training within each section; (1) traditional welding (TW), or (2) the welding guidance system guideWELD™ (GW). Therefore, each section had students completing welds on both the GW and TW in the same lab at the same time, but only to their assigned method. To assist in assigning the students to a method, the researcher conducted a pre-test to make sure any inherent ability, or lack thereof, to weld can be tracked. The pre-test was scored out of ten points by using the rubric for weld samples (Document 1). The scores were grouped in three levels; High (10-8), Medium (7-4), and Low (3-0). To keep the skill level of the students in each group as equal as possible, an even number from each group were randomly assigned to each method of learning.

With approximately 75 students in the entry-level program, each training method had 33 ± 1-2 students. Students assigned to the TW group used the welding equipment that is typically used in a high school welding shop and those students practiced making real welds on metal plates. Those assigned to the GW group used the guideWELD™ system that tracks all the data similar to a virtual system. While the students actually welded on metal plates, they received feedback in their welding helmets and made adjustments in their techniques while they welded. As stated on Realityworks® website, "the guideWELD™ system provides immediate feedback on work angle, travel angle and speed from inside the welding helmet while the user is performing live, arc-on welds". (Realityworks)

Students were given eight hours of shop time. Eight hours was the chosen time frame because of the pace of this particular class. The goal was to simulate one full eight-hour day of training. Most students had never welded before this class. The students practiced only the Gas Metal Arc Welding (GMAW/MIG/wire feed) process on carbon steel while data was being collected. Welding positions were prescribed according to how gravity affects the axis of the weld (Figure 3-1).

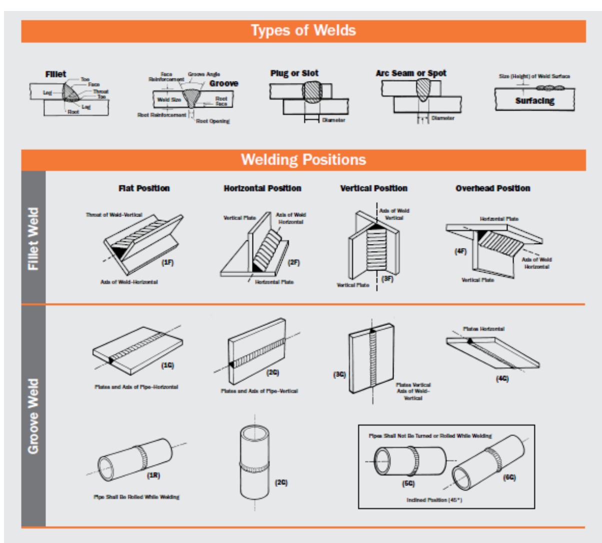


Figure 3-1 Weld Positions

In the eight hours available, students were asked to practice and perform a 1G Square Butt Joint (G Weld), a 2F Tee Joint (T Weld), and a 2F Lap Joint (L Weld) all on 1/8" and 1/4" thick by 2" wide and 6" long carbon steel. There were six total assignments. The eight hours of shop time occurred during approximately eight class periods over a total time of three weeks. A worksheet was given to all students to help them and the instructor track their progress (Document 2). This sheet helped the researcher in collecting the data points necessary.

Class periods ranged from 72 minutes to 82 minutes. This allowed for some instruction on theory and content knowledge at the beginning of class and a ten-minute clean up period at the end of class. When the school year started all students went through shop orientation and safety. This time was not calculated in their training time for this study. As well, all students were shown demonstrations on how to use the welding equipment. All students at this time were then given a welding pre-test. They welded a single stringer bead on 1/4" x 2" x 6" steel plate. Document 1 was used to develop a pre-test score and help with a fair stratified randomization of students assigned to each instructional method.

Students who followed the traditional method (TW) received critique and suggestions for improvement as they sought the guidance from the welding instructor on hand, typical of what they would receive in any traditional welding program. As they reached an approximate skill level of 85 percent, the instructor allowed them to move on to the next assignment. Metal plates were available for both TW and GW already cut into 2" x 6" pieces.

Students learning with the guided method (GW) received help from the instructor on setting up, operating equipment, and troubleshooting the technology. The instructor was available to help interpret the feedback and guide the students in their progress when necessary. It is a firm belief of the researcher that these machines were never intended to replace the role of an instructor, and as such, he still maintained proper intervention with the students. The simulators tracked every movement made by the operator and gave real time feedback. Each student practiced welding while receiving feedback from the machine and then produced welds until they reached the skill level of 85 percent, similar as those on TW.

Inspection and grading of all of the welds was conducted by the researcher who is a Certified Welding Inspector (CWI) and Certified Welding Educator (CWE). Both are credentials earned through the American Welding Society (AWS). Two independent CWI/CWE professionals, inspected the final weld tests to avoid any conflicts of interests. The criteria for inspection was based on Table 6.1 of AWS D1.1 welding code (Document 3). This table is intended to be the minimum standard at which to pass/fail a weld visually according to this particular welding code. Criteria for the rubric for weld samples were taken from this table and compiled as Document 1.

After both groups had eight hours of training time, all students were required to perform actual welds tests using traditional welding equipment and supplies. Students were given one chance at three specific hands-on welding tests on 1/4" thick carbon steel. Three skills competency tests were required, a 1G Butt Joint, a 2F Tee Joint, and 2F Lap Joint, all welded on a single side. These welds were graded visually on a ten point scale using Document 1. If it passed visually with an 8/10 and met the limits set by Table 6.2 it was considered a pass. No physical tests for weld strength were conducted. All weld tests were placed in metal buckets. Students were encouraged to put them in any of the 6 designated buckets. The CWI's pulled from these buckets also at random to do the final scoring.

The data from the different groups was analyzed and compared against each other using ANOVA and several Fisher's tests, which are statistical significance tests used in the analysis of contingency tables. The following observations were made for analysis. What was the amount of time taken by each student to pass each assignment? Did the student use the whole time allotted to him/her, and did the student finish ahead of schedule? Which group passed the most skills competency tests and qualification tests? Did any group do statistically better than the other on these tests? What was the amount time each student used to complete the welds? What was the number of attempts it took each student to complete each welding assignment? What was the number of metal coupons used by each student in order to pass off a weld? The data collected also provided information regarding the relative cost of the training programs.

The dependent variables were the rubric score, time taken, the number of attempts taken with each assignment, and the number of students who passed the weld tests. The independent variables were what method was used, pre-test score, final test score, and a possible look at what grade level the student was in (10^{th}, 11^{th}, or 12^{th}). It was unrealistic to expect perfect attendance among 75 different students throughout the course of the study. Therefore, data was dropped from the study for any student that was absent more than twice during the eight day trail.

4 FINDINGS

4.1 Findings: Question 1

Question 1: Does a welding guidance system (GW) improve an entry-level high school student's ability to learn to weld?

This question was answered by addressing two more specific questions: (a) does the guided system statistically improve final test scores compared to the traditional method on the three final welds completed by the students; and (b) does the guided system improve a student's probability of receiving a passing score on the three welds completed with statistically significance?

4.1.1 Effect of the Guided System on Final Test Scores

The final scores of three welds (T-, L-, and G-Weld) were tested whether the mean scores differed between the traditional and guided learning methods. This was analyzed using t-tests of differences in means. Before the experiment was initiated, it was hypothesized that the guided system would assist learning better than the traditional learning method. Therefore, all p-values are reported as one-sided p-values.

4.1.2 Average of Scores on Three Tests

All three test scores of each student were first averaged to provide an "Average of 3 Tests." A scatterplot of the "Average of 3 Tests" by learning method is shown below.

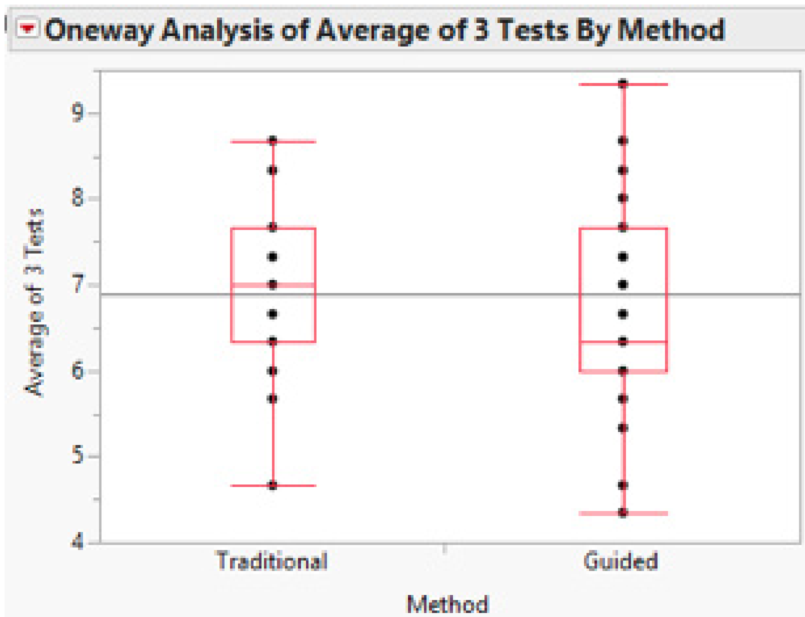


Figure 4-1 Average of 3 Tests

Table 4-1 Average of 3 Tests

Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Traditional	35	7.04762	1.01345	0.17130	6.6995	7.3958
Guided	36	6.75000	1.21466	0.20244	6.3390	7.1610

The data had an approximately normal distribution, and the standard deviations between the traditional and guided methods were not significantly different. The researcher used a pooled t-test to test the difference in the means (shown below).

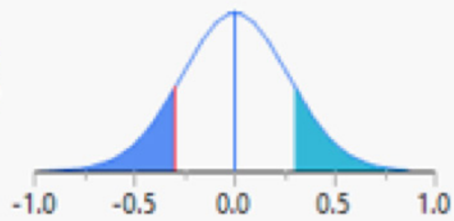
Table 4-2 Average Pooled t-test

t Test

Guided-Traditional

Assuming equal variances

Difference	-0.29762	t Ratio	-1.1194
Std Err Dif	0.26587	DF	69
Upper CL Dif	0.23279	Prob > |t|	0.2669
Lower CL Dif	-0.82802	Prob > t	0.8666
Confidence	0.95	Prob < t	0.1334



No evidence was found that the guided system improves average test scores (one-sided *p*-value = 0.866). Although the difference is not significant, students that used the guided welding system actually scored slightly lower than students using the traditional method, on average (by 0.30 points).

Table 4-3 G-Weld Analysis

Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Traditional	35	6.34286	2.12745	0.35960	5.6121	7.0737
Guided	36	6.25000	2.16960	0.36160	5.5159	6.9841

Table 4-4 T-Weld Analysis

Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Traditional	35	7.42857	1.24347	0.21018	7.0014	7.8557
Guided	36	6.94444	1.54817	0.25803	6.4206	7.4683

Table 4-5 L-Weld Analysis

Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Traditional	35	7.37143	1.19030	0.20120	6.9625	7.7803
Guided	36	7.05556	1.09400	0.18233	6.6854	7.4257

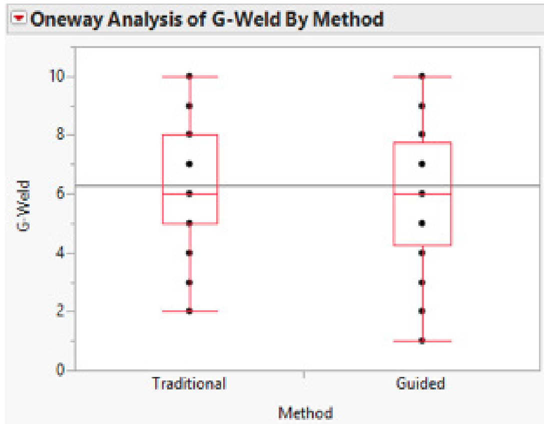


Figure 4-3 G-Weld Analysis

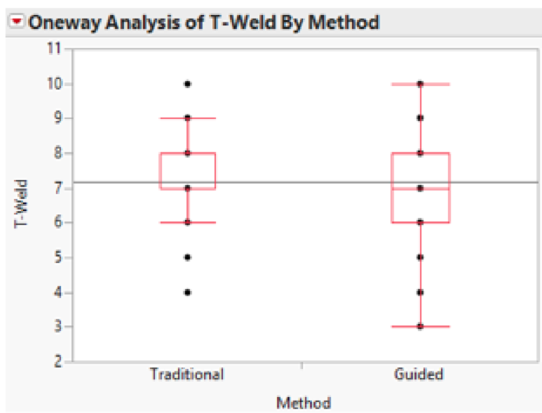


Figure 4-2 T-Weld Analysis

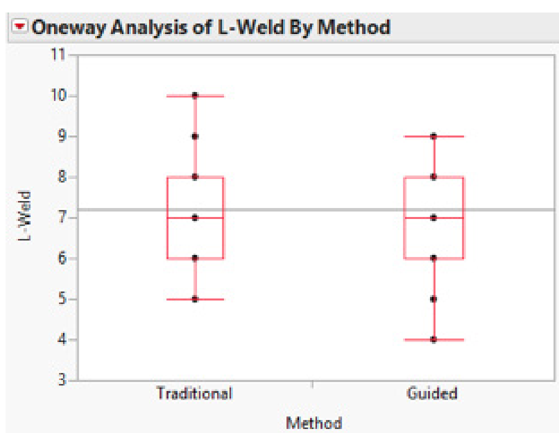


Figure 4-4 L-Weld Analysis

The researcher was interested to know whether the guided system improved any of the three welds. A discussion of these analyses follows. A scatterplot of the scores of each test by learning method is shown below.   As with the "Average of 3 Tests," the data indicates that all three samples had an approximately normal distribution, and that the standard deviations between the traditional and guided methods did not vary significantly. A pooled t-test was used to evaluate the difference in the means for each test (shown below).

Table 4-6 T-Weld Pooled t-test

t Test

Guided-Traditional

Assuming equal variances

Difference	-0.4841	t Ratio	-1.45023
Std Err Dif	0.3338	DF	69
Upper CL Dif	0.1818	Prob > |t|	0.1515
Lower CL Dif	-1.1501	Prob > t	0.9242
Confidence	0.95	Prob < t	0.0758

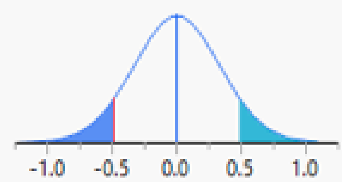


Table 4-7 L-Weld Pooled t-test

t Test

Guided-Traditional

Assuming equal variances

Difference	-0.31587	t Ratio	-1.16473
Std Err Dif	0.27120	DF	69
Upper CL Dif	0.22515	Prob > |t|	0.2481
Lower CL Dif	-0.85690	Prob > t	0.8759
Confidence	0.95	Prob < t	0.1241

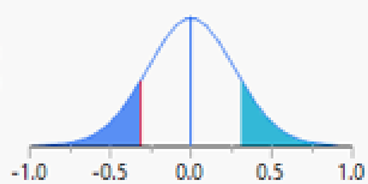


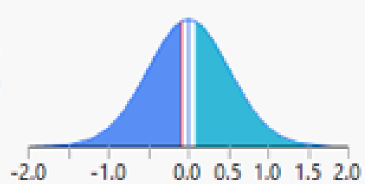
Table 4-8 G-Weld Pooled t-test

t Test

Guided-Traditional

Assuming equal variances

Difference	-0.0929	t Ratio	-0.18203
Std Err Dif	0.5101	DF	69
Upper CL Dif	0.9248	Prob > |t|	0.8561
Lower CL Dif	-1.1105	Prob > t	0.5720
Confidence	0.95	Prob < t	0.4280



There was no statistical evidence that the guided system improved test scores on the T-Weld (one-sided *p*-value = 0.924), L-Weld (one-sided *p*-value = 0.8759), or the G-Weld (one-sided *p*-value = 0.572). Although the differences were not significant, students that used the guided welding system scored slightly lower on all three tests than those using the traditional method (by 0.48 points for T-Weld, by 0.32 points on the L-Weld, and by 0.09 points on the G-Weld).

4.1.3 Effect of Guided System on Final Test Passing Rate

Looking in relation to whether the guided welding system improved a student's passing rate on the final tests. Scores were given on a scale of 0-10. In order to pass the weld test, a score of 8 or higher was required. A mosaic plot showing probability of receiving a passing score on each test is below.

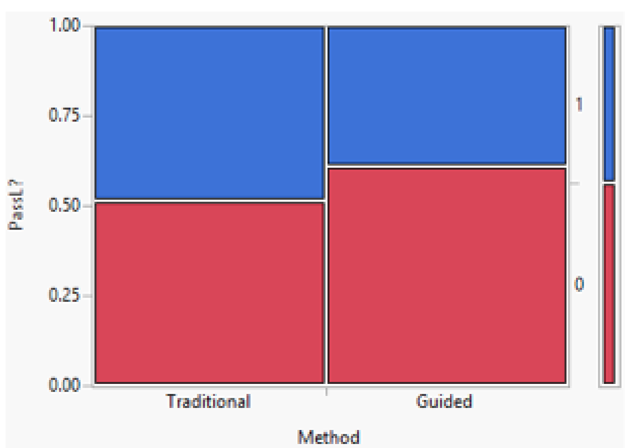


Figure 4-5 L-Weld Mosaic Plot

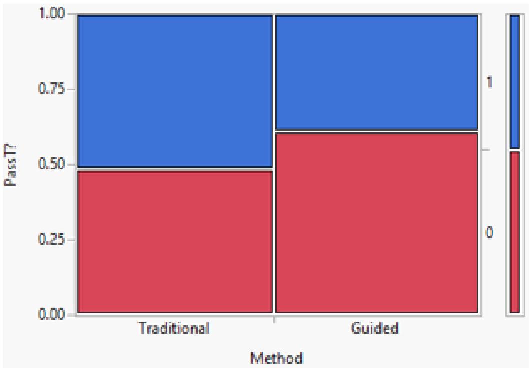


Figure 4-6 T-Weld Mosaic Plot

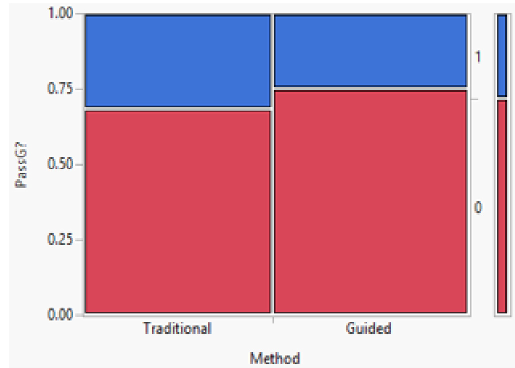


Figure 4-7 G-Weld Mosaic Plot

The contingency table provided below shows that of all students passing the T-Weld test, 43.75 percent used a guided welding system. Fisher's test shows that, given this particular data, the probability of passing the T-Weld test is not significantly greater for a student using the guided system (p-value = 0.903).

Table 4-9 T-Weld Fisher's

Fisher's Exact Test	Prob	Alternative Hypothesis
Left	0.2053	Prob(PassT?=1) is greater for Method=Traditional than Guided
Right	0.9034	Prob(PassT?=1) is greater for Method=Guided than Traditional
2-Tail	0.3442	Prob(PassT?=1) is different across Method

Table 4-10 T-Weld

Method	Count / Total % / Col % / Row %	PassT? 0	PassT? 1	
	Traditional	17	18	35
		23.94	25.35	49.30
		43.59	56.25	
		48.57	51.43	
	Guided	22	14	36
		30.99	19.72	50.70
		56.41	43.75	
		61.11	38.89	
		39	32	71
		54.93	45.07	

The contingency table provided below shows that of all students passing the L-Weld test, 45.16 percent of them used a guided welding system. Fisher's test shows that, given this particular data, the probability of passing the L-Weld test is not significantly greater for a student using the guided system (p-value = 0.856).

Table 4-11 L-Weld Fisher's

Fisher's Exact Test	Prob	Alternative Hypothesis
Left	0.2801	Prob(PassL?=1) is greater for Method=Traditional than Guided
Right	0.8558	Prob(PassL?=1) is greater for Method=Guided than Traditional
2-Tail	0.4771	Prob(PassL?=1) is different across Method

Table 4-12 L-Weld

Method	Count / Total % / Col % / Row %	PassL? 0	PassL? 1	
Traditional	Count	18	17	35
	Total %	25.35	23.94	49.30
	Col %	45.00	54.84	
	Row %	51.43	48.57	
Guided	Count	22	14	36
	Total %	30.99	19.72	50.70
	Col %	55.00	45.16	
	Row %	61.11	38.89	
		40	31	71
		56.34	43.66	

The contingency table provided below shows that of all students passing the G-Weld test, 45 percent of them used a guided welding system. Fisher's test shows that, given this particular data, the probability of passing the G-Weld test is not significantly greater for a student using the guided system (p-value = 0.807).

Table 4-13 G-Weld Fisher's

Fisher's Exact Test	Prob	Alternative Hypothesis
Left	0.3677	Prob(PassG?=1) is greater for Method=Traditional than Guided
Right	0.8066	Prob(PassG?=1) is greater for Method=Guided than Traditional
2-Tail	0.6047	Prob(PassG?=1) is different across Method

Table 4-14 G-Weld

Method	Count / Total % / Col % / Row %	PassG? 0	PassG? 1	
Traditional	Count	24	11	35
	Total %	33.80	15.49	49.30
	Col %	47.06	55.00	
	Row %	68.57	31.43	
Guided	Count	27	9	36
	Total %	38.03	12.68	50.70
	Col %	52.94	45.00	
	Row %	75.00	25.00	
		51	20	71
		71.83	28.17	

4.2 Findings: Question 2

Question 2: Does a welding guidance system (GW) impact the efficiency with which students learn to weld?

To answer this general question, the data must be analyzed to answer two more specific questions: (1) Does the guided system increase the number of passing welds per hour; and (2) Does the guided system improve materials usage efficiency?

4.2.1 Effect of the Guided System on Passing Welds Per Hour

The first question was tested by performing a multiple linear regression using the following model:

$$\text{Passes per hour} = \beta_0 + \beta_1\text{Guided} + \beta_2\text{Average of 3 Tests} + \beta_3\text{Absences} \qquad (4\text{-}1)$$

The reasoning behind including the average score of the 3 tests and absences as control variables is based on our hypothesis. It was expected that the average final score correlated with both the method of learning and the number of welds passed per hour. Also, it was expected that the number of absences would correlate with both the method and the number of passes per hour. These expectations lead the researcher to believe that leaving the variables out of the model would result in a biased estimate of β_1 for the effect of method on passes per hour.

The residual plot from the regression has no discernable pattern (shown below). This suggests that the model meets the assumption of reasonably constant variance. Also, the central limit theorem suggests that normality assumption is reasonable because the sample size was relatively large (70) and the groups were approximately the same size.

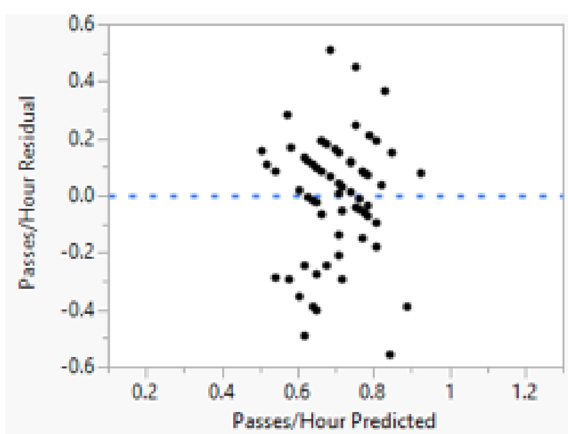


Figure 4-8 Group Residual Plot

Using this data, there was not a significant difference in passes per hour between the two welding methods (p-value = 0.5335, one sided p-value = 0.26675). However, the best estimate for the difference in mean passes per hour between guided and traditional methods while holding the average of 3 tests and number of absences constant is 0.032. Consequently on average this model suggests that a student using the guided system passed 0.032 more welds per hour than a student using the traditional system. The 95 percent confidence interval for this difference is from -0.07 to 0.135. We note that the average of 3 tests is statistically significant while the number of absences only has suggestive significance in effecting passes per hour. The complete results are shown in the table below.

Table 4-15 Welds Per-Hour Guided

Indicator Function Parameterization

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|	Lower 95%	Upper 95%
Intercept	0.1968472	0.166614	67.00	1.18	0.2416	-0.135715	0.5294094
Method[Guided]	0.0321724	0.051398	67.00	0.63	0.5335	-0.070419	0.1347637
Average of 3 Tests	0.0666384	0.023125	67.00	2.88	0.0053*	0.0204808	0.1127961
Absences	0.0688952	0.04144	67.00	1.66	0.1011	-0.013818	0.1516089

4.2.2 Effect of the Guided System on Materials Usage

This research question was tested by performing a multiple linear regression on the following model:

$$\text{Plates per hour} = \beta_0 + \beta_1\text{Guided} + \beta_2\text{Score} + \beta_3\text{Absences} \qquad (4\text{-}2)$$

The reasoning behind including the average score of the 3 tests and absences as control variables are the same as in the prior question. It was expected that including these control variables resulted in an unbiased estimate of β_1. The residual plot below shows a few residuals far above others. However, these residuals do not change across level of predicted values. This suggests that the model meet the assumption of reasonably constant variance. Also, the central limit theorem suggests that normality assumption was reasonable because the sample size was relatively large (46) and the groups were approximately the same size.

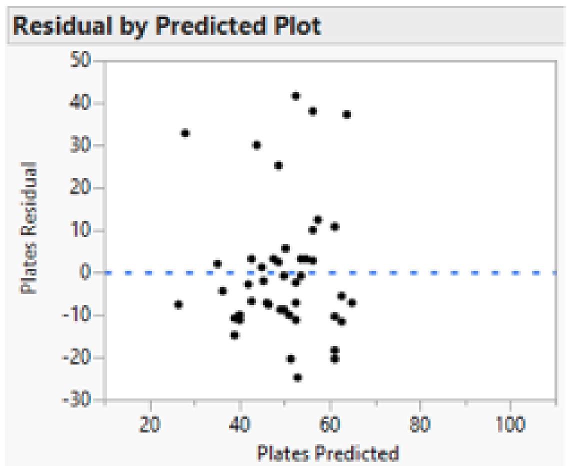


Figure 4-9 Material Usage Guided

Using this data, statistically significant difference was not found in plate usage between guided and traditional methods (p-value = 0.12, one sided p-value =.94). However, the best estimate for the difference in mean plates used between guided and traditional methods while holding the average of 3 tests and number of absences constant is 7.56. Thus, on average this model suggests that a student who used the guided system used 7.56 more plates than a student using the traditional system. However, this difference has a p-value of 0.94 with a 95 percent confidence interval from -2.05 to 17.18. This suggests that we fail to find support that the guided method reduces materials usage. The results are only marginally suggestive of a difference. However, since the coefficient is positive, the marginally suggestive evidence is not in support of guided welding being more efficient in terms of materials usage. The complete results are in the following table.

Table 4-16 Material Usage Guided

Indicator Function Parameterization

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|	Lower 95%	Upper 95%
Intercept	77.79045	19.30024	43.00	4.03	0.0002*	38.867802	116.7131
Method[Guided]	7.5635785	4.76823	43.00	1.59	0.1200	-2.052473	17.17963
Average of 3 Tests	-3.804226	2.572913	43.00	-1.48	0.1465	-8.993	1.3845485
Absences	-9.746594	3.448933	43.00	-2.83	0.0071*	-16.70203	-2.791157

5 CONCLUSIONS

5.1 Limitations

One limitation of this study is derived as a natural consequence of the pool of participants. The subjects in the experiment were high school students that, as a group may have had essential differences from others who would use this guided-welding technology to learn welding. The ages of the students were as follows: 48 students were fifteen years old, 18 students were sixteen years old, 9 students were seventeen years old, and 1 student was eighteen years old. Teenaged individuals may be less cognitively developed, or not as conscientious in their learning as older individuals who would be willing to pay to learn how to weld to progress toward a profession in welding. This lower level of maturity, motivation, and possible lack of effort could play as a confounding element that distorts the true potential of the guided welding system to improve learning for individuals for whom the technology would be intended. Future research should use subjects that are more serious about welding as a career.

Another possible reason that the researcher didn't find more significant results is that the system was used over a relatively short time frame, only eight hours. The complexity of the guided-system equipment might have overwhelmed some students. Much of their welding time may have been used to learn how to use the guided system instead of actually learning how to weld. Setting up the guided equipment and calibrating it regularly, replacing batteries were tasks the students had to bear every class period. It is hypothesized that future research similar to this study with a longer period of time for training may hold different results. As students could become more familiar with the routine of the equipment, they might in turn be more receptive to the feedback and quicker to correct, and pass off at a higher score.

Since the experiment used a randomized treatment, inference can be made that the difference in teaching methods caused the changes in the response variables. However, the results cannot be generalized to a broader population.

5.2 Conclusions

The analysis did not provide any evidence that the welding guidance system impaired the test scores or pass rate of an entry-level high school student to learn to weld. Neither did it suggest that the welding guidance system was able to significantly impact the efficiency with which students learned to weld in terms of passes per hour or material usage. According to the data, students taught using the guided welding system were able to pass off welds slightly faster than students being taught using the traditional instructional method.

Learning how to weld and pass off assignments is time-consuming and often results in delayed feedback from an instructor. From an instructor's perspective, having a line of students waiting for small tidbits of information to help a student progress is concerning. The guided welding system was able to immediately provide information regarding work angle, travel angle, and speed rate to students as they practiced welding. Quickly receiving this information is one of reasons the researcher believes that the guided system helped students pass off welds slightly faster per hour than the traditional method. Therefore, in a high school setting, a guided welding system could be a viable supplement to the traditional welding method provided funding is available to purchase the equipment.

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APPENDIX A. DOCUMENTS

A.1 Rubric

Document 1

A comparison of instructional strategies for teaching entry level welding at

The high school level rubric for weld samples.

Fusion	Weld Profile	Weld Size	Undercut	Porosity	Spatter
Complete + 2	Smooth Contour + 2	= Plate T + 2	None + 1	Under 3/8 + 1	Little/None + 2
Moderate + 1	Moderate Crown + 1	= Plate T +/- 1/8 + 1	Any Over 1/32 + 0	Over 3/8 + 0	Moderate + 1
Little/None + 0	High Stress Riser + 0	= Plate T over 1/8 + 0			Excessive + 0
					Total /10

A.2 Progress Tracking

Document 2

A comparison of instructional strategies for teaching entry level welding at

The high school level worksheet for students.

What Method

Traditional (TW) ☐

teachWELD (VW) ☐

guideWELD (GW) ☐

Student ID#

____

Assignments

Two attempts at 85% each

#1. 2F Tee 1/8" thick   Signature 1 _____/Score_____ Signature 2 _____/ Score_____

#2. 2F Lap 1/8" thick   Signature 1 _____/Score_____ Signature 2 _____/ Score_____

#3. 1G Butt 1/8" thick   Signature 1 _____/Score_____ Signature 2 _____/ Score_____

#4. 2F Tee 1/4" thick   Signature 1 _____/Score_____ Signature 2 _____/ Score_____

#5. 2F Lap 1/4" thick   Signature 1 _____/Score_____ Signature 2 _____/ Score_____

#6. 1G Butt 1/4" thick   Signature 1 _____/Score_____ Signature 2 _____/ Score_____

DAY	Assignments Passed off (I.E. #1, #2...)	How many Attempts at each weld?	# of Metal plates used Today
1			
2			
3			
4			
5			
6			
7			
8			

TESTS	Visual	Destructive
2F Tee	Yes☐ No ☐/ Score________	x
2F Lap	Yes☐ No ☐/ Score________	x
1G Butt	Yes☐ No ☐/ Score________	Yes☐ No ☐

-

A.3 AWS D1.1 Table 6.1

Document 3

Table 6.1
Visual Inspection Acceptance Criteria[1] (see 6.9)

Discontinuity Category and Inspection Criteria	Statically Loaded Nontubular Connections	Cyclically Loaded Nontubular Connections
(1) Crack Prohibition Any crack is unacceptable, regardless of size or location.	X	X
(2) Weld/Base-Metal Fusion Thorough fusion shall exist between adjacent layers of weld metal and between weld metal and base metal.	X	X
(3) Crater Cross Section All craters shall be filled to provide the specified weld size, except for the ends of intermittent fillet welds outside of their effective length.	X	X
(4) Weld Profiles Weld profiles shall be in conformance with 5.24.	X	X
(5) Time of Inspection Visual inspection of welds in all steels may begin immediately after the completed welds have cooled to ambient temperature. Acceptance criteria for ASTM A 514, A 517, and A 709 Grade 100 and 100 W steels shall be based on visual inspection performed not less than 48 hours after completion of the weld.	X	X
(6) Undersized Welds The size of a fillet weld in any continuous weld may be less than the specified nominal size (L) without correction by the following amounts (U): L, specified nominal weld size, in. (mm) — U, allowable decrease from L, in. (mm) ≤ 3/16 (5) — ≤ 1/16 (2) 1/4 (6) — ≤ 3/32 (2.5) ≥ 5/16 (8) — ≤ 1/8 (3) In all cases, the undersize portion of the shall not exceed 10% of the weld length. On web-to-flange welds on girders, no underrun is permitted at the ends for a length equal to twice the width of the flange.	X	X
(7) Undercut (A) For material less than 1 in. (25 mm) thick, undercut shall not exceed 1/32 in. (1 mm), except that a maximum 1/16 in. (2 mm) is permitted for an accumulated length of 2 in. (50 mm) in any 12 in. (300 mm). For material equal to or greater than 1 in. thick undercut shall not exceed 1/16 in. (2 mm) for any length of weld.	X	
(B) In primary members, undercut shall be no more than 0.01 in. (0.25 mm) deep when the weld is transverse to tensile stress under any design loading condition. Undercut shall be no more than 1/32 in. (1 mm) deep for all other cases.		X
(8) Porosity (A) Complete joint penetration groove welds in butt joints transverse to the direction of computed tensile stress shall have no visible piping porosity. For all other groove welds and for fillet welds, the sum of the visible piping porosity 1/32 in. (1 mm) or greater in diameter shall not exceed 3/8 in. (10 mm) in any linear inch of weld and shall not exceed 3/4 in. (20 mm) in any 12 in. (300 mm) length of weld.	X	
(B) The frequency of piping porosity in fillet welds shall not exceed one in each 4 in. (100 mm) of weld length and the maximum diameter shall not exceed 3/32 in. (2.5 mm). Exception: for fillet welds connecting stiffeners to web, the sum of the diameters of piping porosity shall not exceed 3/8 in. (10 mm) in any linear inch of weld and shall not exceed 3/4 in. (20 mm) in any 12 in. (300 mm) length of weld.		X
(C) Complete joint penetration groove welds in butt joints transverse to the direction of computed tensile stress shall have no piping porosity. For all other groove welds, the frequency of piping porosity shall not exceed one in 4 in. (100 mm) of length and the maximum diameter shall not exceed 3/32 in. (2.5 mm).		X

1. An "X" indicates applicability for the connection type; a shaded area indicates non-applicability.

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