# AC 2007-1240: REAL-TIME ACCESS TO EXPERIMENTAL DATA USING TABLET PC'S

**Gregory Mason, Seattle University**

Dr. Mason received a BSME from Gonzaga University, an MS in Computer Integrated Manufacturing from Georgia Institute of Technology, and a Ph.D. in Mechanical Engineering from the University of Washington-Seattle. He developed a robotics laboratory for the Department of Defense in Keyport, WA and was involved in numerous automation projects, including a robotic container welding system and a robotic torpedo fueling system. While at the University of Washington Dr. Mason did post-doctoral research for NASA, designing a multirate flutter suppression system for a commercial jet. His current research interests include digital controls, robotics, and automation. He has published several papers addressing the uses of advanced controls system techniques in manufacturing. Dr. Mason is also active in pedagogical research, receiving an NSF grant with Dr. Shuman for developing a "learning community", and developing a handheld data acquisition system currently in use at Seattle University.

**Frank Shih, Seattle University**

Dr. Shih received a BSME from UC Irvine, MSME, MS Materials Science & Engineering, and PhD in Mechanical Engineering (Solid & Structual Mechanics) from UCLA. His dissertation research is on the characterization and the mechanics of Lamb waves from damaging impacts in fiber-reinforced composite materials. The research was honored by The International Society for Optical Engineering (SPIE) with the 2003 Nondestructive Evaluation (NDE) Best Paper Award. In addition, Dr. Shih has conducted research on laser-based ultrasound at the former Rockwell Science Center in Thousand Oaks, California (1998-2000, hosted by Dr. A. D. W. McKie). As an Associate Staff Scientist at Lasson Technologies in Culver City, California (2000-01), Dr. Shih developed laser ultrasonic diagnostic methods and prototype systems for industrial clients. Dr. Shih holds a US patent and has published a number of articles in nondestructive evaluation, wave mechanics, mechanics of composite materials, and materials science. Prior to joining Seattle University, Dr. Shih taught as a lecturer in the Mechanical & Aerospace Engineering Department at UCLA and in the Chemical Engineering & Materials Science Department at UC Irvine (2002-03).

**Jeff Dragovich, Seattle University**

J. Dragovich was born and raised in Seattle, Washington. He earned his BSCE from Seattle University in 1988. He earned his MS and Ph.D. from the University of Illinois at Urbana Champaign. He worked as a bridge engineer with Andersen Bjornstad Kane Jacobs and was a software developer with the Boeing Company. Prior to joining the faculty at Seattle University, he was a senior design engineer with the Magnusson Klemencic Associates.

# Real-Time Access to Experimental Data Using Tablet PC's


## Abstract

A custom data acquisition system was developed for use in mechanics of materials and materials science laboratories. The new system allows students to observe the physical phenomena demonstrated in the experiment and individually manipulate and examine the experimental data on a real-time basis. In the past, students would gather around an apparatus and passively watch the experiment being performed. The data collected were then distributed and analyzed at a later time, away from the presence of the instructor. The problem with this approach is multifold. First, significant amount of time may have lapsed since the experiment and students have a difficult time associating the calculated results to the experiment itself. Second, some phenomena which occur during the experiment require data reduction to fully explain. Since that reduced data is not available at the time of the experiment it can not be fully explained by the instructor during the experiment. Finally, even if an ordinary data-acquisition system is used, students are forced to observe the "official" data being shown, instead of being given the option of exploring various data output. This can be particularly instructive in complex experiments with multiple measurements. The new system addresses these problems. It couples a computerized data acquisition system to twenty-one wireless Tablet PC's. While the test is in progress, test data is transmitted in real time to each student's Tablet PC. Custom software allows students to view graphs of the test data and manipulate the data as it is being collected. Students can view force-displacement curves, displacement-time or force-time, temperature-time, compare the emerging test results with past results of varying test parameters, and write notes directly on the graphed data. The impact of using Tablet PC in the lab was assessed using directed student surveys. Survey results show that over 90% of students felt that using the Tablet PC's helped them understand the physical significance of the experiment, and over 95% the students felt that the Tablet PCs helped them correlate the test data with the physical phenomena. This paper describes the data acquisition system, the custom software developed for this lab, example of some of the materials science experiments, and the pedagogical benefits of providing students with real-time access to experimental data.


## Introduction

Learning to relate theory to practice is an important component of engineering education. Feisel and Rosa[1] identified this as one of the key objectives of an engineering laboratory. Engineering students must learn how to apply class room theory to real engineering problems. One element of this is learning how theoretical models relate to the physical phenomena and then identifying where these models succeed and where they fail.

At Seattle University, the material science course includes approximately twenty hours of laboratory time in addition to traditional lectures. Lab experiments are designed to help students connect physical phenomena to textbook learning. One set of lectures focus on modification of material microstructures through heat-treatment and the resulting material engineering properties, such as ultimate strength or yield strength. In the lab, the students perform heat-treatment and tensile tests. Theoretical understanding of physical phenomenon can predict the shape of the stress-strain or force-elongation curve. These curves are important because they inform about the limits of the materials used in engineering design. During the laboratory tensile tests, the specimen is pulled until it fails. The changes in specimen length and applied load are recorded as the specimen is pulled. Students are asked to analyze the experimental data and compare it to theory.

The problem with this approach is multifold. First, there is a significant amount of time between the actual experiment and the data analysis, and so students have a difficult time associating the calculated results to the experiment itself. Second, some phenomena which occur during the experiment require data reduction to fully explain. For example, during a uniaxial tensile test of engineering materials, upper and lower yield points, work hardening, effect of strain rate, necking of the test specimen occurring near the ultimate stress, all of which have pronounced effects on the stress-strain curve. Since the reduced data is not available at the time of the experiment these phenomenon can not be fully explained by the instructor during the experiment. Finally, even when a computer based data-acquisition system is used, students are forced to observe the "official" data being shown, instead of having the option of actively exploring various data output.

Our solution is to provide each student with real time access to the test data while the test was in progress. This is done using TabletPCs connected to the university's wireless network. The wireless system is similar to that discussed by Bachnak and Englert[2] except that the data is streamed to multiple collection points. The unique system lets students view a real time plot of the data while the test is in progress. Students can individually change plotting parameters and write notes directly on the plot using the TabletPC's pen. The annotated graph can be saved as a JPEG image so that the notes taken on the tablet PC during the test are not lost. Additionally, the measured data can be saved in table for later use such as plotting and data analysis using Excel.

The remainder of this paper describes the real-time TabletPC based data acquisition system (DAQ), outlines how this equipment was used in our material science laboratory and presents results of student surveys and instructors interviews regarding the effectiveness of this system.

**System Description**

The real-time data collection system is comprised of a desktop computer running LABView and twenty-one Tablet PC connected to a wireless network. The Tablet PCs run custom software which communicates with the desktop computer and can display real-time test data in various formats. Although the data acquisition is portable and can be used on different experiments, it is currently connected to a MTS axial test machine. Figure 1 shows a schematic of the system. A detailed description of each component follows.

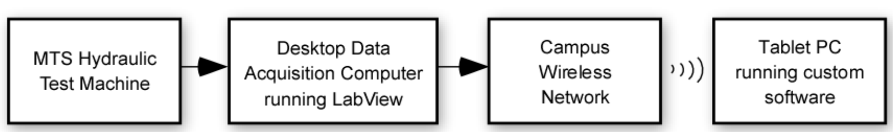



Figure 1. Schematic of Wireless Data Acquisition System

*MTS Axial Testing Machine*

The axial testing machine, shown in Figure 2, is a model 810 manufactured by MTS Corporation. The machine uses a servo controlled hydraulic actuator, located in its base, to move the lower grips. The test machine is controlled by an MTS FlexTest controller (not shown) which provides user selectable analog outputs such as force and actuator displacement.

*Data Acquisition Computer*

Data from the MTS testing machine is collected using LabView and a National Instruments data acquisition (NIDAQ) card, model PCI-6221. The NIDAQ card is connected to the two programmable MTS analog outputs on the FlexTest controller. These outputs are typically configured to transmit load and displacement data. A simple LabView program, shown in Figure 3, is used to collect data and transmit it to the campus wide wireless network. The LabView program is configured to let the instructor select the sample rate for data acquisition, and start and stop data transmission to the TabletPCs.

Figure 2. MTS Hydraulic Axial Test Machine with a 6" long test specimen

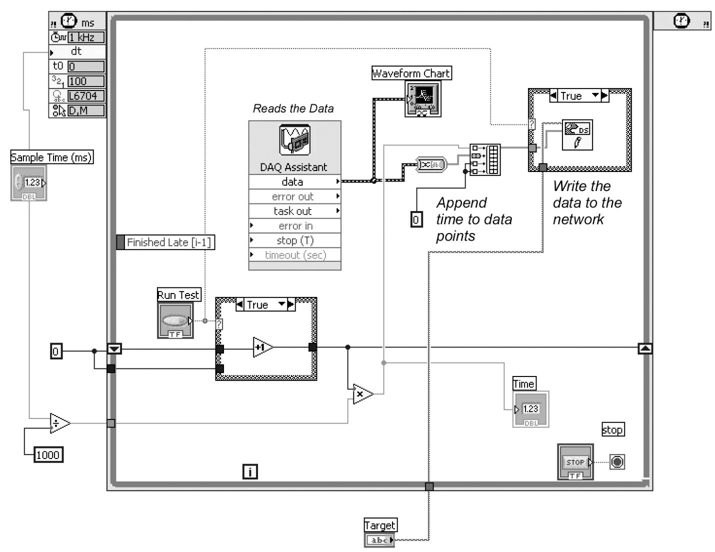



Figure 3. LabView Wiring Diagram

The LabView program uses a data socket to transmit up to four data values plus the time of the reading at each sampling instance, over the campus network. The data socket is implemented in LabView using the built in DSWriter and DSReader blocks. Since only two values are currently read from the MTS, the two additional values are set to zero. This can be seen on the LabView diagram, Figure 3. To access the data socket, a client computer connects to this host computer via TCP/IP using LabView's client data socket reader. This connection can be done using LabView or through a COM (common object model) version of the client. For a detailed discussion of LabView's data socket feature refer to the data socket documentation[3].

*TabletPCs*

The TabletPCs are Hewlett Packard, Compaq TC4200. The Table PC's include a built-in 802.11b/g wireless network card and a touch sensitive screen. The computers run the Tablet PC version of Windows XP. Currently we have 21 Tablets. These were obtained through a grant from the Hewlett Packard Education Initiative[4].

*TabletPC Software*

The TabletPCs run custom software developed at Seattle University. The software connects to the data acquisition computer discussed above through the campus' wireless network. In our case, the connection is preformed using a COM control version of LabView's data socket reader, in a C#.NET program. LabView's data socket manager handles all of the handshaking and overhead associated with this network connection. The software records and displays a real-time plot of the data collected from the MTS machine. A screen shot of the software is shown in Figure 4. While all the Tablet PCs receive the same data set, individual students can change how that data is plotted. They can plot a data set verses time, or plot one data set vs another. When performing a tensile test, for example, the student could, for example, show a plot of force vs elongation and another of elongation vs time. The software also lets the student overlay the graph from a previous test, so student can compare the results of two tests. During the test the user can draw directly on the graph using the Tablet's pen. At the end of a test, the user can capture JPG pictures of the graphed data, or export the data sets to an Excel compatible comma separated values (CSV) data file for further data reduction.

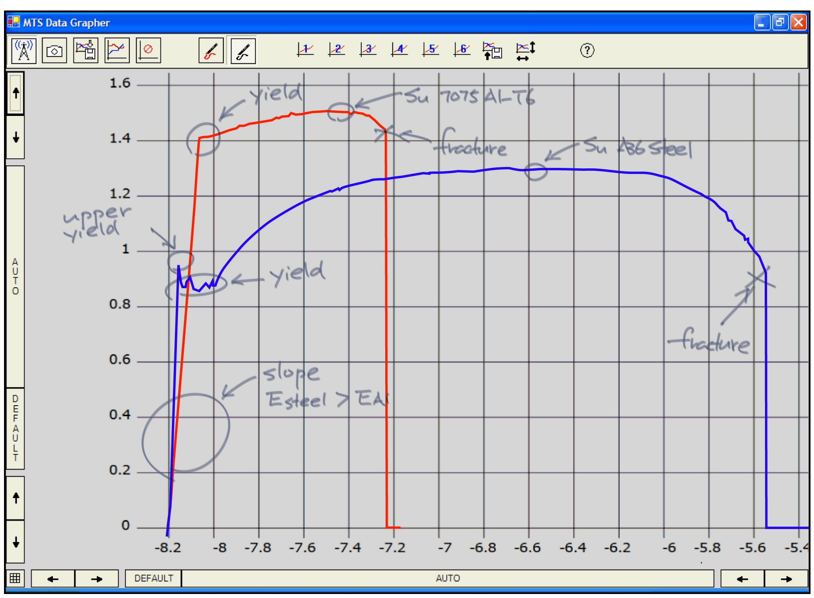



Figure 4. Screen Shots of the real-time plots showing the stress strain curves of A36 steel and 7075-T651 aluminum alloy, including annotation

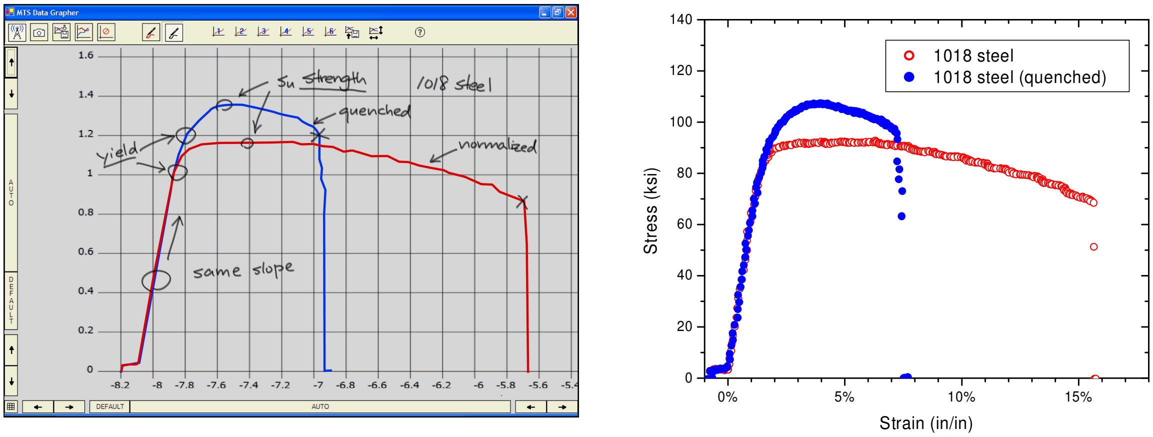
## Application

The wireless data acquisition system and MTS machine was used in a junior level materials science laboratory associated with a lecture course (MEGR350 Material Science). The course is only taken by mechanical engineering students. During the MEGR350 lab, students performed uniaxial tensile tests in order to determine mechanical properties of various engineering materials, such as common metallic alloys and polymers. In these tests, a standard specimen is pulled (strained) at a constant displacement rate, typically at 0.002 in./sec. The resulting load verses gage length elongation is plotted until the specimen fails. The use of the custom DAQ system is most meaningful when demonstrating significant differences in properties of two materials, or materials having gone through different processing or testing conditions. Several sets of tests, design to highlight these differences in mechanical properties and materials processing, were performed.

It is a misnomer that steels are always stronger than aluminum alloys. Furthermore, student sometimes mistakenly uses A36 steel, a widely available structural steel used in civil engineering applications, in the design of load bearing mechanical components. To give mechanical engineering students a strong impression that such steel can be weaker than well-engineered aluminum alloy, tensile tests of A36 steel and 7075-T651 (a comparatively high strength aluminum alloy, commonly used in aerospace applications) were carried out. The screenshot of resulting data, shown in Figure 4, were plotted side-by-side using the system for comparison.

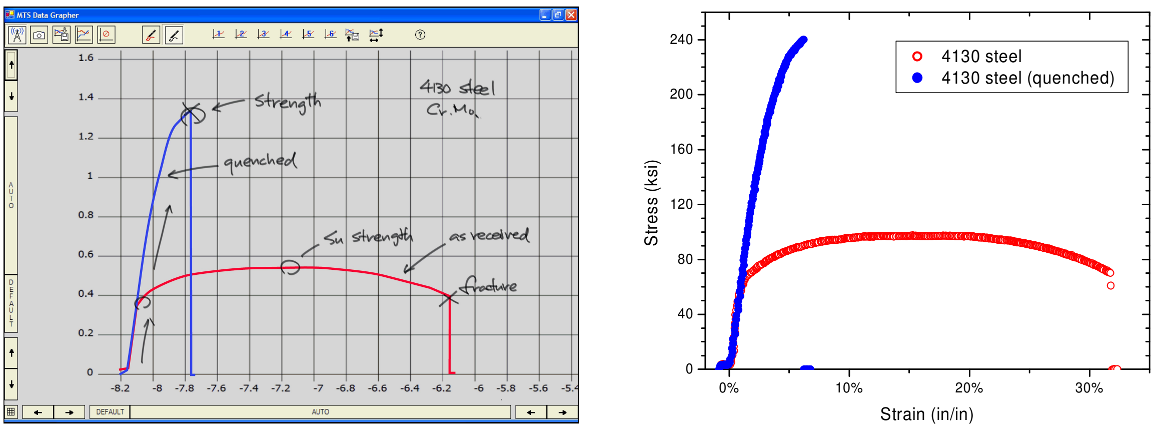
A number of important information that can be pointed out to the students are annotated in the screen shot shown in Figure 4. First of all, the slopes of the elastic portion of the stress-strain curve are markedly different. The slopes are used to compute Young's moduli of the materials. The plots clearly show that the Young's modulus of A36 steel is higher than that of 7075-T651 aluminum. The elastic property is due primarily to the stretching of atomic bonds and are unaffected by alloying elements. Upon closer examination, the 7075-T651 aluminum has greater yielding and tensile strength than A36 steel. The A36 steel is two and a half more ductile, based on fracture strains, than the 7075-T651 aluminum. The A36 steel also exhibits upper and lower yield points. The wireless DAQ system makes it easy for the instructor to emphasize these interesting features during the experiment.

Heat-treatment greatly enhances the property of engineering materials. This is another area where real-time data comparisons are meaningful. In one test, students compared the properties of normalized and quenched 1018 low carbon steel and 4130 chrom-moly alloy steel. Half of the specimens were heat-treated by austenizing and then quenching the steels in oil at room temperature. All heat treatments were performed in presence of students so they are clear that the specimens have identical composition. Figure 5 shows a screen shot of the real-time DAQ during testing of the heat-treated 1018 steel along with a formal plot. The 1018 steel had an increase of 20 % in strength. The similar test on the quenched 4130 chrom-moly steel, plotted in Figure 6, also showed a substantial increase of 2.5 times of the original strength. The test demonstrates to students, that without proper heat treatment, the high-priced 4130 alloy steel is not much better than 1018 low-carbon steel. Higher strength also means lower ductility. These concepts are easily demonstrated real-time with the use of tablet PCs because students have immediacy to the data being plotted. It also gives the instructor a controlled time-frame to highlight and emphasize important concept, instead of letting student plot out the data on their own at a later time, where such teachable moments are lost.




(a) Real-time plots including annotation (b) Formal plots after data reduction

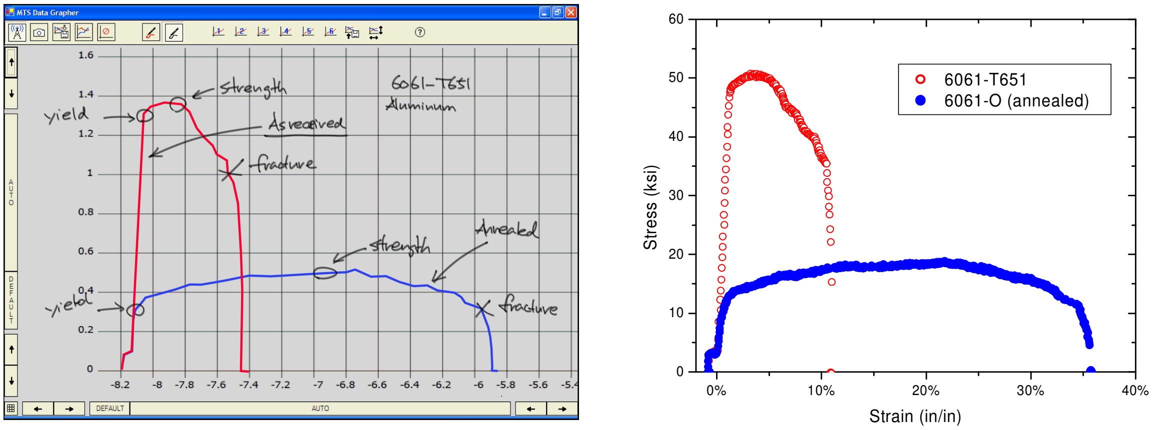
Figure 5. Stress-Strain Curve for 1018 carbon steel




(a) Real-time plots including annotation (b) Formal plots after data reduction

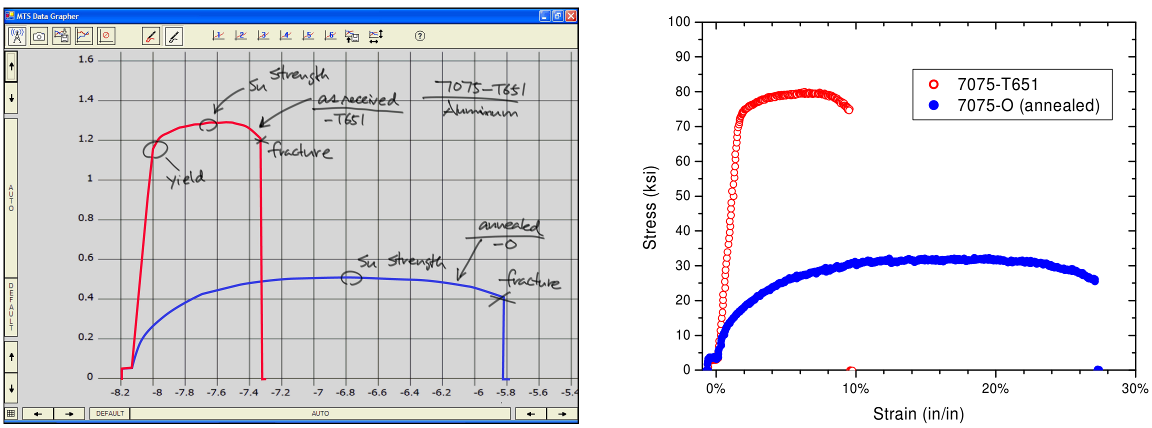
Figure 6. Stress-Strain Curve for 4130 alloy steel

Finally, improper heat-treatment can also bring detriment to the materials, significantly reducing its load carrying capacity. Students often design welded aluminum component while seldom consider the strength reduction in the weld and the heat affected area. In another test, students compared the properties of 6061 and 7075 aluminum, both in as-received precipitation hardened state of -T651 and annealed -O state. Again, half the heat-treated specimens were annealed in a furnace to O condition. Tests were performed on the original heat-treated specimens and on the annealed specimens. Figure 7 shows a screen shot of the DAQ taken during testing of the annealed 6061. A similar test was performed on the 7075 aluminum, shown in Figure 8. These plots highlight the effects of annealing on the material. Both alloy had a strength reduction between 60 to 70%. In addition, the ductility of both annealed aluminum alloy, based on final fracture strain, increases significantly. The real-time data plots make it easy for students to appreciate the difference in the material properties resulting from two different treatments of the same material.




(a) Real-time plots including annotation (b) Formal plots after data reduction

Figure 7. Stress-Strain Curve for 6061 aluminum alloy




(a) Real-time plots including annotation (b) Formal plots after data reduction

Figure 8. Stress-Strain Curve for 7075 aluminum alloy

We have also compare results of stress-stain curves of polymeric materials based on the fact that strain-rate can greatly affect the mechanical behavior. In addition to comparing results from different tests, the DAQ system makes it easier for students to monitor the progress of these tests. The uniaxial tensile test is very slow and there is very little observable physical change in the specimen until the end of the test when the specimens begin to neck. When using the tablet based DAQ system, students are able to monitor the progress of the test and see exactly when the specimens begin to yield and neck. When a physical change in the specimen does occur they can immediately see the effect on the test data, and annotate their personal copy of the test data for later review.

## Student survey and observations

The wireless DAQ system has now been used in four separate lab classes. In two of these classes students were given a survey to help gauge their perceptions about the usefulness of the wireless DAQ system. In all four of the classes, the professor who ran the lab were interviewed and asked to compare the student's interaction with and without the wireless system.

The results of the student surveys are shown in Figure 9. The results show that a majority of the student felt that having real-time data during the test was useful and helped them better understand the experiment. All students found the ability to compare the results of two test in real time more useful than being able to take notes on the screen. Some of the positive student response may be because using the TabletPCs is fun. However, the instructors observed that most students were indeed taking notes on the tablet. During one lab the instructor circulated amongst the students and asked them individual question about what the data meant. After the class they noted that students were more engaged than usual and were using the real-time data to follow the test.

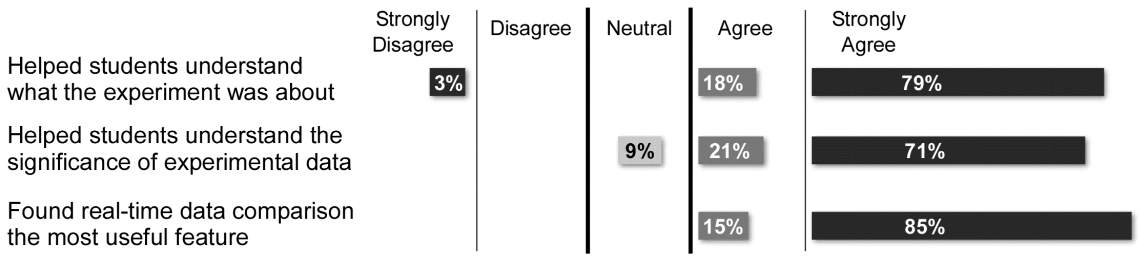


Figure 9. Student Survey Results (sample size = 34)

**Conclusions**

Overall the wireless data acquisition system has been successful. Students seem more engaged because they can follow, and analyze the test data while the test is in progress. Since the software makes it easy to view the data in different ways, students tend to "play" with the data. This too helps solidify their understanding of the data, it's correlation to the observed physical test, and it's correlation with expected results.

The ability to compare results from previous test was very powerful when studying the effects of heat treating. Without the use of Table PC's, the test for heat treated and untreated specimens would appear to be exactly the same, except that the maximum load is different. However, the real-time data plots show that there are significant differences in the test results. Since student can see these results emerging as the physical test progresses, they can better correlate the physical test with its engineering significance.

The wireless system does have some disadvantages. First, the system requires more setup by the instructor. They must make sure that all the Tablets are charged and ready for the students. Second, the system is currently limited to a sample rate of around 10Hz. This limitation is due to the small packet size used to transmit data. This was an acceptable level of performance for the tensile test experiments, but the software will need to be modified if higher sampling rates are required. Finally, the novelty of the TabletPCs initially distracted some students from the actual test. Fortunately this was only a temporary problem.

In the future we plan to modify the TabletPC software to make it easier to use with other experiments in other university departments. The mechanical engineering department is currently in the process of instrumenting a four cycle engine. We will be using the wireless data acquisition system on this lab to allow student to monitor various parameters such as engine speed, exhaust gas temperatures and carbon dioxide and oxygen content.

## Resources

For more information, including program source and executables, visit
http://fac-staff.seattleu.edu/mason/HP

## Acknowledgements

This work was made possible by a 2005 Hewlett-Packard Technology for Teaching Grant which provided both the Tablet PCs and faculty support. Hewlett Packard is gratefully acknowledged for providing support for this work.

Additionally, The Seattle University Information Technology extended the campus wireless network into the engineering lab spaces in order to complete this work.

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