AC 2009-1764: INTEGRATING LABVIEW AND REAL-TIME MONITORING INTO ENGINEERING INSTRUCTION

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Integrating LabVIEW and Real-Time Monitoring into Engineering Instruction

Abstract

Authors' experiences with programming modules in a freshman engineering course at Virginia Tech are documented. An approach involving gradual integration of the LabVIEW programming concepts into this course is suggested. A variety of assessment data indicate success of the proposed approach. A LabVIEW Enabled Watershed Assessment System (LEWAS) is introduced and status of its development is discussed. It is proposed to integrate the LEWAS into the curriculum of this freshman engineering course. Integration of LEWAS is a logical extension of the current LabVIEW activities and is targeted at enhancing sustainability component of the course. After the integration of real-time water quality monitoring, enabled by the LEWAS, students will be able to learn about environmental sustainability using data from an on-campus impaired stream.

Introduction

In 2004, a group of engineering and education faculty at Virginia Tech received a major curriculum reform and engineering education research grant under the department-level reform program of the NSF[1]. This grant resulted in developing a framework for reformulating the curricula of bioprocess engineering, within the Biological Systems Engineering (BSE) department and general engineering (GE, also called freshman engineering), within the Engineering Education (EngE) department using a spiral theory approach[2]. A number of hands-on activities were developed and implemented in the freshman engineering program as a result of the Departmental Level Reform (DLR) project[3,4,5]. Engineering Exploration (EngE1024), a freshman engineering course required of all engineering undergraduates, is the most affected course by the DLR project in the GE program. This course primarily focuses on hands-on design, problem solving, professional ethics and skills, and critical thinking skills[9]. This course is taken by about 1700 freshmen every year. One of the learning objectives of this course is that after successful completion the students should be able to develop and implement algorithms and demonstrate understanding of basic programming concepts. In late 90s, FORTRAN was replaced by MATLAB to cover basic programming instruction in this course. Beginning in Fall '04, MATLAB was replaced by Alice programming language. In Spring '07, Alice was replaced by LabVIEW programming. The dataflow programming approach of LabVIEW is suitable for many engineering applications. Furthermore this approach is well suited for collection, processing and communication of environmental data which can be used to teach sustainability concepts; the details of this application are covered in the section "LabVIEW Enabled Watershed Assessment System (LEWAS)".

No formal assessment of students' learning experiences was conducted until the beginning of DLR project in 2004. Several assessment tools are developed and implemented by DLR investigators to assess the outcomes of learning activities[6,7,8]. Rest of the paper is organized as follows. First we share our experiences with Alice programming briefly along with the lessons learned. Then we discuss how lessons learned from Alice experiment helped us introduce LabVIEW instruction. Analysis of assessment data from LabVIEW module is presented next. Finally, we discuss a LabVIEW enabled system that has potential to enhance sustainability instruction into EngE1024.

Alice Experiment

In Fall '04 computer science (CS) department joined the College of Engineering at this university. As a result, all CS bound freshmen are now required to take EngE1024 just like any other engineering freshman. Prior to Fall '04, EngE1024 included MATLAB instruction for developing logical thinking and basic programming skills. However, in consultation with the faculty in CS department, it was decided to replace MATLAB by a programming language called Alice (www.Alice.org) beginning in Fall '04. Alice provides a completely new approach to learning programming concepts as it uses 3D Interactive Graphics Programming Environment to teach fundamentals of programming and has been used in CS101 type courses. For novice programmers, one major advantage of using Alice is the mitigation of syntax issue due to the drag and drop method of developing Alice code. Further, the objects in Alice are available in 3D and provide better visualization of the interaction between various objects and their properties and methods/functions in an object-oriented program. In Fall '04 and Spring '05 semesters, students in EngE1024 were assigned a semester programming project in addition to regular programming homework and they were invited to participate in a "best project" competition. Alice software had some bugs, particularly in 04-05, and we sought help of Alice support staff at Carnegie Mellon University to provide necessary help to students. Several students, particularly the ones with prior programming experiences, got frustrated with the capability of Alice as they could not program their ideas effectively for the programming competition. Based on students' feedback, the programming project was dropped during Fall '05 and Spring '06 semesters. Alice was continued in Fall '06 and we continued collecting/analyzing student feedback.

Based of systematic evaluation of all assessment data, we decided to replace Alice by LabVIEW programming in Spring '07. Various assessment tools (i.e., pre-and post tests, focus group sessions, new student survey, etc.), developed as a part of the DLR/NSF project, were used to assess the learning outcomes of Alice instruction. Based on the data collected as part of the New Student survey, about half of the engineering freshmen join our engineering program with prior programming experinces[8]. EngE1024 instructors, however, do not take into account prior programming experiences of ~50% freshmen while designing programming instruction modules. Therefore, engaging ~50% freshmen with prior programming experience into programming instruction present a major challenge for EngE1024 instructors. Students, particularly those with prior programming experience, did not enjoy the programming environment Alice offers for learning basic concepts of object-oriented programming. Students who had had experience in programming in Java or C++ did not appreciate the drag and drop approach for developing a program in the Alice environment and did not consider Alice a "true" programming software.

The authors, however, note that several first time programmers admitted liking the programming approach in the Alice environment and pre-and post-test results showed positive learning gains[8]. Although students did a number of programming exercises on engineering applications using Alice (e.g., simulation of a sine wave, simulation of a circular motion of an object, simulation of a motion of a pendulum, etc.)[10], several students did not perceive direct engineering applications of Alice in future engineering courses. In fact, the authors are not aware of any upper level courses that directly use Alice programming language although use of object oriented programming concepts is done in several courses.

A summary of lessons learned in the Alice experiment is below:
    a. When introducing a new programming tool for a freshman class, make sure that the software is free from programming bugs.
    b. Start with a few core programming concepts, particularly in the first semester, and gradually add new concepts and/or applications.
    c. Show real life engineering applications of the proposed programming environment
    d. If programming is not a major component of the course, then assigning a programming project involving a student competition is perhaps not a good idea, particularly if the class includes a significant number of students with prior programming experiences.

LabVIEW Programming

LabVIEW (**Lab**oratory **V**irtual **I**nstrumentation **E**ngineering **W**orkbench) is a visual programming language from the National Instruments. LabVIEW uses a dataflow programming model in which the output of each computation node is calculated when all the inputs are determined for that node. The calculations take place concurrently for nodes that do not have a data dependency. LabVIEW has been used in educational settings for implementing capstone design projects in the undergraduate curriculum. It has been used in data acquisition and control for a variety of systems including electrical and mechanical systems [11]. In addition, it has been used in data acquisition for monitoring a renewable energy based power system [12]. LabVIEW was taught in an interdisciplinary course on data acquisition [13] and integrated in a laboratory course to provide students with realistic, industry-based simulation experiences in the laboratory section of an upper division electronics course [14]. LabVIEW has also been integrated into a freshman engineering curriculum [15], and student feedback are discussed in [16] . The introduction of LabVIEW in [15] and [16] has been limited to three class sessions (the major emphasis of the course is on MATLAB). In [17], the authors reported how students developed programs in LabVIEW in a freshman engineering course to learn basic feedback control concepts. Since feedback control is an integral part of many engineering majors, the authors developed the course as the first layer of a spiral sequence of multidisciplinary courses.

During Fall '07 the LabVIEW graphical programming language was introduced in EngE1024. In fact, LabVIEW was introduced in Spring '07 but due to the tragic events at Virginia Tech, the LabVIEW curriculum was not completely implemented. In contrast to its predecessor, ALICE, which is educational software for teaching introductory computer programming in a 3D environment, LabVIEW is a dataflow programming platform used in industry for data acquisition and instrument control. LabVIEW provides extensive support for connecting

instrumentation hardware, a feature used in developing LabVIEW based activities in the course. Major programming concepts covered using LabVIEW are shown in Table 1.

Table 1: LabVIEW Concepts/Applications in EngE1024

Core Concept	LabVIEW(LV) topic covered	Activity/Homework
A	**A:** Introduction to LV programming environment, VIs	Watching LabVIEW video that introduces the programming environment and dataflow programming using a small program. Completing LabVIEW tutorial (finding the roots a quadratic equation)
B	**B:** Controls and Indicators, Data types Observing dataflow by execution highlighting	Calculating grade from grade components
C	**C:** Overview of Control Structures in LV: Repetition Structures and decision structures	Water tower problem (LV block diagram shown in Figure 1. In this problem students are instructed to calculate height of discharged water in cylindrical and rectangular tanks periodically until the user-entered time is reached.)
D, E	**D:** Repetition Structures in LV: For loop **E:** Boolean variables in LV	Controlling a two wheel robot when road boundaries were sensed
N	Repetition Structures in LV: While Loop	**N:** Nanotechnology activity: develop VI for Plotting normalized nanoscale potential and use provided VI to measure the surface to volume ratio of carbon nanotubes
F	**F:** Decision Structures in LV: Case structure	Use case structure to calculate letter grade from numerical grade
G	Introduction to data acquisition	**G:** Data Acquisition Activity: collecting and analyzing data (using exponential, linear and power regression) from three sensors (temperature, force and motion)
H	Publishing a Virtual Instrument over the Internet, acquiring real time water quality data	**H:** Remote Data Acquisition Activity: collecting water quality data from server computer connected to multi-probe sonde [25]

Following the lesson learned in Alice experiment we have tried gradual integration of LabVIEW core concepts into ENGE 1024 (see Figure 2).
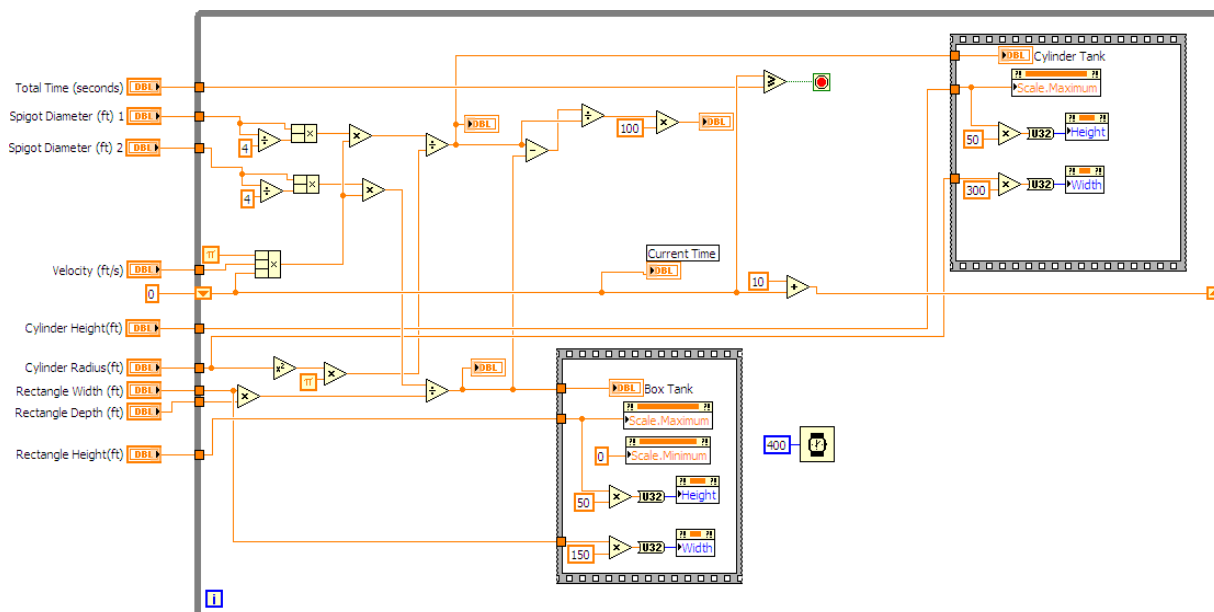

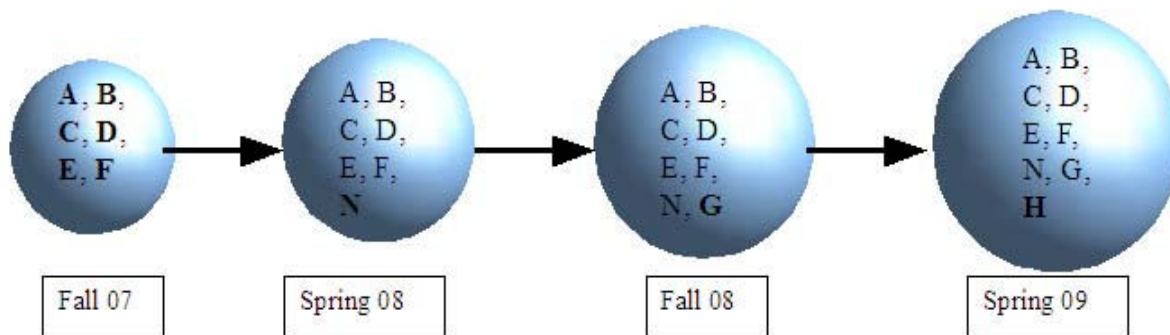Figure 1. LabVIEW block diagram for a water tower problem

Figure 2. Gradual integration of LabVIEW core concepts/applications into EngE1024 (letters represent LV core concepts/applications, newly introduced items for each semester are shown with bold letters; see Table 1 for explanation)

A major addition to the LabVIEW curriculum in Fall '08 was the introduction of the Data Acquisition (DAQ) activity. The objective of the activity was to demonstrate to the students how data can be collected from a physical phenomenon (e.g., force, motion and temperature) using LabVIEW compatible sensors and therefore emphasizing the data flow part of programming concept in LabVIEW. Students were also instructed to derive mathematical equations from the

time plots of these variables that describe how they change in time in an experimental setting. The latter reinforces what students had earlier learned about fitting linear, power and exponential functions in the course. Students are expected to achieve the following two objectives by completing the activity:

1. Observing Data flow programming in a real time data acquisition environment
2. Constructing three types of plots from physical phenomena and determine the representative equations for each plot along with their related coefficients. The students have been introduced to linear, power and exponential regression earlier in the course and have learned to derive analytical functions from empirical data. The cooling temperature probe provides an exponential curve (Newton's law of cooling), the displacement of a falling ball onto the motion detector provides a power (quadratic) function and the force sensor can be exited linearly.

Three sensors (i.e., temperature, force, and motion detection) are used to develop this activity. The system setup and LabVIEW output are shown in Figures 3 and 4, respectively.
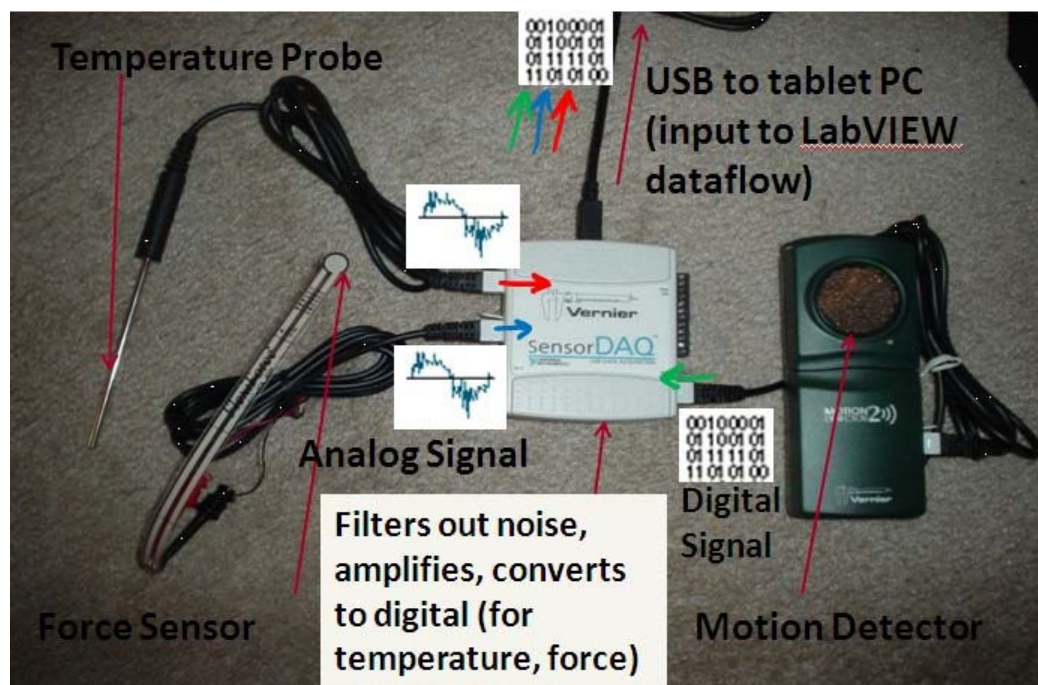

Figure 3. DAQ activity setup. The analog signals from temperature and force sensors are filtered out from noise, amplified and converted to digital (0's and 1's) in the Vernier SensorDAQ (middle). The Motion Detector implements these conversions internally.
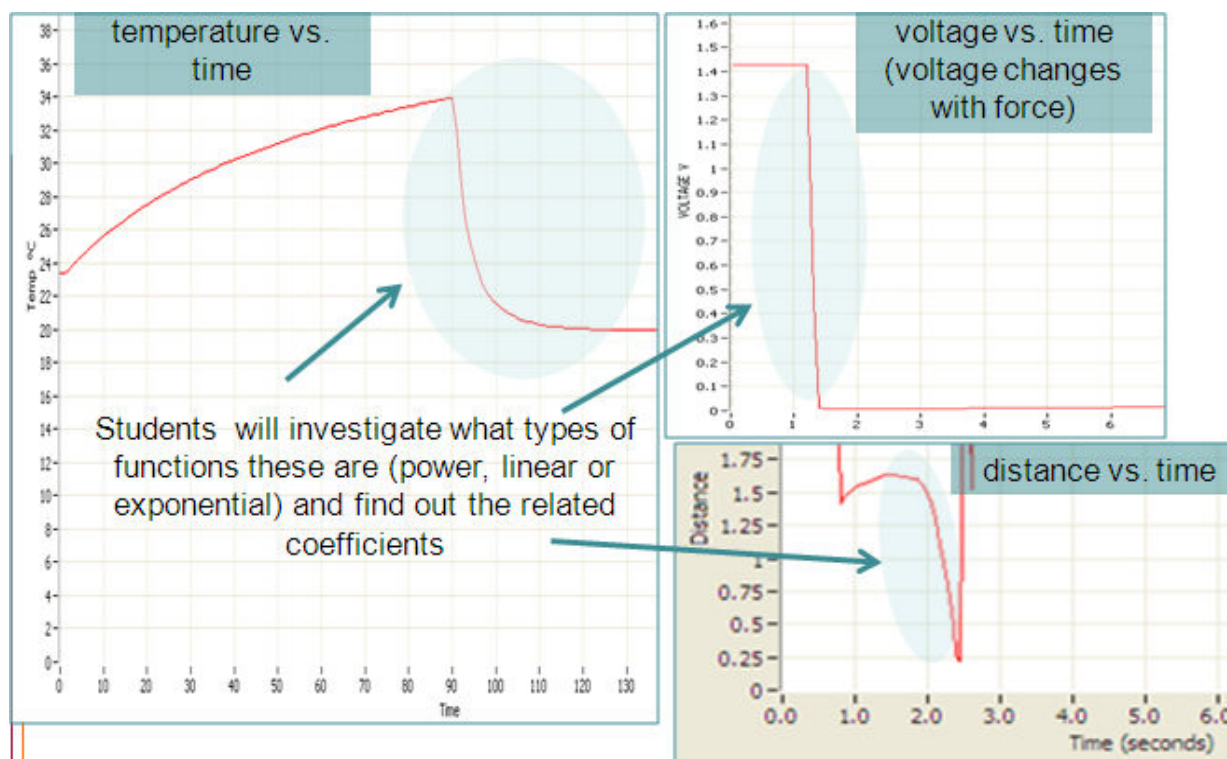
Figure 4. LabVIEW Output of Data Acquisition Activity

As shown in Figure 2, the new core LabVIEW concepts introduced in the course each semester are the logical conclusion of previous semester's activities/experiences and also show the main application of a dataflow programming language, data acquisition while learning core concepts taught in any other programming language. Next, we present results of our assessment activities.

Assessing LabVIEW Curriculum

<u>LabVIEW Pre- and Post-Test</u>

In order to assess student familiarity with basic programming constructs, a pre- and post- survey was administered using scantron forms during Fall '08. Students had 45 seconds to answer each of the ten multiple choice questions which were displayed by projector on the screen. These questions examined students on general programming concepts as well as questions pertaining to dataflow programming. According to the exit survey collected at the end of Fall '08, 43% of the students (N=314) had reported having programming experiences in high school. A statistic test (paired t-test) reveals that students' average number of correct responses out of 10 questions (n = 676) increased from 5.54 to 6.41 (see Figure 5) and this increase was statistically significant at the .0005 level: t-statistic = -13.45 < - t Critical one-tail = - 3.29. It may also be noted that the variance of the scores was reduced from 3.72 to 3.33.
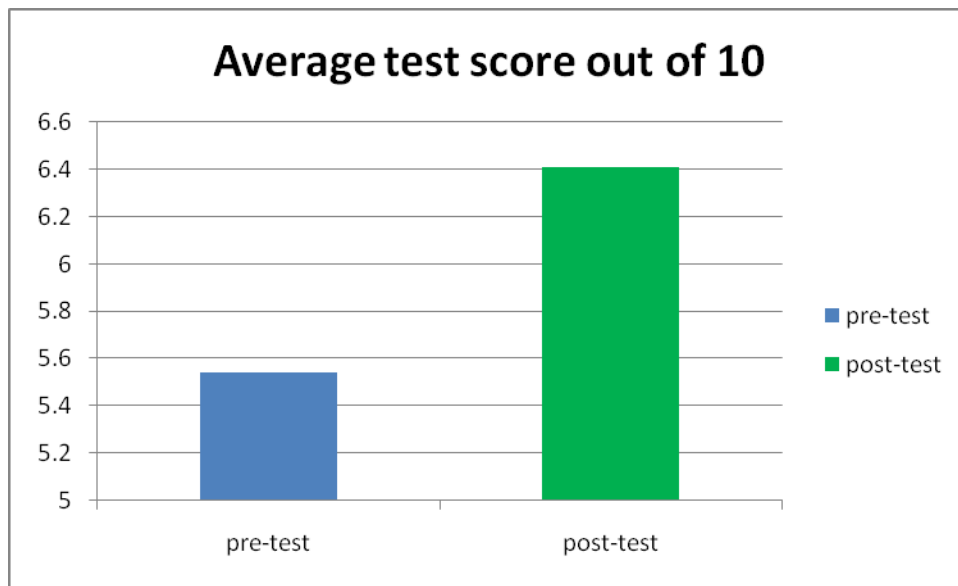
Figure 5: Pre-and Post-Test Scores – Programming Concepts

It is inferred that the course activities designed to introduce various programming concept using LabVIEW had resulted in a statistically significant gain in the students' score between the pre-test (administered before introducing the LabVIEW material) and post-test (administered at the end of the course).

 Exit Survey Data

An exit survey, recording students' experiences with EngE 1024, was administered at the end of Fall '08. During the three semesters that LabVIEW was introduced (i.e., Fall 07, Spring 08 and Fall 08), there were three questions that measured students' perceptional responses on LabVIEW based activities on a Likert scale. Furthermore, analysis of student responses to the open ended question "What have you learned in this class [EngE 1024] that you think will be useful in your engineering studies?" revealed that a number of students perceived LabVIEW to be useful in their engineering studies. Figures 6 through 9 summarize the semester by semester responses to each question and also show the trends observed over these semesters.

What have you learned in this class [ENGE 1024] that you think will be useful in your engineering studies?
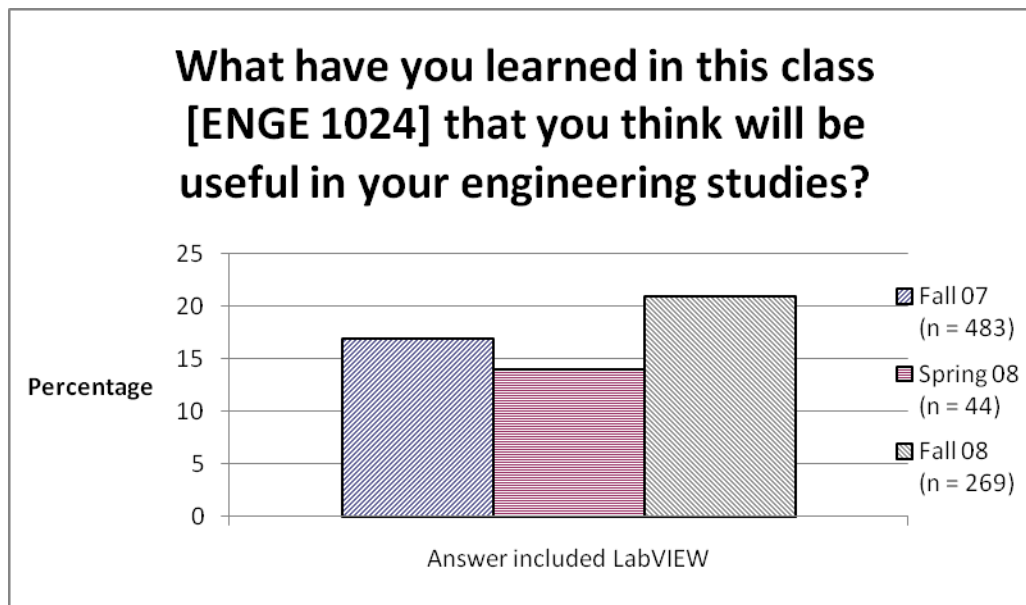
$$n_1 = 483 \quad \hat{\pi}_1 = 0.17$$

$$n_2 = 44 \quad , \hat{\pi}_2 = 0.14, \; z_{1,3} = \frac{\hat{\pi}_1 - \hat{\pi}_3}{\sqrt{\dfrac{\hat{\pi}_1(1-\hat{\pi}_1)}{n_1} + \dfrac{\hat{\pi}_3(1-\hat{\pi}_3)}{n_3}}} = \text{-1.33} < \text{-1.28(-z at.1)}$$

$$n_3 = 269 \quad \hat{\pi}_3 = 0.21$$

Figure 6: Summary of Exit Survey Data (Spring 08 data was excluded from the comparison due to much smaller sample size.)

As seen in Figure 6, there is a statistically significant increase from Fall '07 to Fall '08 in the percentage of students (about one in five in Fall '08) who believed LabVIEW is among the topics that they learned in this class that would be useful in their engineering studies.

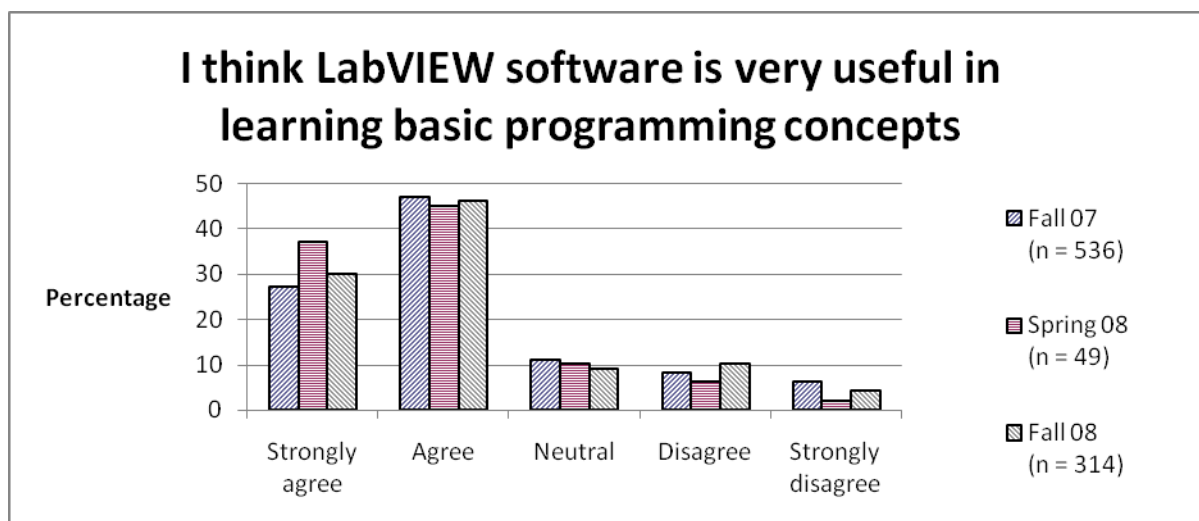I think LabVIEW software is very useful in learning basic programming concepts

Figure 7: Summary of Exit Survey Data

Figure 7 shows that over the three semesters about three quarter of the students perceived LabVIEW to be very useful in learning basic programming concepts. This result complements the statistical significant gain in student post-tests over their pre-tests as discussed earlier.
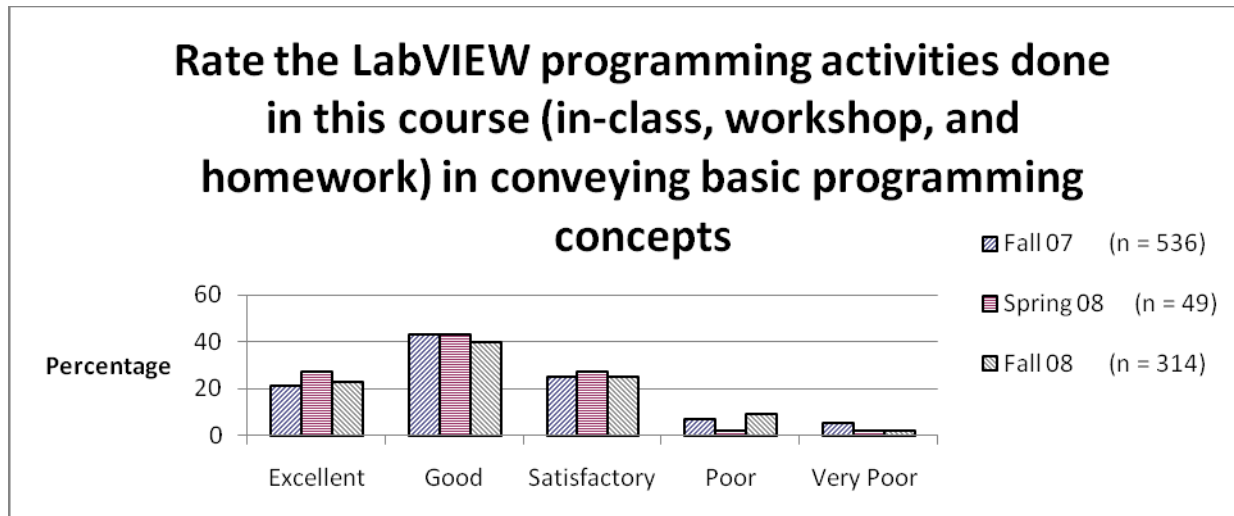

Figure 8: Summary of Exit Survey Data

Figure 8 reflects students' perception that the majority of the students (distributed with almost the same proportions for all the semesters under study) believed the course activities were successful in conveying basic programming concepts.
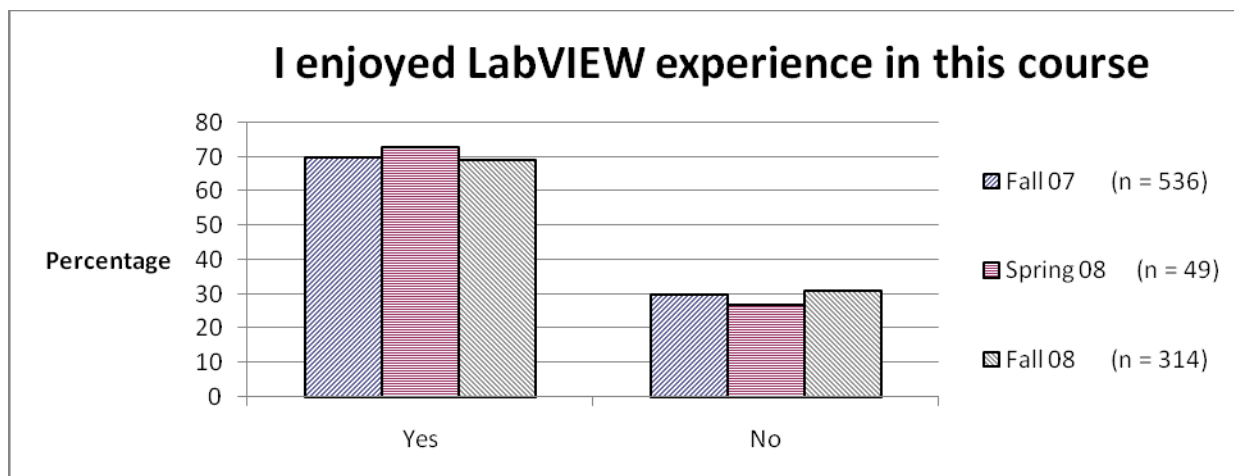

Figure 9: Summary of Exit Survey Data

Finally, the results shown in Figure 9 indicate that in all three semesters more than two thirds of the students enjoyed the LabVIEW experience in the course. These results are definitely better than the responses we received during our Alice experiment.

LabVIEW Enabled Watershed Assessment System (LEWAS)

Having successfully introduced a variety of LabVIEW activities, we are now well positioned to take advantage of the LabVIEW environment to enhance the sustainability component of EngE1024. For this purpose we propose to use a LabVIEW Enabled Watershed Assessment System (LEWAS) that will have capability to access real time water quality and quantity data from an on-campus stream. These data will be used to introduce water sustainability concepts into EngE1024. Obviously, LEWAS is a logical extension of the hands-on LabVIEW modules that have been successfully implemented in EngE1024.

Researchers have taken advantage of DAQ capability of LabVIEW for developing systems in which data is acquired for the phenomena under study in one location and stored and analyzed in another location. In [18] a local PC controls a DAQ card on a remote PC to acquire and subsequently uses the standard telephone line to transfer the data between the PCs. Authors in [19] discuss and compare different Web/Internet available technologies in LabVIEW that can be used to control/monitor experiments. The system described in [20] enables students to perform experiments over the Internet by connecting to PCs running LabVIEW using a browser based user interface. These PCs are connected to pre-built circuits that constitute the test circuits for the distance experiments. The proposed LEWAS system differs with the above systems in the fact that real time data is acquired from physical phenomena remotely. This setup requires special considerations for the ruggedness of the computer that performs the data acquisition and the design of the communication system between the data collecting station and users. In addition to the LabVIEW based data acquisition systems discussed above, LEWAS is compared against systems designed specifically for collecting and processing water quality parameters in table 2.

Table 2. Comparing LEWAS with other real-time remote monitoring systems

System	Can it be programmed?*	Data Collection Method	Multiple Remote Access Enabled ?	LabVIEW used for data collection?
Riverwatch Field Station [21]	No	GSM/Satellite/Ethernet	Yes	No
YSI 6200 [22]	No	Radio/Cellular/Modem	No	No
YSI EcoNet [23]	No	Cellular/Modem/Satellite/ Wireless Ethernet	Yes	No
Campbell Scientific DCP 200 [24]	No	Satellite	No	No
LEWAS	**Yes**	**Wireless Ethernet**	**Yes**	**Yes**

* For the purpose of this paper, a system is considered programmable when the time between samples can be changed by the client, sampling can start and end by the client remotely and potentially commands can be sent to the server by the client.

As it can be observed in Table 2, unlike other systems, LEWAS provides LabVIEW based programmability to user and enables multiple remote access. Both these features make LEWAS an ideal candidate for students to learn about sustainability concepts by remotely monitoring water quality parameters and having the ability to program the collection, processing and communication of the data.

The development and implementation of LEWAS has been planned in three phases. In the first phase (see Figure 10), which is implemented in an engineering lab in summer 2008, water quality data was collected using a multi-probe sonde and sent to LabVIEW which was loaded on the server computer (Tablet PC). The sonde had capability to sense temperature, conductivity, dissolved oxygen, and pH of water. The data was shared with a remote client via Wireless LAN. Clients can control the server LabVIEW program, Virtual Instrument (VI), remotely and receive measurement data.
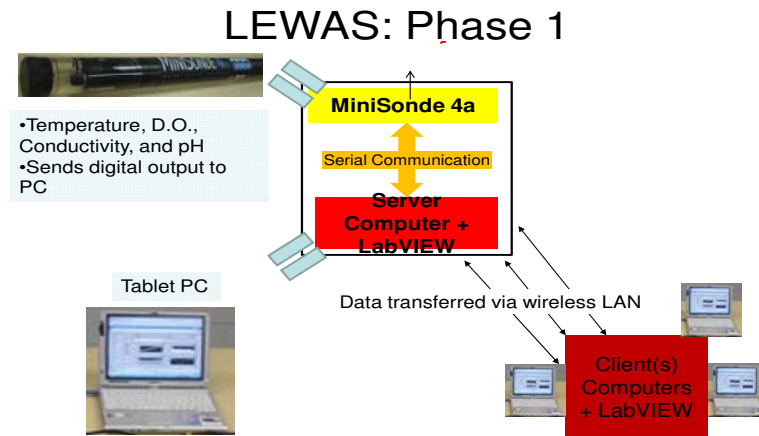

Figure 10: LEWAS – Phase I

A sample reading of data by the server computer which was also received by the client computers is shown in Figure 11.
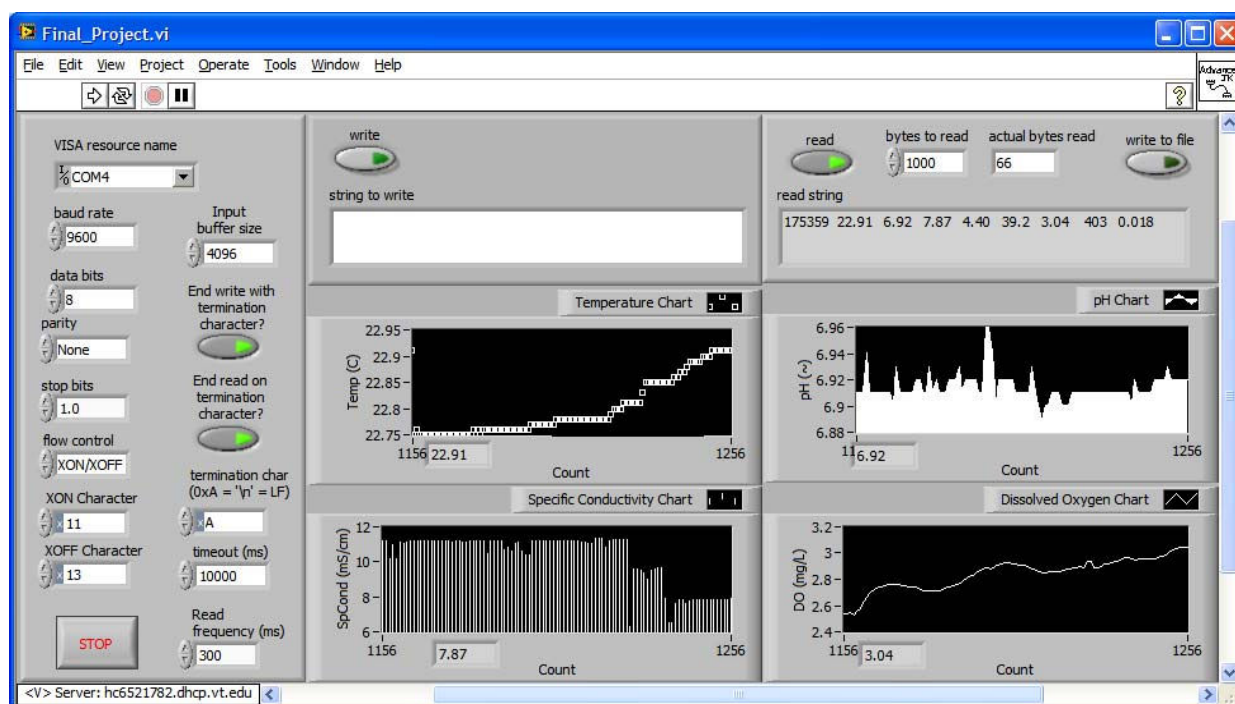
Figure 11. Developed Virtual Instrument front panel showing data that was read in while multi-probe sonde was attached in the Laboratory.

In addition to the NSF/DLR project, the first phase of the LEWAS was developed and implemented as a part of a National Science Foundation Research Experiences for Undergraduates (NSF-REU) program held during summer 2008 in the interdisciplinary area of watershed sciences and engineering [25]. The program allows undergraduate students from across the country to conduct research under the mentorship of faculty and graduate students for 10 weeks in a stimulating interdisciplinary environment at the host institution.

Ongoing work and future plans

The second phase of LEWAS, which is under development, employs an industrial computer (compactRIO) as server which can run remotely and continuously without user intervention. It is equipped with three modules for serial communications, non-volatile data storage and wireless communications (see Figure 12). The system is operated in an indoor lab setting. We have already procured all required hardware and the phase 2 work is in progress at the time of this writing.

LEWAS: Phase 2

MiniSonde 4a

Serial Communication

Server Computer + LabVIEW

Embedded Computer:

compactRio:

•8 available slots for I/O modules
•Potential for multi parameter measurement. Displayed:
•RS-232 I/O
•Non-volatile Storage
•Wireless LAN Module

Data transferred via wireless LAN

Client(s) Computers + LabVIEW

Figure 12: LEWAS – Phase II

After successful testing of phase 2 which involves remote login of students enrolled in the class to the system, the development of the phase 3, field deployment, will take place. In this phase (see Figure 13), a solar powered and battery backed electrical power supply system and a high gain wireless antenna and I/O module are added to the system.
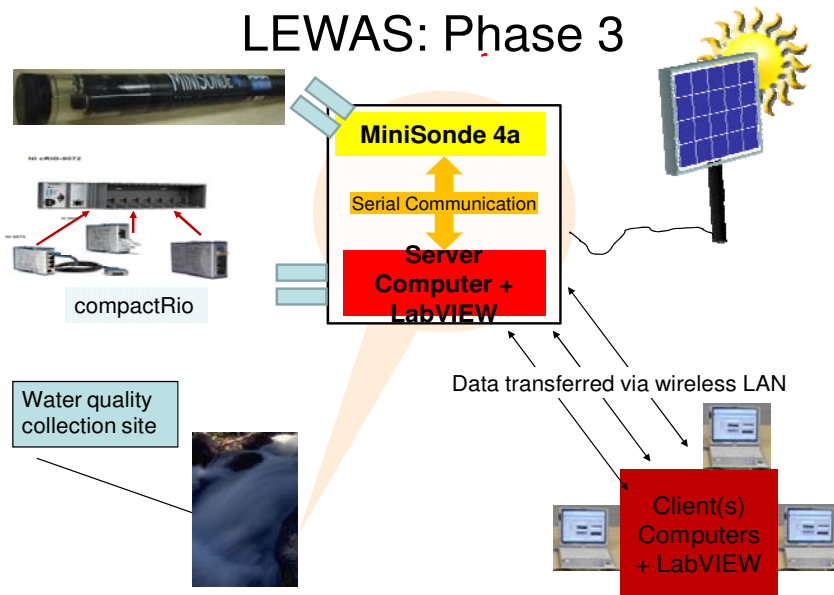
LEWAS: Phase 3

MiniSonde 4a

Serial Communication

Server Computer + LabVIEW

compactRio

Water quality collection site

Data transferred via wireless LAN

Client(s) Computers + LabVIEW

Figure 13: LEWAS – Phase III

Summary

Authors' experiences with Alice programming language in EngE 1024 and lessons learned are documented. We have discussed an approach involving gradual integration of the LabVIEW programming concepts into the freshman engineering course EngE1024. Pre- and post-test results indicate statistically significant gains in students' learning of general programming concepts as a result of LabVIEW activities. A variety of exit survey data indicates positive learning experiences of students as a result of various LabVIEW assignments. This increase in attitudinal responses has coincided with the introduction of new hands on activities that demonstrate DAQ capability of LabVIEW. Integration of LEWAS is a logical extension of the LabVIEW activities into the course which is targeted at enhancing sustainability component of the course. After the integration of real-time water quality monitoring, enabled by the LEWAS, students will be able to learn about environmental sustainability using an on-campus stream. Additionally, students will see real life application of dataflow programming in acquiring, transmitting and analyzing the data. It may be noted that as per the EPA classification, this on-campus stream is an impaired stream.

Acknowledgement

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