The Near Real Time Welding Monitor

(Patent Pending)

Graphic displays and statistical analysis provide an effective welding instruction tool.

By: Mark Spencer

Introduction. Teaching and learning proper welding techniques is a challenge. Welding is just as much an art form as it is an application of science. Added to this mix are the safety requirements, protective equipment, and the cramped space of a welding station; all making real and effective student/instructor interaction difficult.

I have developed an instructional tool that helps them overcome some of the obstacles to effective welding instruction. This teaching tool is the Near Real Time Welding (NRTW) Monitor.

NRTW Description. The NRTW is a micro-controller based transmitter/receiver system that senses and measures the arc voltage at the student welding station, transmits this data by a radio data link to the receiving component at an instructor's consol (a standard computer) where the data can be displayed and analyzed. The data that is collected as the student makes a weld is displayed graphically on the instructor's computer screen in near real time (see Figure 1). The NRTW system is capable of monitoring up to 8 separate student-welding stations though only one live "feed" can be received at a time. The transmission distance can be up to 1000 feet but, realistically, obstacles in the typical welding environment would reduce this optimum distance. At the college where the NRTW was tested, transmissions were reliable within a building with cinder block interior walls, a distance of a few hundred feet. The NRTW system is battery powered and uses no special computer systems or software. Office 2000 with EXCEL is the only software required on the instructor's computer and one serial port is required to connect the NRTW receiver to the computer.

<u>Power in NRTW.</u> The real power of the NRTW is in the analysis of the data once it has been transmitted to the instructor's computer. The graphs can be saved and then reviewed with the student. Many times the students want to see the results of their weld immediately. Figure 2 is a depiction of a typical graph produced by the NRTW. At other times the instructor may elect to sample a student's activities without the student's knowledge. The graphic display compliments the visual inspection of the weld as well as the student's anecdotal recollection of his/her performance during the creation of the weld. Therefore the graph provides reinforcing feedback as well as new insights.

Along with the graphical presentation, using the standard statistical analysis tools contained in EXCEL, the data can be numerically analyzed to provide a second picture of the weld. Figure 3 is a typical statistical summary of a weld monitored by the NRTW. The table in figure 4 relates the NRTW information to selected statistics. The most significant statistics generated by analyzing the data is the mean and the standard deviation (though the other statistics can provide powerful insight depending on the instructor's familiarity with the meaning behind the statistics). The **mean** is the **average arc voltage** that the student used during the weld. The appropriate voltage depends on the type of weld, position, material, and rod type. Manufacturer recommended parameters can be compared against the average voltage used by the student and technique adjustments made accordingly. The **standard deviation** is a measure of **arc consistency or stability** during a weld. In a perfect weld, the arc would not deviate from the perfect nominal voltage; therefore the standard deviation of the perfect weld would be zero. By applying a reference standard based on the factors that influence a particular welding situation, a numeric score or grade could be generated from the mean voltage and the standard deviation of the weld. The **count** is a measure of the **time** required to complete the weld. Comparing the time of weld to a physical measurement of the weld bead length gives an indication of the rate of weld.

Before we look at actual student data gathered with the NRTW, there needs to be a short tutorial of how to interpret the graphs and the weld representation. Refer to figure 2 as a typical weld graph. The y-axis (vertical) represents the voltage of the arc. The NRTW is calibrated for both AC and DC currents and the data can be scaled accordingly. The x-axis (horizontal) represents the time since data collection began in seconds. This time is generated by the instructor's computer and actually includes a full time stamp of date and hour. At the beginning of data collection, the voltage is at maximum because the arc has not yet been struck. When the arc is first stuck, there is an immediate drop in voltage down to the operating voltage (and ideally the arc voltage intended for the weld). Variations in this area of the graph can provide insights into the student's striking technique and could highlight problems that need additional instructor intervention as will be illustrated later. Once the arc is struck and the weld bead progresses, the voltage is measured, transmitted, and depicted as points along the graph. Minor variations in voltage result in the horizontal erratic line, the amount of deviation is indicative of the stability of the arc. At the end of the weld when the arc is broken, the voltage immediately raises to the no-load level. This area of the graph can give insight into the student's technique for breaking the arc. A less then clean, crisp, abrupt rise in the voltage here would indicate an arc breaking technique that is slow. The graphed voltage drops to zero volts when the welder is turned off.

NRTW Examples. The following figures represent actual student data and are provided to give a sample of the types of analyses that can be done with the NRTW.

<u>Rod Type</u>. Figures 5 through 8 were collected from four different rods: 6010, 7024, 7014, and 7018. Note that the average voltage of the weld as indicated by the graphs and the mean statistics are different for each rod type. When comparing this voltage with the voltage recommended by the rod manufacture, a check can be made if the student is using the recommended arc length and the appropriate critique and instruction offered. Also note that the 6010 weld was more erratic than the other welds. This could be due to the student operator skill, but more likely this supports the notion that 6010 is a more difficult rod to control.

<u>Effect of Over Current</u>. Figure 9 was collected from an instructor deliberately using well above the recommended current setting with a 3/32 inch 6013 rod. Notice that the arc was quickly struck and maintained with some consistency, however notice the gradual reduction in the arc voltage. The anecdotal observation stated that the arc was consistent throughout the pass. This graph clearly depicts the effect that over current can have on the arc voltage. As the rod overheated (as well as while it was being consumed), the resistance of the rod changed and caused a significant degradation of the arc voltage.

Position. The weld in figure 10 is a practice vertical weld of a previously horizontally certified student. Notice the erratic weld and the short duration (only count of 99). The NRTW also provides insight into the difficulties posed by weld position as well as rod type and operating conditions.

Temperature and Speed. Figure 11 depicts a weld produced by one instructor who has a reputation of being "hot and fast." Surprisingly the instructor had some difficulty striking the arc, in his defense this was probably due to a cold start. Once the arc was struck, the arc was maintained with a fair amount of consistency (standard deviation of 1.14). Note however the arc voltage of 31.6 and the count of 92. The voltage used for this bead was significantly above the norm for 7018, and the rod was consumed very rapidly based on the count. Visual inspection of the weld confirmed that it was the appropriate length and the right amount of rod was consumed. It was obvious from the graph that the weld was rushed.

Learning Progress. Figure 12 was produced by a student early their tenure in working with 7018 rod. Notice the difficulty in striking the arc, the arc was erratic throughout the weld, and the student was hesitant when completing the bead. Anecdotal observation by the student was that the slag was difficult to remove. Information collected by the NRTW supports the instructor's critique of the student's performance.

Figure 13 is another interesting graph. This student was in the first day of practice with the 7018 rod. Notice that there was some difficulty in striking the arc, which is consistent with 7018 rod. Once the arc was struck, the student initially buried the rod and had a short arc length, but then recovered and maintained a very stable arc for the first two thirds of the bead. But then something happened, probably shifting in position caused the student to deeply bury the rod and virtually short out the arc. Recognizing the situation and making an adjustment, the student drew the rod away from the work, the arc reestablished, and the student over compensated. However, notice that the student quickly regained the arc consistency and completed the bead with a smooth arc. The statistics reflect an arc voltage that may be a little on the low side (indicative of beginning students), and a standard deviation that reflects the error in the middle of the weld. All this not withstanding, this student demonstrated good composure and understanding of arc mechanics and probably has a bright future in welding.

Figure 14 was produced by a mid-skill-level student. Notice the difficulty this student had in striking the arc. Consistent graphs like this would indicate that additional instruction in striking an arc is warranted. However, once the arc was established, the arc stability was very good. This observation is supported by the standard deviation statistic with the value .616 being in the very good range. Finally the student had a clean break in the arc at the end of the bead. The count value of 170 signifies that the student used up the right amount of rod. The weld time was approximately 1 minute. A visual inspection of the weld length compared to the time of weld would provide some insight into proper weld speed. Finally, the mean voltage for the arc was 19.8 volts. This is probably a little on the low side for 7018 rod and may indicate a use of short arc length.

Model Student Weld. A very good weld is depicted in figure 15. After a false start as the result of a "stick weld" the student recovered and continued with a stable arc at the proper voltage for the remainder of the weld.

Looking At An Entire Weld. More insight can be gleaned by the NRTW by looking at all the welds that make up a joint. The graphs in figure 16 represent summary data from a complete horizontal certification weld test. The average voltage and standard deviation for each pass is plotted against the sequential pass number. Notice that early in the weld test, when the welds are being laid deep within the “V” grove, that the arc voltage and consistency varied significantly, and as the weld began to build out of the “V”, the student was able to better maintain proper and consistent arc voltage. Additional instruction in rod placement and angle, and perhaps body position would be warranted for this student.

The graph in figure 17 is another look at the welds produced during the certification test. The y-axis is the level of standard deviation, the x-axis is the average voltage used for each pass. The individual data plots represent the individual weld passes during the test. There is a definite correlation between the arc length and the weld stability. As the arc length approached the optimum value (around 23 volts) the stability improved. During those passes where the arc voltage deviated from the optimum, the stability was significantly worse. The instructional point here could be that proper arc length helps the welder to produce consistent beads.

Figure 18 was made by the same student, the left graph depicts a weld on the first day of 7018 practice, and right graph depicts a weld during a horizontal certification test at the end of the semester. Notice the typical student errors, difficulty striking the arc, difficulty in maintaining a stable, inconsistent arc voltage, and a ragged break at the end of the bead. For the early weld the statistics show the student used a high arc voltage (22.7 volts), and produced a high standard deviation (2.13). In contrast, at the end of the semester the student quickly struck the arc at the proper voltage (20.9 volts), maintained a consistent arc throughout the length of the bead (.92) and had a clean break. This student made significant progress throughout the course and that progress is documented by NRTW.

NRTW Produced Portfolio. As indicated above, one of the powerful aspects of the NRTW is the collection of data over time to demonstrate progress and achievement for the student. It is far more informative to review a portfolio of recorded graphs and statistics than try to maintain a portfolio of actual weld samples. Two students were tracked with the NRTW during a complete semester and the summary of the data gathered is depicted in figure 19. The students had class once a week during the semester and a number of weld samples were collected each week. The solid squares on the graphs indicated the average value for that day’s activity. The vertical lines above and below end at the extreme high and low value for the measured parameter for the day. Following the average value would give an indication of overall progress, while the length of the line above and below would indicate the level of consistency in the student’s performance. Ideally, the average voltage and standard deviation would show steady improvement and the amount of inconsistency would also steadily go down. Although the students did not achieve the same level of proficiency (as indicated by comparing their graphs, which by the way do not have the same scale factors), both students showed steady and noticeable improvement over the course of the semester.

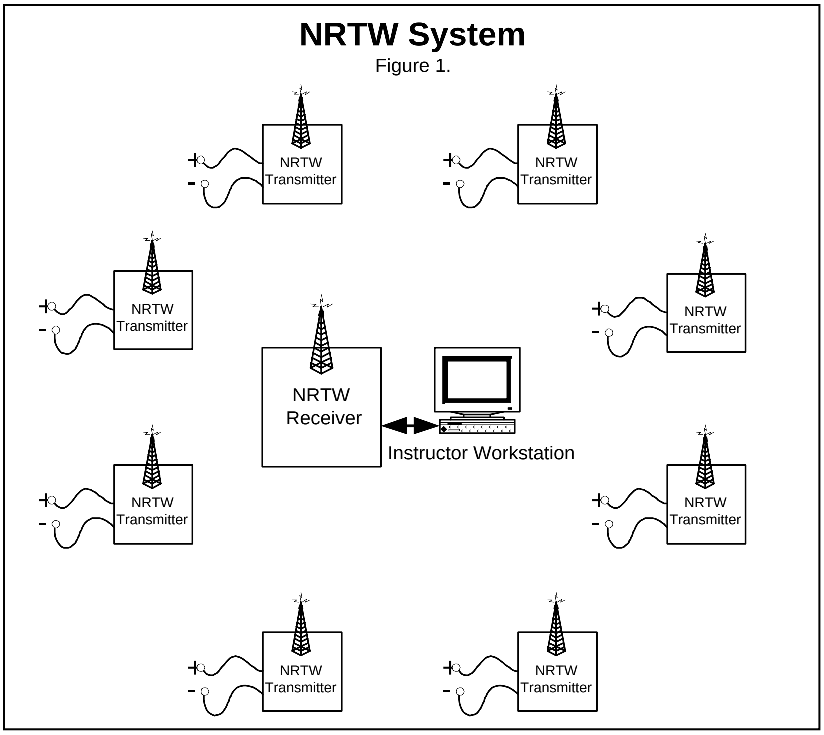
NRTW Beyond the Classroom. The NRTW can support the students long after they leave the classroom. A portfolio of recorded weld data can be shown to perspective employers to document the proficiency of the job applicant. A portfolio along with the requisite certifications can illustrate that not only has the job applicant demonstrated the proper weld outcome, but also has demonstrated a consistent pattern of using proper welding techniques over a long period of time.

Also beyond the classroom, the NRTW may have some utility out in the field. Though it will never replace visual and technical weld inspection, recorded NRTW data can serve as a pre-inspection quality assurance measure that could help management detect potential weld defects due to operator technique before the expensive formal visual and technical inspection. In addition to generating a welder performance portfolio, the NRTW could produce an archival portfolio for specific welds within a larger project. A certain percentage of NRTW recoded welds within a welded joint could provide a valuable archival record and support for forensic investigations.

Conclusion. The NRTW is a cost effective tool that can enhance welding instruction. The immediate graphical and numerical feedback provides one more avenue for student learning. The capability to record data over time provides documentary evidence of learning and achievement that the student can use to support employment applications.

If you would like to know more about how the NRTW is used in the classroom, or for more information about the technical side of the NRTW, contact Mark Spencer, at 860-594-0396, e-mail mspencer@arrl.org.

Near Real Time Welding Monitor Figures and Illustrations



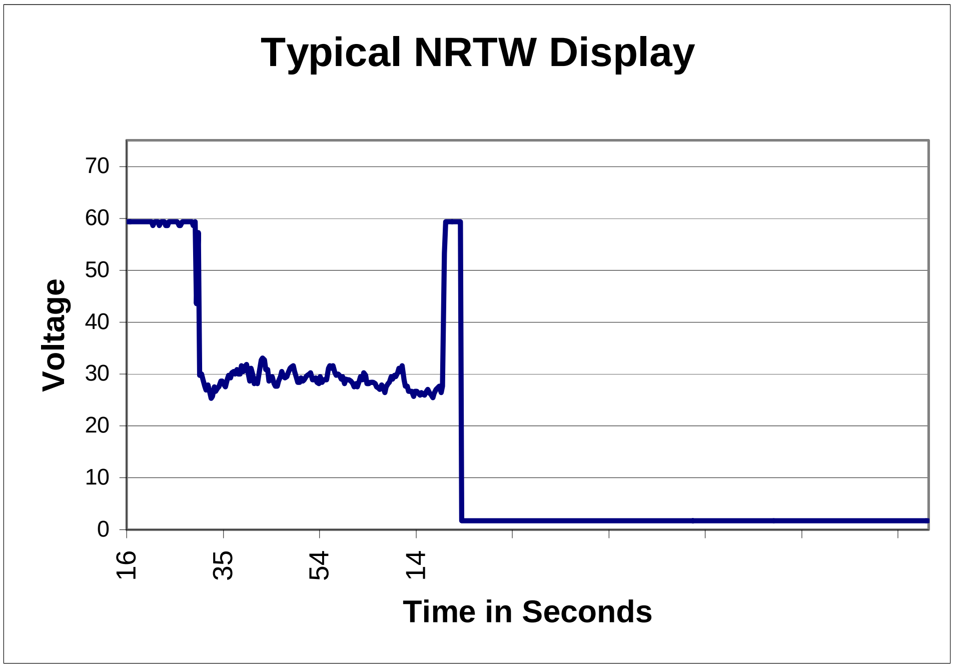
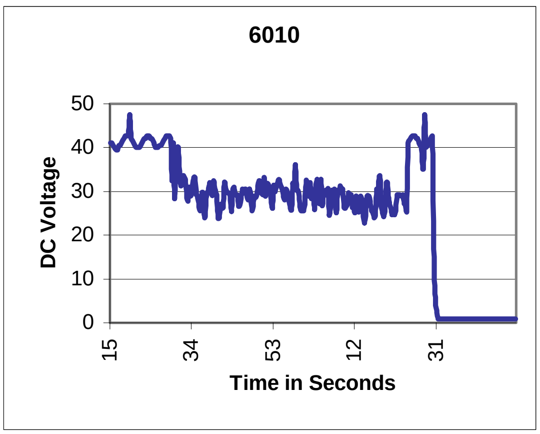


Figure 2.

Typical Statistical Display	
Mean	28.77804889
Standard Error	0.132482252
Median	28.8117091
Mode	28.13020261
Standard Deviation	1.6333509
Sample Variance	2.667835161
Kurtosis	-0.390128787
Skewness	0.113036489
Range	7.72144738
Minimum	25.28107838
Maximum	33.00252576
Sum	4374.263431
Count	152

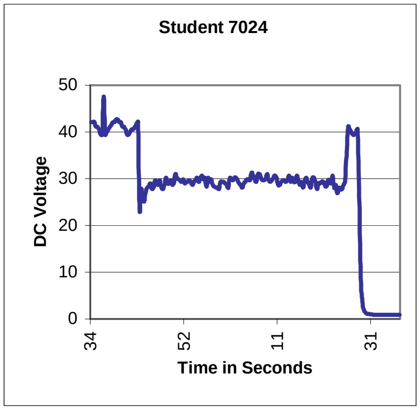
Figure 3.

Statistical Vocabulary for the NRTW Figure 4.	
Mean	The average arc voltage measured between selected points on the graph.
Standard Deviation	The typical deviation of the voltage from the mean voltage between selected points on the graph. A perfect weld would have a standard deviation of zero. The lower the standard deviation, the more consistent the arc length during the weld.
Count	The number of data points between selected points on the graph. This number equates to the amount of time it took the student to make the weld. The count number divided by 3 is roughly equal to the weld time in seconds.



6010	
Mean	**28.84841599**
Standard Error	0.195140148
Median	29.13148751
Mode	28.9733865
Standard Deviation	**2.529305397**
Sample Variance	6.397385791
Kurtosis	-0.491213441
Skewness	-0.076264909
Range	13.36405988
Minimum	22.778264
Maximum	36.14232388
Sum	4846.533887
Count	168

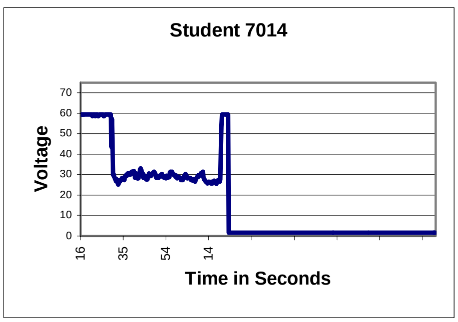
Figure 5.
Pass recorded of a student 6010 pass. Note the relatively arc stability on the graph and the measure of the standard deviation in the statistical summary. The average voltage of the pass was 28.8 volts. This illustrates the utility of the NRTW to show the different voltages required for different rods and the difference between the “ease of use” of some rods.



Student 7024	
Mean	29.18228574
Standard Error	0.096080027
Median	29.28958852
Mode	29.28958852
Standard Deviation	1.108048926
Sample Variance	1.227772423
Kurtosis	6.02535393
Skewness	-1.593493816
Range	7.947796492
Minimum	23.37228495
Maximum	31.32008145
Sum	3881.244003
Count	133

Figure 6.

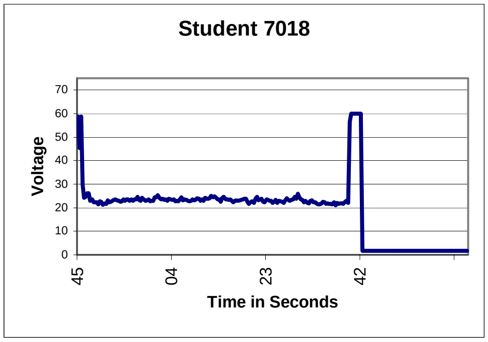
In this student 7024 weld, notice that after the arc was initially struck, the student held a shorter arc length and then made the proper adjustment for the remainder of the weld. The arc voltage was 29.2 volts which appears to be proper for this rod.



Student 7014	
Mean	28.77804889
Standard Error	0.132482252
Median	28.8117091
Mode	28.13020261
Standard Deviation	1.6333509
Sample Variance	2.667835161
Kurtosis	-0.390128787
Skewness	0.113036489
Range	7.72144738
Minimum	25.28107838
Maximum	33.00252576
Sum	4374.263431
Count	152

Figure 7.

In this student 7014 weld, notice that the arc length was initially short after striking the arc but the student recovered to maintain fair consistency. The arc voltage was 28.8 volts which appears to be proper for this rod.



Student 7018	
Mean	23.11013895
Standard Error	0.071862461
Median	23.16828269
Mode	23.50439248
Standard Deviation	0.934211999
Sample Variance	0.872752059
Kurtosis	0.628714893
Skewness	0.417507808
Range	5.147437039
Minimum	21.09515755
Maximum	26.24259459
Sum	3905.613483
Count	169

Figure 8.
In this student 7018 weld, the arc length started a little long after the initial strike. The student demonstrated good arc stability. The arc voltage for 7018 was 23.1 volts.

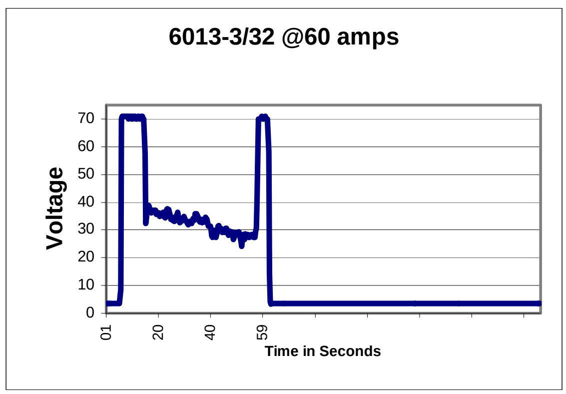
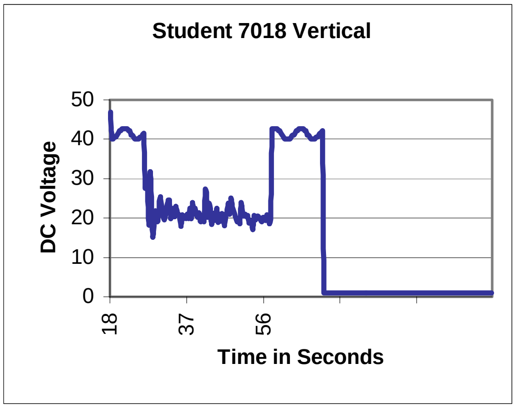
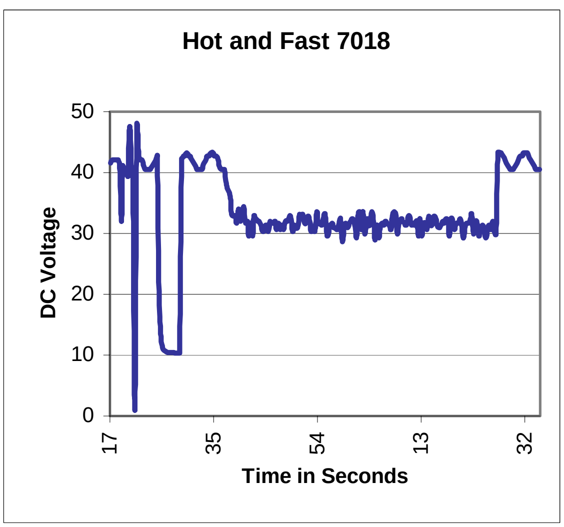


Figure 9.
Sagging arc voltage due to over current and resulting overheating of the rod. During the weld, the arc appearance was consistent across the length of the weld.



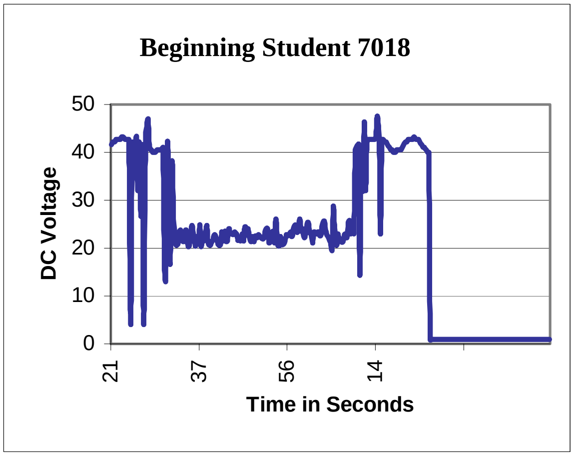
Student 7018 Vertical 2	
Mean	21.09788265
Standard Error	0.253726731
Median	20.55943337
Mode	21.025464
Standard Deviation	2.524549101
Sample Variance	6.373348162
Kurtosis	3.669572885
Skewness	1.50696857
Range	16.59275008
Minimum	15.08897361
Maximum	31.68172369
Sum	2088.690383
Count	99

Figure 10.
Student 7018 vertical weld. The student was previously certified for horizontal position. Note the arc stability on the graph and in the statistics indicating the difficulty of the vertical position.



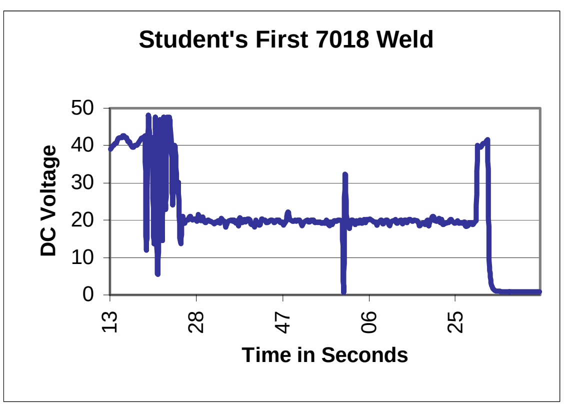
Hot and Fast 7018	
Mean	**31.57707381**
Standard Error	0.118442534
Median	31.68172369
Mode	31.68172369
Standard Deviation	**1.136060878**
Sample Variance	1.290634318
Kurtosis	0.139935734
Skewness	-0.119143938
Range	5.75037737
Minimum	28.66324663
Maximum	34.413624
Sum	2905.09079
Count	92

Figure 11.
This pass was “Hot and Fast.” The instructor who accomplished this weld has extensive professional experience and is known for his technique. Note the voltage of this 7018 pass was 31.6 volts versus the nominal voltage of 21 volts. The time to complete this pass was less than half the time required for a more normal pass.



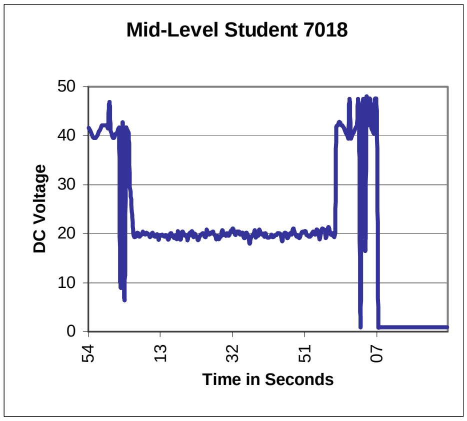
Beginning Student 7018	
Mean	**22.69043228**
Standard Error	0.19312289
Median	22.40083588
Mode	23.37228495
Standard Deviation	**2.133112037**
Sample Variance	4.55016696
Kurtosis	21.6819137
Skewness	3.247042484
Range	20.98735949
Minimum	17.01505975
Maximum	38.00241924
Sum	2768.232739
Count	122

Figure 12.
A typical student weld early in the program. Note the difficulty in establishing the weld (a few stick welds), followed by significant variation in the arc during the weld that is quantified by the high standard deviation value. Finally, the arc voltage was 22.7 volts, indicating a long arc length. This pass is a good candidate for retention in a student portfolio to show improvement over the course of the training.



Student's First 7018 Weld	
Mean	**19.58411091**
Standard Error	0.120925388
Median	19.69719675
Mode	19.83491921
Standard Deviation	**1.739813357**
Sample Variance	3.026950516
Kurtosis	77.40819609
Skewness	-4.476686115
Range	31.14969661
Minimum	0.9006
Maximum	32.05029661
Sum	4053.910959
Count	207

Figure 13.
This plot of one of a new student's first welds is remarkable for a number of points. As indicated and typical of new welders, this student had some difficulty in striking the arc. However, once the arc was established, the arc stability was remarkable. About half way through the weld though, the student shifted position and buried the arc (actually stuck the rod), quickly recovered the arc, and finished the bead with the same consistency shown in the first part of the weld. This student showed early talent for welding.



Mid-Level Studnet7018	
Mean	**19.83304374**
Standard Error	0.047308137
Median	19.83491921
Mode	19.83491921
Standard Deviation	**0.616822639**
Sample Variance	0.380470168
Kurtosis	5.860564945
Skewness	1.057360721
Range	5.39913456
Minimum	17.97315039
Maximum	23.37228495
Sum	3371.617436
Count	170

Figure 14.
Mid-Level Student 7018 pass. Notice difficulty striking the arc, good consistency during the bead but at perhaps a low voltage. The erratic trace at the end of the bead is the result of the student improperly laying the rod clamp while the power was still on.

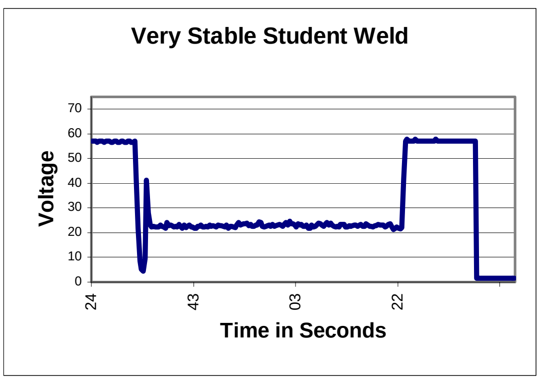
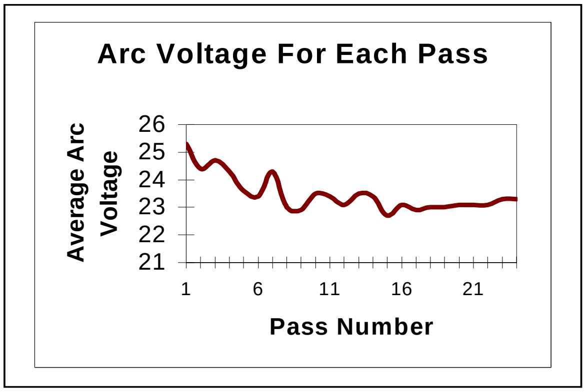


Figure 15.
After a false start when the student stuck welded the first strike, the remained of the weld was one of the most consistent seen during the semester with a standard deviation of .06.

Very Stable Student Weld	
Mean	22.8213158
Standard Error	0.04883285
Median	22.837511
Mode	23.0022568
Standard Deviation	0.59608089
Sample Variance	0.35531243
Kurtosis	0.18469002
Skewness	0.2904964
Range	3.30011884
Minimum	21.2491508
Maximum	24.5492697
Sum	3400.37606
Count	149



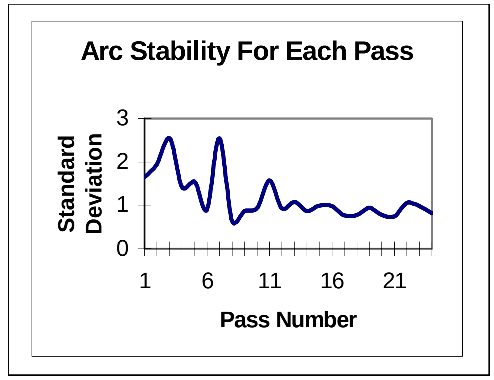


Figure 16.
Cumulative data for a complete certification weld test.

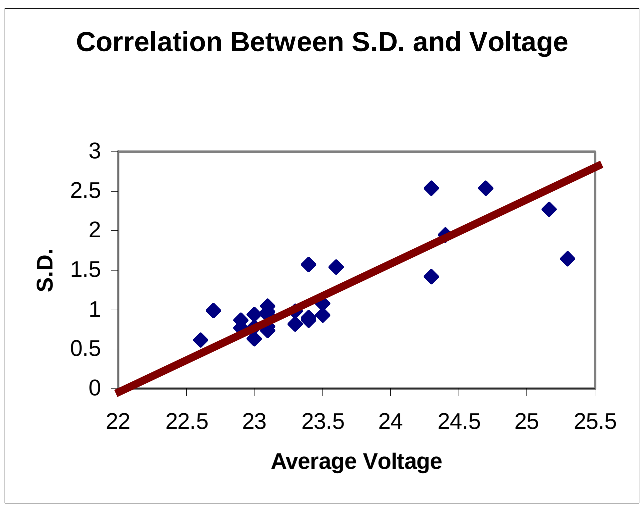


Figure 17.

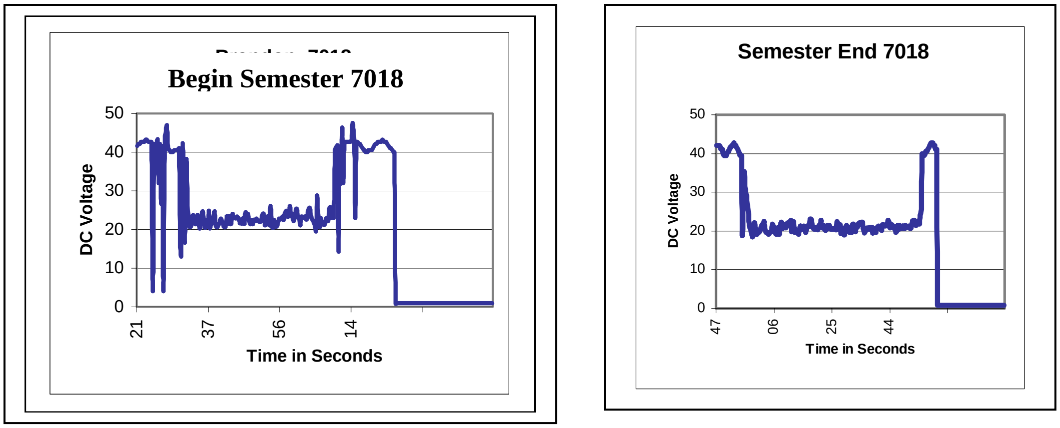


Figure 18.
Same student at beginning and end of the semester.

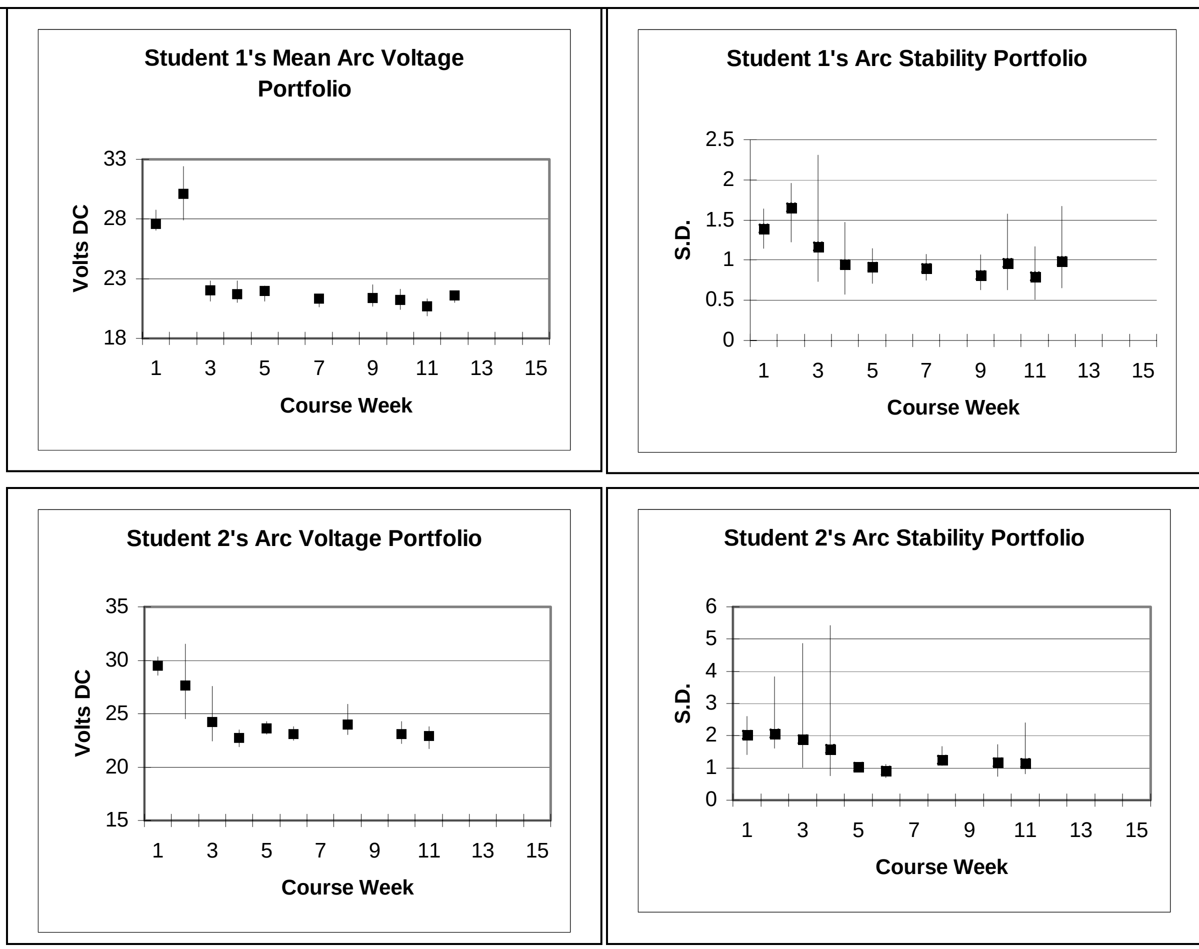


Figure 19.
Student Portfolio Summary Data