# Integrated Web-based Data Acquisition System in Civil Engineering Laboratories

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## Introduction

A hands-on laboratory education has been considered a necessary part of teaching assignments in undergraduate engineering education. Since the 1980's, many changes have been made to the classroom teaching due to the advancement of personal computers. In recent years, the usage of web-based technology has brought even more potential to improve teaching, especially in various laboratory environments.

In the Civil Engineering department at Southern Illinois University Edwardsville (SIUE), one of our departmental educational objectives requires students to be able to conduct laboratory experiments and to critically analyze and interpret data pertinent to civil engineering applications. A series of four laboratory courses were set up from the sophomore year to the senior year to achieve this objective. It is also our wish that through these four laboratory courses students will also learn how to properly compose either an internal or external laboratory report that to be presented to its intended audience.

At SIUE, the schedule allotted for each CE laboratory course includes three contact hours per week and is only assigned to have one credit hour for its academic unit. Students have to put in a lot effort in order to learn all the sample preparation, equipment setup, experimental steps and data acquisition for each experiment. On top of that, students are also expected to analyze and interpret the collected data to compose a significant laboratory report to be turned in. In the end, however, students earn only one credit hour for all the effort and time invested in each laboratory course. This is one of the main reasons why some instructors and students often feel frustrated when taking these laboratory courses.

One of the ways that we are trying at SIUE to remove this frustration is to develop and deploy a common tool in all the laboratory courses so that they can be simplified and some of redundant procedures and steps can be eliminated. In all of the laboratory courses, collecting data and sharing the data among group members is always required. It would be very convenient if a web-based data acquisition system could be developed to serve in all the laboratory courses. Students could learn the system once and then use it for subsequent laboratory courses. Instructors could also save valuable time because students who already know how to operate the data acquisition system could do with less assistance in the class. Students would also have the freedom to post necessary data to the course web page to share the data with fellow students. By using the web, students would feel greater accessibility to instructors or their classmates, and also save time in composing the needed laboratory reports.

Besides these apparent advantages for students and instructors, there are other practical advantages for having the same web based data acquisition system used in all the laboratory courses. One of the advantages is that laboratory managers and teaching assistants can more easily prepare a proper setup for each experiment. Another advantage is that because it is a web-based system, it often saves a great deal of time in installing the application on individual workstations.

The CE laboratories at SIUE have been using a PC-based data acquisition system for more than 10 years. There were two major editions of the software developed during these ten years. In 1999, a new set of signal conditioners was purchased and a newer edition of the software was developed using the web technology. In the following sections, the development process of this web-based data acquisition system will be discussed including its special features and some of the problems it solved. In addition, some of the necessary hardware setup, such as transducer linkages, will be described in detail.

**Previous System**

The development of GENTEST, a data acquisition software application, began in 1992. The key hardware components initially consisted of an IBM PC-compatible system (PC) workstation running MS-DOS, an internally installed 8-channel analog-to-digital converter (ADC) adapter, outboard signal conditioners and either strain gage or LVDT- based transducers and connecting cables. Figure 1 shows the block diagram of the original GENTEST system architecture. The essential element in this configuration was that all the transducer signals remained in analog form up to the workstation enclosure. The analog to digital conversion was performed inside the workstation enclosure. Therefore, the particular workstation used must be considered to be a unique component of the system and thus needed to be part of the system calibration along with the transducers. Note that the numerical values displayed by the optional digital readout may come from a different ADC rather than what was used in the workstation. This meant that the externally displayed number did not always match what the data acquisition software displayed and recorded, leading to some confusion about what the "real" measurement was.

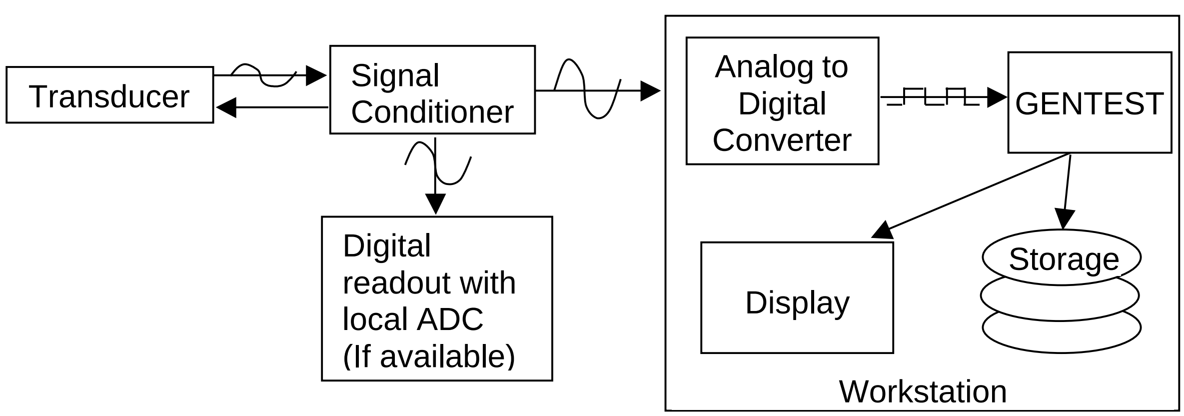



**Figure 1.** Data acquisition hardware configuration for original GENTEST version. Calibration necessarily included all of these major components.

The original GENTEST software was written using Microsoft Quickbasic (QB) running under MS-DOS. Since the earlier systems used internally installed ADC adapters, several Quickbasic sample subroutines supplied by the adapter manufacturer were used to provide a high-level interface to the adapter's driver functions.

Calibration is the crucial process by which the accurate representation of each physical reading is attained. This process was aided by the use of WINCALB[1], a software application designed in conjunction with GENTEST. WINCALB is a relatively user-friendly utility that prompts for pertinent hardware identification information. It led the user through a simple calibration procedure and then stored the coefficients computed from a polynomial regression calibration equation. These stored coefficients were later retrieved and used by GENTEST to interpret the digitized transducer signals.

The setup information for the older version of GENTEST, prepared and stored in a text file, included several items, such as transducer serial number, regression coefficients, periodic sampling criteria as well as graphical display parameters for plotting the data collected. Since an internal ADC adapter was used, a Teaching Assistant or Lab Manager needed to either locate the appropriate coefficients file or perform a calibration for the equipment to be used for each upcoming lab.

For the most part the data collected was usable and demonstrated to the students several advantages offered by computer-based data acquisition over manual methods. However, a few limitations were observed by students and instructors through the use of the system. These included:

1. The system architecture required each combination of computer, transducers and signal conditioners be calibrated as a set. Replacing or adjusting any component required a new calibration procedure be performed. This not only affected the accuracy but also the precision (resolution) of the transducer's digital representation.
2. The GENTEST software was hard-coded to work with a specific ADC adapter.
3. Digitizing noise seemed to plague certain hardware combinations. This noise was inadvertently added to the low-level analog signal fed to the ADC. The source of the noise was often difficult to pinpoint.
4. The text-based interface appeared austere compared to the graphical user interface (GUI) applications students were familiar with outside the laboratory. This often left students with the feeling that the department was providing an obsolete system to them.
5. Installation of the ADC adapter card in the computer required opening the case, setting jumpers and verifying that no hardware conflicts were created. This problem became particularly acute when we began connecting the computers to the network, or when changing or adding workstations.

After determining the shortcomings listed above, a major overhaul of the original program was initiated. Parallel developments in transducer/signal conditioner technology, GUI development tools, programming languages, local area networks and web-based applications kindled the desire in the department to develop a new generation of GENTEST. This new implementation was intended to accomplish the following improvements:

- reduce dependence of calibration on specific hardware components;
- expand flexibility to use wider variety of data acquisition subsystems;
- improve data acquisition signal chain to mitigate effects of electrical interference;

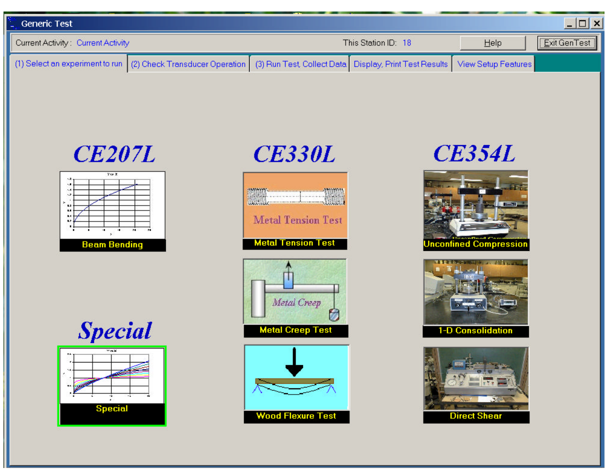
- update the user interface to utilize growing array of GUI components and tools;
- utilize web connectivity to simplify the setup process and laboratory preparation;
- improve data dissemination procedures and increase flexibility.

## Implementation of Improvements

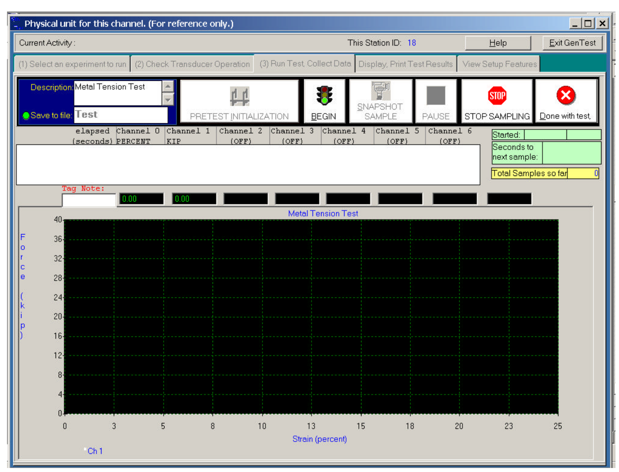
Some of the technologies adopted were chosen specifically attain the improvements listed above. These key technologies and their corresponding benefits are discussed below.

**Extensive use of an interactive GUI.** The original GENTEST QuickBasic code was completely replaced by a progression of versions based on Microsoft Visual Basic for Windows (VB) versions 3.0 through 6.0. VB and its development environment allowed us to move to an application having a Windows-type “look-and-feel” fairly quickly. While the data acquisition hardware architecture initially stayed close to that of the original DOS implementation, the improvement in the program's appearance and usability was felt as soon as it became available for student’s lab use. Screenshots of the most recent version of GENTEST are shown in Figure 2.

A significant drawback was encountered when migrating from the relatively simple DOS application to the more sophisticated Windows graphic environment version. The original DOS version and supporting files easily fit on a single 3.5-inch floppy diskette, and could be simply copied to a single directory on a workstation's hard drive. However, due in part to the GUI interface, the Windows version of the program required three diskettes and the use of a setup program to properly install and register all relevant software components. Therefore, some of the third party software was omitted and replaced with more streamlined code specifically tailored to simplify the installation process and improve performance. Before 1999, the internal ADC adapters were still used. This continued to impose a limitation on the software distribution design. Improvements were made after further redefining the instrumentation hardware configuration and adding web connectivity to GENTEST. These improvements and resulting benefits are discussed in the following section.




2a




2b

**Figure 2.** Screenshots GUI examples in most recent version of GENTEST. Opening screen (2a) allows students to select test. Data collection screen (2b) allows students to enter test description and name and start/pause/stop/snapshot control of data collection.

**Stand-alone instrumentation subsystem.** Due to the problems associated with the internal ADC adapters, several alternatives to the existing assemblage of external signal conditioners and amplifiers and cabling were considered. A decision was made to adopt a stand-alone instrumentation subsystem. This subsystem, depicted in Figure 3, consists of a transducer connected to an external (to the workstation) integrated signal digitizer module that includes the signal conditioner, ADC, visual readout and digital communication functions. The subsystem may be used with or without a computer. When operated with the computer, the digital interface connected to a standard I/O port transfers all measurements from the instrumentation subsystem to the data collection software. If used without a computer, the user can observe all measurements via the integrated LED display readout. This increases the flexibility of equipment utilization since the transducer and corresponding readout may be used not only for manual measurement but also for providing the sensory input for a computer-based data acquisition system. Note that this configuration also results in a unique digital representation of the measurand since one ADC feeds both the digital display and the data acquisition program, thus eliminating a source of doubt about the measurement data.

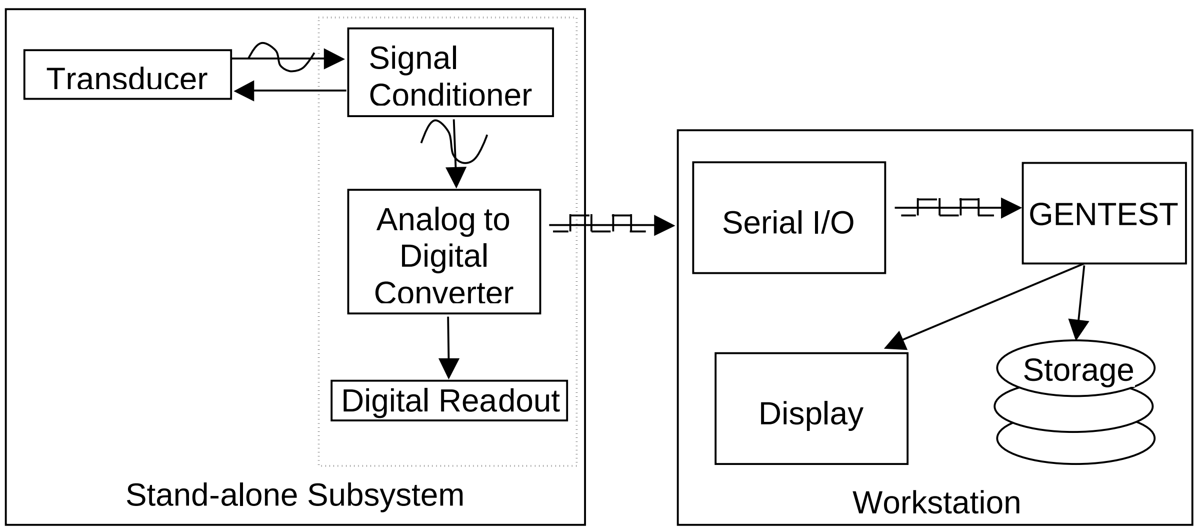
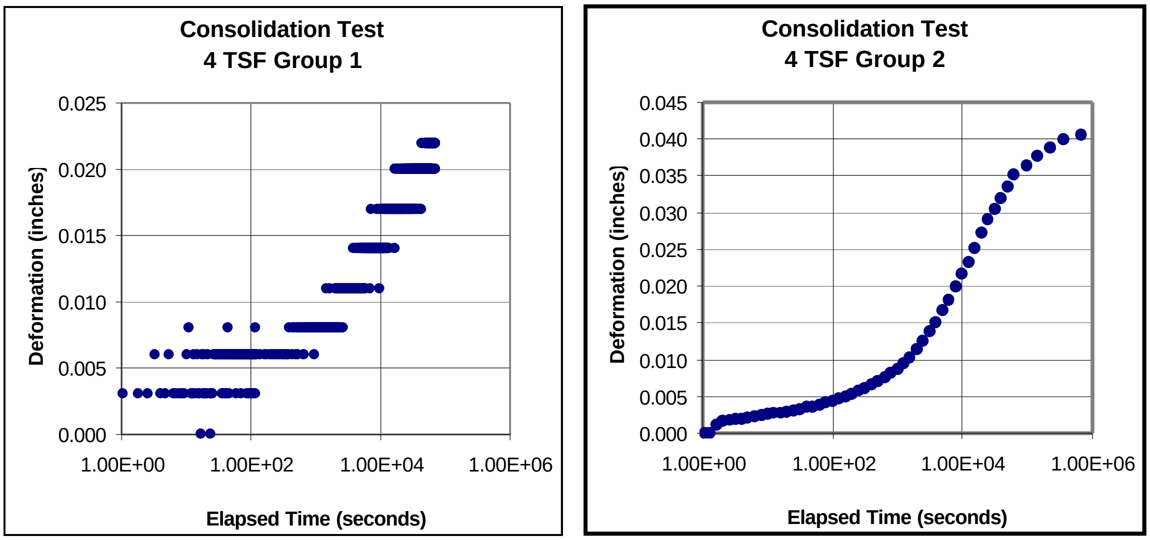



**Figure 3.** Data acquisition hardware configuration for the recent GENTEST version. Calibration is only needed for those components outside of the computer.

Another significant advantage of the stand-alone instrumentation subsystem is that by combining the signal conditioning and ADC functions outside of the workstation, the transducer calibration is independent of the workstation used for data acquisition. This results in a great benefit since it is possible to reconfigure a data acquisition system without having to be concerned about the workstation with respect to transducer calibrations. We also found that by removing the ADC function from the workstation enclosure a significant decrease in digital data noise was observed in our lab experiment measurements. Figure 4 shows sample data plots from the Consolidation test for both an internal ADC system and a stand-alone system with external ADC. The left plot, from an experiment using an older GENTEST version, shows a large amount of variation for relatively constant data due to the combined effects of rather course resolution and substantial noise component imposed on the analog signal. The right plot shows a typical result from the stand-alone subsystem that features better resolution and is less prone to noise.




4a 4b

**Figure 4.** Plots of noisy data sometimes encountered in older test setups (a) vs. much cleaner data routinely collected with the new system (b). The plot in 4b also shows data collected using N-samples-per-decade logging.

**Support of multiple instrument interface protocols (RS-232, RS-485, IEEE-488).** It is necessary to select an instrument interface protocol to enable the computer to accept input data from the stand-alone subsystem. Several interface protocols are available on the market. For our purposes the most significant factors to consider were availability of inexpensive hardware, low susceptibility to noise and the flexibility to support various instrument command structures. The communication interface protocols adopted for the recent versions of GENTEST include RS-232 and RS-485. The advantages of RS-232[3] for our lab implementation included:

1. Most workstations have one or two RS-232 ports so this built-in feature was considered to be a natural contender for helping to reach our goal of simplified connectivity and interchangeability.
2. It is a well-understood technology and many instrument manufacturers offer this protocol for their equipment.
3. Many hardware options are typically available to support a variety of physical layout situations for lab or field use.

A significant disadvantage of the RS-232 protocol, however, is that it was not designed to handle more than one receiver-sender pair. Moreover, we anticipated applications where signal runs could exceed the standard recommended length of about 50 feet. Furthermore, the unbalanced-line signaling mode makes RS-232 subject to induced noise even for runs less than 50 feet.

A related interface standard is RS-485. Though the instrument command syntax would likely be the same as for RS-232, the balanced differential signaling used in the RS-485 interface offers additional and significant advantages[4] several of which are described below:

1) RS-485 uses disconnectable line drivers which permits networking multiple subsystems (typically up to 32 receivers and 32 senders) together via simple addressing commands;

2) The balanced differential signal protocol may permit signal runs reaching 4000 feet because of relatively low susceptibility to induced electrical noise;
3) Several manufacturers have integrated RS-485 into their family of signal conditioner/digitizer products;
4) Inexpensive RS-232-to-RS-485 adapters are readily available and permit the use of one RS-232 port for interfacing with multiple RS-485 instruments.

Based on the significant advantages offered by RS-485 interface protocol, we selected it for our standard laboratory setup. This interface easily supports the range of setup configurations in our undergraduate laboratory program.

Though not strictly meeting the desire for using a standard I/O interface, GENTEST has been programmed to work with test equipment using the IEEE-488 communication protocol. A wide range of instruments developed over the last two decades has adopted this interface. However, this interface requires a special internal adapter and thus deviates from our original goal of avoiding special equipment installed in the workstation. Because we have some test equipment equipped with this interface, it was necessary to include IEEE-488 in the recent GENTEST edition.

**Database.** It was considered desirable to incorporate relational database storage and retrieval features to facilitate better organization and accessibility to a variety of runtime parameters. Microsoft Access was selected to create the database subsystem because VB and many software resources extensively support it. Moreover, since Access has received wide acceptance in engineering offices, it is a good opportunity to acquaint students with its applications. We wish that more systems using database features would be developed so that more engineers could appreciate the value of databases.

**Web connectivity.** As mentioned earlier in this article, using web connectivity offers a great deal of convenience for teaching assistants and students for setting up and learning laboratory experiments. Some of the tasks for which we use web connectivity to improve data acquisition in the laboratory are listed below.

1. Software distribution – In the older version of GENTEST, it was necessary to distribute and install software in each workstation via three floppy disks. This step was streamlined using the high transfer speed offered by the internal LAN or web.
2. Hardware/software configuration - For all versions of GENTEST, data acquisition setups require certain specific parameter information needed to communicate with the data acquisition hardware and to sample and display the collected data. This process was simplified by the use of web connectivity and a central Access database. Currently, users select a test to run which indirectly directs the GENTEST software to the appropriate network file location. The software "finds" the corresponding setup information for the appropriate laboratory test setup.
3. Data transfer – The GENTEST software can store the data collected in a number of ways. The most direct method is to save the collected data file in text format to the workstation's hard drive or floppy disk drive. The second method is that data can be saved to an Access database file on the network server for future processing. A third way is to save the data to an HTML file that is immediately accessible on a course's website.

4. On-line help – Students can link to course-specific web-based documents for quick reference in the laboratory.
5. Remote control and monitoring - Another enhancement to the laboratory data acquisition systems include the ability to remotely monitor and control the host computer. We currently use the Virtual Networking Computing software package created by AT&T Labs. This free utility software allows nearly complete control via intranet and internet connections. The software adds convenience particularly for supporting staff members to monitor and adjust systems remotely.

Web-connectivity offers many possible advantages, however its actual implementation is constrained by network security policies and procedures established by the university. We expect to utilize web-connectivity even more as we gain understanding of the security issues and how to deal with them.

**Data acquisition refinements.** Most undergraduate CE lab experiments are typically conducted at a quasi-static or low-speed sampling rate. However, in some special cases, experiments (consolidation, creep, etc.) require variable sampling rates. The recent version of GENTEST contains multiple sampling techniques beyond the usual fixed-period sampling methods.

1. N-samples per decade – This technique reduces the amount of data collected, and has proven to be particularly useful for the soil consolidation test. Our current implementation is set up to collect the deformation vs. time relationship for the consolidation test. In this test, log time is displayed on the x-axis. The user can establish the number of samples to be collected and displayed per log decade. As the test begins, the samples are collected rapidly, but as the test progresses the sampling rate continually decreases. This works particularly well for the consolidation test since initial deformation happens rather quickly, but also dramatically reduces the total amount of data collected as the testing continues for hours or days. Figure 4 shows a comparison of the results between the old (constant-rate) and new (N-samples-per-decade) methods.
2. Snapshot – In addition to the automatic collection of data at a prescribed interval, the user may also choose to force a sample to be taken at any time. This “snapshot” feature allows additional points to be taken as needed.
3. List – In one of our labs we have the students observe deformation of small wood beams incrementally loaded with specific loads. The setup in the database contains a list of these load values. As the test begins the student is prompted to apply the first load then click “snapshot” to take the corresponding deformation reading. The prompt automatically advances to the next increment and the process repeats until the list is exhausted. There is also a procedure to allow the student to redo any missed step.

**Related web-based laboratory support.** The web-based features outlined above for the data acquisition system augments related websites developed to help students in several of our lecture and lab courses. For example, a web-based database[2] was developed in 1998 to allow students to manually enter data on the web for easy sharing with other lab group members. The successful development of the web-based GENTEST program also allows us to closely tie the data acquisition system with this web database. After using the web database and GENTEST students gain convenience in composing their lab reports.

## Future Enhancements

Development of the web-based data acquisition system continues. Further advances in web and data acquisition technology will allow refinements and features. Student feedback will also prompt improvements. Some areas of potential improvement have been identified, such as:

- The understanding of the effect that a computer interface protocol will have on the data sampling rate. An option could be added to GENTEST to automatically set an appropriate sampling rate for the selected interface protocol.
- A study is required to understand the effect of a delayed response from any one device in the serial polling mode. A proper procedure could be developed to accommodate this delay so that the accuracy of data collection will not be affected.
- Database management should include more user-friendly features (prompts, hints, etc.) to allow new teaching assistants to make changes without extra help. Also, time is required to develop an interfacing subprogram to automatically connect GENTEST to the web database. Therefore, the data files created from GENTEST could be directly deposited to the database, and thus be shared with other users immediately upon collecting the data.
- Reliability and security are two major concerns for web-based technology. These are also prime concerns to be addressed in the future development of GENTEST. As the technology continues to advance, GENTEST will be require to be routinely maintained an updated.

## Conclusions

The CE department has been using the web-based version of GENTEST for the past two years. CE 354L, Soil Mechanics Laboratory, was the first class to use the program. At the beginning, students felt a little apprehensive and uneasy about using an unfamiliar system. However, this feeling gradually faded away as they used it for the second time. The GUI and interactive design were very effective in catching their attention. The feeling from the teaching assistant who taught the lab at that time was especially excited since he could easily retrieve the calibration file from the database without having to physically perform the tedious calibration steps.

In Spring 2001, GENTEST was first used in a sophomore course, CE 207L (CE Computer Applications). Specially designed software was used in the course before this time. A short lecture was given in the course to introduce the sophomore students to this new system. The system was used three times in the course for three different experiments. After the third lab, students' feedback indicated that in general they had a positive attitude toward the system and some of them even indicated that they wish to use the system more often. Currently, the system is used by three separate laboratory courses, CE 207L, CE 354L, CE 330L (Engineering Materials Laboratory). We plan to also incorporate it in CE 415L (Applied Fluid Mechanics Laboratory). A common standard for composing lab reports has been posted on each of the course web pages. A new web-based database is being created this semester for the CE 330L course to allow students to post and share data on the web. It is our wish that through this integration we can enhance the communication among instructors and students, and reduce some of the unnecessary complexity existing in each laboratory course.

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**Biographical**


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