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Assessing the Impact of Sequencing Practicums for Welding in Agricultural Mechanics

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Abstract

This study examined the impact of sequencing practicums for welding on students' ability to perform a 1F (flat position-fillet lap joint) weld on low-carbon steel. Participants were randomly assigned a specific practice sequence of welding for using gas metal arc welding (GMAW) and shielded metal arc welding (SMAW). A total of 71 participants (70.3%, N = 104) completed the research project. The majority of participants (95.8%, f = 69) were male. There was no significant difference between treatment groups on the written pretest (F = .847(3), p = .473) or posttest scores (F = .669(3), p = .574). Few students (15%, f = 11) met the performance standards for passing the cracks criterion using SMAW. The majority of students were able to meet the undercut criterion standard using both GMAW and SMAW. The mean weld performance test score among all treatment groups for GMAW was three out of four (SD = 1.04), while the mean weld performance test score for all SMAW treatment groups was two out of four (SD = 1.36). There were no significant differences between treatment groups and weld test performance. This project provided baseline data in understanding sequencing welding laboratory practicums by limiting operator-controlled variables.

Keywords: Agricultural Mechanics, Welding, Laboratory, Skill Development, Learning

Obtaining expertise, the highest level of proficiency in a motor skill, generally requires years of practice (Ericsson & Lehmann, 1996). Learning to acquire a motor skill requires relevant instruction in controlled, coordinated movement sequences (Wulf, HÖß, & Prinz, 1998). Typically, instruction is focused on correct movement patterns through teacher-led demonstrations and supervised laboratory practicums (Wulf et al., 1998). Factors such as available classroom time and laboratory equipment can limit the amount of time available for practice. These factors have placed added emphasis on time management of agriculture teachers to maximize laboratory time used for practicing motor skills (Guadagnoli & Lee, 2004). Moore (2010) stated there are process-controlled and operator-controlled variables that determine the quality of an acceptable weld. Operator-controlled variables include travel speed, work angle, arc length, and travel angle. These variables are taught to students through welding practicums

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designed by agriculture teachers. To demonstrate welding competency, students are frequently asked to complete performance based tests. Utah's introductory agricultural systems and technology courses require students to fabricate metal projects using gas metal arc welding (GMAW) and shielded metal arc welding (SMAW) processes. Mastery of these welding processes are determined by having students perform various weld tests using low carbon steel (Utah State Office of Education, 2011). This study addresses the "meaningful, engaged learning in all environments" priority area of the 2011-2015 American Association for Agricultural Education National Research Agenda as it pertains to effective instructional interventions for agricultural systems technology (Doerfert, 2011). This study focused on reducing the number of operator-controlled variables during welding practicums to improve secondary students' ability to meet weld quality standards.

The theoretical framework underpinning this study was constructed using cognitive information processing learning theory as it describes the influence of cognitive load (Andre & Phye, 1986; Mayer & Moreno, 2003), an ecological approach to motor-skill acquisition, and the role of deliberate practice for the development of expert-like motor skills.

Cognitive information processing learning theory conceptualizes learning and behavior being generated through a person's interaction with the environment, previous experiences, and current knowledge (Andre & Phye, 1986). From a cognitive information processing perspective, learning is viewed as a series of active, constructive, and goal-oriented mental processes that rely heavily on the presence of metacognition (Shuell, 1986). Pate and Miller (2011) explained that metacognition is actively attending to one's thinking processes. Individuals have the ability to adapt to new learning scenarios, such as transferring between performing GMAW and SMAW, through information processing (Phye, 2005). This process begins through stimulus input either by visual or audio, acting on the corresponding senses followed by pattern recognition where the stimulus input is assigned meaning (Schunk, 2008). This information is then transferred into working memory to be acted upon for incorporation into long-term memory storage. This regulation of information flow is controlled by executive process commonly termed as metacognition (Nelson & Narens, 1990).

Through the cognitive information-processing lens, learning is described as a complex and dynamic progression, taking shape through different types of cognitive information processing. Learning is commonly exhibited in various outcome measures such as, intellectual skills, verbal information, cognitive strategies, motor skills and attitudes, depending on the type of performance desired (Gagné, 1984). Motor skills are observed and targeted as learning outcomes in many agricultural education welding courses. To examine the development of motor skills needed for welding, we can conceptualize the model of the human mind as a computer. The processing of information is limited by the capacity of the human mind, where raw, sensory information is channeled and then acted upon through the realization of a stored motor skill progression (Handford, Davids, Bennett, & Button, 1997). Handford's et al. (1997) view of movement coordination and skill acquisition suggested that instructors incorporate an ecological approach when designing instructional interventions. Examining instruction for motor skill development through an ecological approach suggests that the organization of practice sessions should focus on the manipulation of environmental and task structures to guide students through the development of an appropriate motor skill progression (Handford et al., 1997). Having structured practices should create a positive effect on acquiring welding skills.

Guadagnoli and Lee (2004) stated that learning a motor skill is intimately related to the information available and learning can be slowed due to the presence of too much information. To improve the effectiveness of deliberately structured practices it is suggested that students concentrate on the resulting effects of movements, rather than on the movements themselves (Wulf, HÖß, & Prinz, 1998). This theory suggests that performance will be disrupted if individuals are paying too much attention to their own motor skill movements. This attention may distract from attending to perceptual information created during the activity that may improve the quality and control of coordinated movements (Handford et al., 1997). As indicated previously, introductory welding students must attend to numerous variables in order to perform a quality weld. Operators of welding equipment must manage complex hand-eye coordination to complete various welding positions, such as overhead and vertical. The operator must manipulate the electrode by hand to establish and maintain the arc, as well as providing a continuous steady travel over the joint to complete the weld. This increase in the number of variables competing for students' attention may increase the chances of cognitive overload (Mayer & Moreno, 2003).

If a reduction in the number of variables can be achieved by sequencing skill practicum, it is possible to improve introductory welding students learning experiences within agricultural mechanics courses. Ericsson, Krampe, and Tesch-Römer (1993) stated motor skill practice should be approached in such a fashion so that learners are presented a structure with clearly defined limits and properties of the perceptual-motor workspace. Congruent with the ecological approach, Ericsson et al. (1993) suggested that the instructor organize the sequence of appropriate training tasks and monitor improvement to decide when transitions to more complex and challenging tasks are appropriate. This could prove to be a valuable tool when transitioning students from GMAW to SMAW laboratory practicums.

Eliminating variables students have to control during the welding process can help in mastering American Welding Society (AWS) welding skill tests, students can be better prepared more quickly for a welding related career. Examining different welding approaches may be beneficial in helping shorten the preparation time of entry welders (Sgro, Field, & Freeman, 2008). The AWS (2006) recommended welding sequence instructors teach individuals in an entry-level course shielded metal arc welding (SMAW) followed by gas metal arc welding (GMAW). Although this sequence is not mandatory, the instructor, organization, or state educational authority should use a sequence that has been found to be most suited to the capabilities of the trainees. Pate, Warnick, and Meyers (2012) found experienced agriculture teachers perceived pre-service teacher training should focus on "managing the laboratory setting, for effective student learning" to help new and beginning teachers successfully teach a welding course (p. 179). Anecdotal evidence has shown that SMAW is the most difficult weld process to master by secondary students. GMAW requires fewer operator-controlled variables than SMAW (Hoffman, Dahle, & Fisher, 2012). Having fewer operator-controlled variables during welding practice sessions should improve secondary students' ability to meet weld quality standards for an ASW 1F test (flat position-fillet tee weld). This could be accomplished by sequencing the welding practicums so students practice welding with GMAW first followed by SMAW. This may translate to improved student performance of SMAW. Little research has been done to determine if reducing focus on operator-controlled variables during welding will improve students' ability to produce higher quality welds.

The purpose of this study was to determine if having fewer operator-controlled factors during welding practicums will improve secondary students' ability to meet weld quality standards for an AWS 1F test (flat position-fillet lap joint). The following research objectives guided the study:

1. Determine the impact of sequencing welding skill laboratory practicums for GMAW and SMAW mastery of AWS standards for AWS 1F (flat-position fillet lap joint) welds.
2. Determine if limiting variables that secondary students have to control during welding practice will improve their ability to produce higher quality AWS 1F (flat position-fillet lap joint) welds using the SMAW process.

Null Hypothesis

There will be no significant difference between treatments of welding practice sequencing on students' SMAW AWS 1F weld scores.

Methodology

Participants

The research protocol was approved under Utah State University's Institutional Review Board under protocol number 4954. Four classes with an average of 26 students with a total of 104 students enrolled in agricultural systems and technology courses at a rural school in Utah participated in this quasi-experimental design study. Students ranged from freshman to seniors in high school (14-18 years of age).

Project Design

Intact classes were utilized for this quasi-experimental study. A randomized block design was used for the implementation of the treatments. The experiment was performed over six class periods with a span of three calendar weeks. Each class met every other day (block schedule) for 75 minutes. Classes held on Monday were shortened by 10 minutes due to an early-out schedule within the school district. The first 15 minutes of each day was used to attend to classroom policies and procedures. During day one of the experiment, all students were given an instructor developed pretest. This multiple choice exam consisted of 15 questions aligned with Utah Agricultural Systems and Technology I Standards and Objectives (Utah State Office of Education, 2011). The exam was reviewed by four curriculum experts and was deemed valid. Questions were designed to assess students' knowledge of each welding process. The pretest was used to check for any preexisting differences that may impact test results. The differences detected were used as a covariate to explain any prior welding experience. Prior to each practicing session, an instructor based demonstration was given for each welding process. Welds were created on 3/16"X 4" flat carbon steel using Lincoln Power MIG 255 MIG welders using ER70-S electrode with 100 percent carbon dioxide shielding gas and Lincoln Invertec V275-S stick welders with E7018, 3/32" electrodes. All students were provided with personal protection equipment including a passive filter shade 10 welding helmet. The demonstration discussed and exposed students to proper machine settings, ways to properly position the metal coupons for the AWS 1F position, proper bead formation and size, and correct travel angles, speed, and arc length. The demonstration was given before each practice session and students were asked to rotate between processes each day of the study.

Treatments

During day three of the experiment, students in each class were randomly assigned into treatment groups. A total of four treatment groups – with differences based on sequence of welding process practice sessions and sequence of welding process performance exams, were used. Table 1 provides the schedule of events. The students practiced AWS 1F lap joint welds using the first assigned welding process for 60 minutes. The following class session, students practiced the second assigned welding process for 60 minutes. As students engaged in the practice sessions, the instructor supervised and provided instantaneous feedback during the welding process and immediately after each weld was completed. Students were asked to perform one practice weld and present it to the instructor for feedback. After suggestions were made, students then completed other practice welds.

During the last two class sessions, students were asked to complete two welding performance exams using either the SMAW process or the GMAW process. Upon completion of the welding performance exams, all students were administered an instructor developed posttest to determine retention of content knowledge.

Table 1

Schedule of Events – Practice (P) and Test (T)

	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Session 1	Pretest	Pretest	Pretest	Pretest
Session 2	Instruction	Instruction	Instruction	Instruction
Session 3	PGMAW	PSMAW	PGMAW	PSMAW
Session 4	PSMAW	PGMAW	PSMAW	PGMAW
Session 5	TGMAW	TSMAW	TSMAW	TGMAW
Session 6	TSMAW	TGMAW	TGMAW	TSMAW
Session 7	Posttest	Posttest	Posttest	Posttest

Instrument

Each student was required to complete AWS 1F lap joint welds that were evaluated using a rubric based on the AWS (2000) Guide for the Visual Inspection of Welds Visual Examination Criteria. Welding coupons were collected from each student. Each coupon was graded using the modified AWS rubric for fillets with a total of four criteria categories based on 1) presence of cracks or porosity, 2) complete fusion, 3) fillet leg size is specified minimum, and 4) undercut – not to exceed 1/32 inches. Each category was scored as either pass or fail (Pass = 1, Fail = 0) for meeting the criteria requirements. A maximum possible test score was four.

Data Analysis

Descriptive statistics including frequencies and percentages were reported for the number of students passing the four weld criteria. Means and standard deviations were reported for the pretest and posttest scores. The outcomes analyzed were GMAW and SMAW exam scores for each student. Students' weld test scores were reported for each treatment group using means and standard deviations. These scores are counts of passing the four individual weld criteria for each weld test and are therefore binomially distributed ($n = 4$). In the study, independent variables of interest were the lab practice orders (four orders) and the dependent variables were weld test results (GMAW or SMAW). Each variable and interaction were tested. Classrooms and students within each classroom were random factors in the model. All analysis was performed using PROC GLIMMIX (generalized linear mixed model) in SAS/STAT 12.1, (SAS version 9.3, SAS Institute Inc., Cary, NC). Parameter estimates were considered significant at the 0.05 level.

Findings/Results

A total of 71 students (70.3%, $N = 104$) completed the research project. This was due to students missing at least one of the classes during the study. The majority of students were male (95.8%, $f = 69$). Students' grade levels ranged between ninth grade, as 73.6 % ($f = 53$), tenth grade as 9.7% ($f = 7$), eleventh grade as 12.5% ($f = 9$) and twelfth grade as 2.8% ($f = 2$). Ages of all participants ranged from 14–18 with an average age of 15 ($SD = .971$). There was no significant difference between classes concerning the number of upperclassmen participating ($\chi^2 = .544$, $df = 9$). The pretest was administered to determine if there were any significant differences of content knowledge between classes. There was no significant difference between classes on the pretest scores, *F* = 1.41(3), *p* = .247. The average pretest score for all classes was 56.01 (*SD* = 13.17) with a maximum score of 100. Students between the ages 14 and 15 (underclassmen) scored an average of 53.21 (*SD* = 12.62) while students who were between 16 and 18 years (upperclassmen) averaged a pretest score of 64.28 (*SD* = 11.4). This difference was significant, *t* = 3.29(69), *p* = .002.

The weld quality criterion pass rates for the GMAW test by treatment group are presented in Table 2. Weld quality criterion pass rates for the SMAW test are presented in Table 3. Few students (15%, *f* = 11) met the performance standards for passing the cracks criterion using SMAW. The majority of students were able to meet the undercut criterion standard using both GMAW and SMAW.

Table 2

Weld Quality Criterion Pass Rate for GMAW Welding Test by Treatment Group (*n* = 71)

	Criterion							
	Cracks		Fusion		Leg Size		Undercut	
Treatment	*f*	%	*f*	%	*f*	%	*f*	%
1 (*n* = 19)	16	84.2	18	94.7	11	57.9	19	100.0
2 (*n* = 18)	11	61.1	12	66.7	12	66.7	15	83.3
3 (*n* = 16)	11	68.8	8	50.0	9	56.3	14	87.5
4 (*n* = 18)	13	72.2	10	55.6	13	72.2	18	100.0

Table 3

Weld Quality Criterion Pass Rate for SMAW Welding Test by Treatment Group (*n* = 71)

	Criterion							
	Cracks		Fusion		Leg Size		Undercut	
Treatment	*f*	%	*f*	%	*f*	%	*f*	%
1 (*n* = 19)	2	10.5	10	52.5	7	36.8	19	100.0
2 (*n* = 18)	3	16.7	9	50.0	11	61.1	15	83.3
3 (*n* = 16)	3	18.8	5	31.1	5	31.1	14	87.5
4 (*n* = 18)	3	16.7	8	44.4	6	33.3	18	100.0

Students' estimated welding test scores were calculated using a generalized linear mixed model. Inputs for the model were grade level, treatment group, GMAW exam score and SMAW exam score. Students' pretest scores and grade level were significantly correlated, *r*(69) = .331, *p* = .005. Therefore, students' grade level was assigned as a covariate. Estimated scores for GMAW and SMAW weld test exams are shown in Table 4.

Table 4

Estimated GMAW and SMAW Scores by Treatment (*n* = 71)

Treatment	GMAW score ± *SE*	SMAW score ± *SE*
1 (*n* = 19)	3.3 ± 0.25	1.4 ± 0.37
2 (*n* = 18)	3.0 ± 0.39	1.6 ± 0.47
3 (*n* = 16)	2.7 ± 0.33	1.4 ± 0.34
4 (*n* = 18)	3.1 ± 0.27	1.4 ± 0.37

The estimates for the binomial distribution are chances of successful weld criteria passes (the number of passing weld criteria for each weld test). Estimated welding test scores were calculated by n*p, where n equals the maximum possible score of four and p is the chance estimates from the model. Table 5 provides the differences between estimated treatment effects. The estimates and standard errors are given on the log scale for the odd ratio of successfully scoring a four out of four on the weld test. Tukey-Kramer multiple comparison method was used to test pairwise treatment effects. Adjusted *p*-values less than 0.05 were considered significant. There was no statistically significant ($p = .241$) difference between treatments. There was no significant difference between treatment groups on the written posttest scores, $F = .669(3)$, $p = .574$. The average posttest score for all classes was 85.28 ($SD = 6.16$) with a maximum possible score of 100.

Table 5

Treatment Effects on GMAW and SMAW Scores (n = 71)

Exam	Treatment	Estimate[a]	*SE*	*df*	*t*	*p*
GMAW	1 vs. 2	0.506	0.649	9	0.78	.455
GMAW	1 vs. 3	0.940	0.539	9	1.74	.115
GMAW	1 vs. 4	0.331	0.562	9	0.59	.569
GMAW	2 vs. 3	0.433	0.588	9	0.74	.480
GMAW	2 vs. 4	-0.174	0.610	9	-0.29	.780
GMAW	3 vs. 4	-0.608	0.484	9	-1.25	.241
SMAW	1 vs. 2	-0.139	0.582	9	-0.24	.816
SMAW	1 vs. 3	0.006	0.487	9	0.01	.989
SMAW	1 vs. 4	0.061	0.516	9	0.12	.907
SMAW	2 vs. 3	0.146	0.566	9	0.26	.802
SMAW	2 vs. 4	0.200	0.594	9	0.34	.743
SMAW	3 vs. 4	0.054	0.500	9	0.11	.915

[a] Success estimate is provided on the logarithmic scale.

Conclusions/Recommendations

The purpose of this study was to determine if having fewer operator-controlled factors during welding practicums would improve secondary students' ability to meet weld quality standards for an AWS 1F test (flat position-fillet tee weld). Major emphasis was given during the instructional period for students to focus on their welding technique through travel speed and arc length during the practicing and testing periods. Written posttest scores indicate a change in students' content knowledge during the research project. There were no significant differences between upperclassmen and underclassmen on posttest scores (p = .167). Results of this study show several of the student participants were able to perform welds that meet AWS quality standards using the GMAW process. The GMAW process has fewer operator-controlled variables than the SMAW process, which may lessen the number of variables the student participants had to control while learning to weld with GMAW. The odds ratio for students practicing GMAW first then testing first on GMAW (treatment group one) compared with students practicing GMAW first then tested on GMAW last (treatment group three) was 2.5:1. This indicates that the odds of students successfully meeting GMAW weld quality standards following the practice sequence of GMAW followed by practice with SMAW while testing first on GMAW is two and half times greater than students following the same practice sequence but first testing on SMAW then completing the GMAW test. However, this difference was not statistically significant (p = .115). Similarly, the odds ratio for students practicing GMAW first who completed the SMAW test first (treatment group three) compared with students practicing SMAW first then testing on SMAW last (treatment group four) was 0.54:1. This indicates that students following the practice sequence used in treatment group three would be approximately one-half the odds of those following the sequence used in treatment group four. However, there was no statistically significant difference in SMAW scores between treatment groups. Therefore, the null hypothesis was retained.

The mean performance test score among all treatment groups for GMAW was 2.96 (*SD* = 1.04), which is 1.42 points above the mean test score for all SMAW treatment groups of 1.54 (*SD* = 1.36). Hoffman et al. (2012) explained that the methods for starting and maintaining an arc differ greatly between the two welding processes. Starting and maintaining an arc in the GMAW process is not difficult. The trigger is pulled on the welding gun to initiate the arc. However, starting an arc with the SMAW process is operator dependent and increase in complexity if traditional passive welding lenses are used rather than the use of the auto-darkening lens. Using a traditional passive welding lens requires the operator to identify the target area for establishing the arc then transition by flipping the helmet down causing a loss of visual contact with the target area until the arc is struck. This is accomplished by the operator either tapping or scratching the electrode on the base metal and lifting the electrode to a correct arc length. Once the arc has started, the operator must maintain a proper arc length as the electrode is burnt off to become the solidified weld. Improper starting techniques result in an extinguished arc or an electrode stuck to the work piece. Eliminating this one variable may have benefited students. The low SMAW test scores may be influenced by the complexity of switching between welding processes or the increase in complexity in starting and maintaining the arc using traditional welding helmet and lens. We recommend that agriculture teachers may benefit from teaching, practicing, and testing one welding process before introducing a new welding process. This is contingent on the welding facilities having sufficient welding equipment to instruct multiple students simultaneously. This research design required individuals to learn both the GMAW and SMAW process simultaneously. Cognitive overload may have become an issue for students when trying to learn both processes at once. Information specific to each welding process may have been mixed during the learning process. Students may have been overwhelmed with the process of engaging metacognitively to pull from memory the specific techniques need for each process. Although not statistically significant, the highest difference of scores occurred between treatment group one and treatment group three for the GMAW performance test. Data indicated that when students' test session was soon after their practice session their test scores were higher. Observation during the practice and testing periods suggests that test subjects were confused with the specific operator-controlled variables for each welding process.

The results from this study would suggest that the GMAW process may prove to be a legitimate beginning weld practicum over SMAW. This is evident in the overall GMAW test scores being higher than SMAW scores. The operator-controlled variables in the GMAW process allow students to have an increased focus of attention on the external environmental factors rather than placing attention on the placement of their hands and arms to manipulate the electrode when performing SMAW. The welding techniques used in the GMAW process such as arc length control, weld angle and travel angle positions may be easier to control which produce welds that meet AWS quality standards. Additionally, agriculture teachers may better serve students by incorporating technologies, such as auto-darkening lens, in order to reduce the number of variables that compete for valuable cognitive processing capacity. With less operator-controlled variables present in the GMAW process, agriculture teachers may have legitimate reason to begin students using GMAW if the goal is to build students' confidence in welding by having them produce welds that meet AWS quality standards. Additionally, we recommend extending practice sessions before collecting data on student proficiency when conducting research on sequencing laboratory practicums. Incorporating metacognitive training sessions could help students reach their potential by becoming more proficient are accessing information on welding techniques for each process. The research design of this study limited the amount of time students were able to practice resulting in low overall test scores. Educational programs should allow ample time for students to practice performing skills as required by program guidelines and regulations.

Agricultural education programs will benefit from the extra time spent in practice sessions by having improved end results.

This research has provided baseline data in understanding sequencing welding laboratory practicums by limiting operator-controlled variables. Future research should be conducted to assess the benefits of sequencing laboratory practicums while limiting variables for entry-level agricultural systems technology courses. In continuing this project, future research should be conducted to assess the length of practice time essential produce welds that meet AWS quality standards. This study utilized one day (60 minutes) of practice time for each welding process before assessing the ability to produce welds meeting AWS quality standards. Future studies should consider lengthening the practice session times to two days (120 minutes) or more to determine if longer practice sessions will result in a higher percentage of welds that meet AWS standards. Agriculture teachers should consider giving timely feedback during practice sessions to help improve welding technique and outcomes. Future studies should analyze the benefit of solely teaching, practicing, and testing one welding process before introducing students to a new welding process. This studies sample population began at $N = 101$ and had a completion rate of 70.3% or ($N = 71$). We acknowledge a limitation of this study was the schedule of events and limited number of students participating. We attempted to schedule practice events and testing in order to limit the amount of time elapsed between sessions. Multiple attempts were made to encourage students to participate and attend sessions. Continuing this research study by adding more participants will increase the validity of the study. Scores from this study were widely scattered indicating a need to increase the sample population to determine any significance on sequencing the order of practicum operations.

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