AC 2012-4820: DEVELOPMENT OF LEARNING MODULES TO TEACH INSTRUMENTATION TO BIOLOGICAL SYSTEMS ENGINEERING STUDENTS USING MATLAB

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Development of learning modules to teach instrumentation to biological systems engineering students using MATLAB

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ABSTRACT

The Biological Systems Engineering (BSE) Department at Virginia Tech is undergoing significant curriculum change through implementation of a spiral theme based curriculum. The primary focus of the spiral curriculum is to provide opportunities for learning in repeating themes based on authentic problems in the profession of engineering with increasing complexity over the years. One outcome (theme) is the ability to control processes and systems and to address that we are developing learning modules that could be implemented from freshmen to senior year in the curriculum. Majority of the activities will be grouped into an instrumentation course and overall objective of this paper is to describe the development of laboratory modules for measurement and control and implementation of the same through the course "Instrumentation in Biological Systems Engineering". This is a core BSE course that all BSE students will take with an average the enrollment of 30 students. Currently MATLAB is being taught at freshmen (Introduction to Engineering) and sophomore years (Numerical methods course). As MATLAB is being considered as one of the standard software tool in Engineering programs, it would be logical to use the same for the instrumentation course as well, instead of learning new software. MATLAB can be used to communicate with data acquisition and control to measure temperature, pressure, flow and stress in biological systems and/or bioprocess operations. However, the laboratory modules that were conducted have not used MATLAB and required extensive development of such activities (learning outcomes, assessment, and implementation of the activity and hand-on exercises) to implement a spiral theme based approach to instrumentation in the curriculum. The primary goal of the course development is to implement a meaningful learning experience for students with design of instrumentation for measurement and control through laboratory hands-on exercises. A repeat enforcement of concepts with increasing complexity (spiraling) with authentic problems within a course and across the curriculum will provide a best learning environment. In this regard, using tools like MATLAB for problem solving, numerical simulation and acquisition from and control of instrumentation systems will make a connectedness with learning activities.

We identified several laboratory modules, namely, temperature measurement using thermocouple, thermistor, pressure measurement using a pressure probe, velocity measurement using velocity probes and stress measurement using strain gauge. All measurements in the lab used breadboard connected to a data acquisition board (DAQ). The voltage or current data acquired is transformed to engineering units of temperature, pressure, velocity, flow and force with appropriate implementation of transfer functions and is reported to the students in those engineering units. Steps included development of MATLAB (.m) files and GUIs for various operations (data acquisition, data processing, display of results and instrument simulation). The student learning progress was evaluated through pre- and post- test and the tests evaluated both instrumentation concepts and MATLAB applications. Based on the data collected over three implementation cycles (2009, 2010 and 2011), the results indicate that the student see the connectivity in using engineering tools like MATLAB for variety of applications: algorithm development, problem solving, numerical simulation and for measurement and control of instruments. This paper will provide the lessons learned in spiral theme based curriculum development with an emphasis on controlling biological systems.

BACKGROUND

Research on how engineering students learn is gaining momentum and has achieved some breakthroughs with an emphasis on effective pedagogy. This consensus by experts in engineering education presents with unprecedented opportunities to improve student learning, but effective pedagogy has entered the practice at a slow pace. In addition, the ballooning cost of higher education, is primarily limiting resources for a quality education (Wellman et al. 2009). Due to this situation, there is increasing concern that declines in number of technologically innovative graduates, and further the decline in economic competitiveness. To address these shortcomings, the engineering programs have to be innovative to bring meaningful learning experiences to the students. One such measure to reformulate the approach to the learning process through implementation of spiral theme based curriculum.

The Biological Systems Engineering (BSE) Department at Virginia Tech is undergoing significant curriculum change through implementation of such a spiral theme based curriculum. The primary focus of the spiral curriculum is to provide opportunities for learning in repeating themes based on authentic problems in the profession of engineering with increasing complexity over the years. Jerome Bruner, in his book *The Process of Education* (1960), proposed that a learning curriculum ought to be capable of engaging students of any age in any subject matter and do it in an intellectually honest manner.
The key idea in his approach is that the learning curriculum could be arranged so that the central questions, or themes in a discipline, would be returned to again and again as learners advance in their knowledge and intellectual capacity. The learning trajectory is thus represented as a spiral rather than the linear pathway that is characteristic of traditional schooling. As learners participate in increasingly complex investigations, organized carefully around the major themes of choice, they acquire in a more natural way the knowledge they need because it is connected to problems of real import and interest, and they acquire also the full intellectual apparatus associated with being the scientist, historian, or engineer rather than learning about their chosen discipline. In particular, it is this notion of learning to be something, rather than learning about something, that we saw as a key basis for reformulating our curriculum.

The development of spiral theme based curriculum was carried out as an iterative series of steps and has been explained in detail elsewhere (Lohani et al., 2011). The first step involved identifying the overall outcomes for the program. The faculty brainstormed and listed many items that students should be able to do by the time they graduate. As a result, we defined four high-level, overall outcomes for bioprocess engineering students: (1) Design a bioreactor; (2) Design a process and optimize the process conditions; (3) Select units in the process and design a plant layout; and (4) Control the process.

To address the outcome (theme) about the ability to control processes and systems, we were developing learning modules that could be implemented from freshmen to senior year in the curriculum. Activities were developed to be part of freshmen year through mechatronics and introduced concepts related to measurement, communication and control through group activities. In the sophomore year, students had an opportunity to work on a laboratory exercise to measure temperature in a confined space and control the temperature by turning on or off an electric fan (cooling) or a halogen light bulb (heating).

Majority of the activities will be grouped into an instrumentation course and overall objective of this paper is to describe the development of laboratory modules for measurement and control and implementation of the same through the course “Instrumentation for measurement and control of biological systems". This is a core BSE course that all BSE students will take with an average the enrollment of 30 students.

The use of software programs like LABVIEW (National Instruments, Austin, TX) has been used to teach instrumentation in this course. However, the choice of MATLAB (MathWorks, Natick, MA) in this study was mainly based on several factors including the use of the software in several Engineering programs across the nation as a script-based programming and problem solving tool and its prevalent use in the industry. In addition, in order to implement a spiral theme based approach, we selected MATLAB as it has been used in the program from the first year, and it is used in other required BSE courses before and after the instrumentation course. Currently MATLAB is being taught at freshmen (Introduction to Engineering) for graphing, plotting and curve fitting and sophomore years (Numerical methods) for solving differential equations. As MATLAB is being considered as the standard software tool for the College of Engineering, it would be logical to use the same for the instrumentation course as well, instead of learning new software. MATLAB can be used to communicate with data acquisition and control systems to measure temperature, pressure, flow and force in biological systems and/or bioprocess operations. However, the laboratory modules that were being conducted did not use MATLAB and required extensive development of such activities (learning outcomes, assessment, and implementation of the activity and hand-on exercises) so as to implement a spiral theme based approach to introduce instrumentation. The primary goal of the course development is to implement a meaningful learning experience for students with design of instrumentation for measurement and control through laboratory hands-on exercises. A repeat enforcement of concepts with increasing complexity (spiraling) with authentic problems within a course and across the curriculum will provide a best learning environment. In this regard, using tools like MATLAB for problem solving, numerical simulation and acquisition from and control of instrumentation systems will make a connectedness with learning activities, both within this single course and across four year curriculum.

OBJECTIVE

The objective of this study is to evaluate the effectiveness of introducing instrumentation concepts for measurement and control of biological systems through the use of MATLAB. The primary goal of the paper is to describe the implementation of meaningful learning experiences for students with design of instrumentation for measurement and control through laboratory hands-on exercises. Hands-on laboratory exercises provide active learning environment. Active learning simply means students are active participants in the class rather than passive listeners (Smith et al. 2005). A significant body of research has shown that in well-organized classes active learning gives rise to significant improvements in performance (Schwartz et al. 1999; Froyd 2007). In addition, we believed a repeat enforcement of concepts with increasing complexity (spiral curriculum) with authentic problems will provide a best learning environment. In this regard, using tools like MATLAB for problem solving, numerical simulation and acquisition from and control of instrumentation systems will make a connectedness with learning activities.

METHODS

We identified several laboratory modules (Mallikarjunan, 2011), namely, 1) temperature measurement using thermocouple and thermistor, 2) pressure measurement using a pressure probe, 3) velocity measurement using velocity probe and 4) force measurement using strain gauge. All measurements in the lab used breadboard connected to a data acquisition board (DAQ). The virtual instrument (.m files) developed converted the measured voltage or current with appropriate transfer functions to give the required engineering unit for the measurement (temperature, pressure, velocity, flow and force). Steps included development of MATLAB (.m) files and GUIs for various operations (data acquisition, data processing, display of results and instrument simulation). The student learning progress was evaluated through pre- and post- test and the tests evaluated both instrumentation concepts and MATLAB applications. Based on the data collected over three implementation cycles (2009, 2010, and 2011), the results indicate that the students see the connectivity in using engineering tools like MATLAB for variety of applications: algorithm development, problem solving, numerical simulation and then for measurement and control of instruments. In addition, the students also experienced the flexibility of the software to interface with different hardware/instrument throughout all the laboratory experiments. The course was offered with a new syllabus in Fall 2009 and we worked on the planning the course activities during the Summer 2009.

The implementation process started with the developmental work in association with technical help from Mathworks, Inc. First we identified concepts for laboratory modules that could be able to work through a spiraling framework: Introduction of electrical voltage measurement to measurement using advanced sensing systems. Each laboratory module was planned to build on the skills learned from the previous laboratory exercise. For example, the second lab involved temperature measurement using thermocouple and thermistor that involved measurement of voltage either directly or using a voltage divider circuit. The flow measurement laboratory exercise followed pressure measurement which included flow measurement through the measurement of velocity and head (pressure). When appropriate, the students used various electrical components and a breadboard to obtain voltage output that can be measured through a data acquisition board (DAQ). Each module included appropriate MATLAB (.m) files and GUIs for various operations (data acquisition, data processing, display of results and instrument simulation) and these files are being shared through Mathworks MATLAB Central (http://www.mathworks.com/matlabcentral/linkexchange/links/2202-bse-4004-instrumentation-measurement-and-control-in-biological-systems).

The implementation of the course and laboratory modules were assessed using pre- and post-tests. The pre-, post-test questionnaire is shown in Table 1. The students were exposed to MATLAB over the years before they have the instrumentation course but their experience using MATLAB for measurement and control was first introduced during this course and thus the assessment focused on their learning experience with this particular course. This course did reinforce previous skills of programming, plotting, and other basic skills of MATLAB.

The progression of each laboratory exercise and how each one was building on the spiral framework is presented in Table 2. The concepts were emphasized in each lab with specific questions to be addressed by the student team. The students turned in individual lab reports and the reports were graded with importance to the reflective discussions that addressed the specific learning objectives for the laboratory exercise. These activities were made to reinforce the spiral framework within the course. The theoretical lectures were planned to coordinate the lab activities. In addition to the pre- and post-test, student's input about the course was collected through the university course evaluation.

RESULTS AND DISCUSSION

The results from the pre-, post- test are summarized in Table 3 and 4. The data was analyzed using paired-t test to see the effects of the learning activities in the course. The pre-test was given in the beginning of the course and then was administered at the end of the course. The results from the perceptions of the students in relation to the knowledge of instrumentation (questions 1 to 6) show a clear improvement between pre and post-tests. Question 1 on the ability to define and differentiate between sensor and control showed a significant difference between pre- and post- tests. This clearly demonstrated that the students had a positive learning experience with sensors and control mechanisms in the course. Similarly, the question on understanding the importance of controlling a biological system for getting maximum benefit showed a significant improvement between pre- and post-tests. Instead of just learning few concepts related to instrumentation, students also could relate to the importance of measurement and control of biological systems with an aim to maximize the benefit from the system. The examples and laboratory exercises had allowed the students to relate the role of instrumentation for both measurement and control in variety of scenarios.

The question on “I feel that skills I learned with respect to MATLAB have broader use to my future courses, and my career” also showed a significant difference between pre- and post- tests and positively demonstrated that repeated experience through multiple courses enforced the skills on using specific engineering tool and gain an understanding on lifelong professional implications of such skills. Some of the students from the class continued to use the software during their capstone design project.

With respect to the question on ability to perform specific tasks using MATLAB showed improved performances for all types of tasks (Importing data, creating and manipulating vectors, simple data analysis, plotting data, curve fitting, writing scripts, accessing documentation, publishing, and connecting to laboratory hardware). In this regard, the specific tasks of importing data, plotting data, curve fitting and connecting to hardware showed significant improvement from the beginning of the course to the end of the course. The weighted means from pre-test scores ranged from 2 to 7 on a 10 point scale and the same from post-test scores ranged from 7 to 9 on the 10 point scale. The course provided a very positive experience for the students in learning the concepts related to instrumentation using MATLAB. Few written comments from the students included the recommendations for laboratory exercises. Specifically students want to see more hands-on activities with variety of instruments instead of spending time with bread-board circuit building for the lab activities. In addition, students also want to have more exercise problems worked out in the class and assignments.

CONCLUSION

In conclusion, the efforts to introduce the concept of controlling biological systems through a variety of activities have resulted in positive reinforcement of that concept. Specifically, the introduction of MATLAB as the tool for measurement and control provided the opportunity to implement the spiral theme based curriculum to address the concept of controlling biological systems. The implementation of specific activities through the instrumentation course resulted in significant improvement in the students’ understanding of sensors and controls, importance of controlling a biological system and the role of MATLAB as an engineering tool for measurement and control. In addition, for the specific tasks using MATLAB, the implementation resulted in significant improvement for importing data, plotting and curve fitting the data, and connecting the hardware for data collection and analysis. The efforts to include more MATLAB based activities in other BSE courses are being considered so as to reinforce the use software tools like MATLAB toward a meaningful engineering practice.

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Table 1. Pre-, Post-test Questionnaire

1. I can define and differentiate between sensor and control.
☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree

2. I can define precision and accuracy and explain the difference between the two.
☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree

3. I understand the importance of controlling a biological system is for getting maximum benefit from the system.
☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree

4. I can define the term sensitivity and know its importance with measurement and control
☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree

5. I feel my previous exposure to MATLAB in Freshman and Sophomore years have prepared me to use the tools for this class and others
☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree

6. I feel that skills I learned with respect to MATLAB have broader use to my future courses, and my career?
☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree

7. On a scale from 1-10 (with 10 being best), rate your ability to do the following tasks in MATLAB:

_ Importing data into MATLAB
_ Creating and manipulating vectors
_ Doing simple data analysis (e.g., calculating mean and standard deviation)
_ Plotting data
_ Fitting data to a line
_ Writing a MATLAB script to automate routine tasks
_ Accessing the MATLAB Documentation
_ Publishing a MATLAB script to a HTML or MS Word document
_ Connecting to laboratory hardware (such as data acquisition cards and oscilloscopes)

8. Name at least three important properties of biological systems that can be measured

Table 2. Spiral framework for laboratories in the instrumentation course

Laboratory Description	Activity	Additional Details
Introduction Lab	Voltage, Current and Resistance measurement	Fluke Multi-meter to collect data
Temperature measurement	Thermocouple and thermistor (voltage divider circuit)	Time constant estimation, data collected from Fluke is exported to MATLAB for analysis
Optical measurement	Photodiode to measure color changes	Calibration of photodiode (light intensity), data analysis using MATLAB
Communication	RS232-C and GPIB	Serial and GPIB tools in MATLAB
Force measurement	Strain gauges and whetstone bridge and signal amplification	Bridge design and instrument amplifier and use of DAQ
Pressure measurement	Pressure transducer	Transfer function development
Flow measurement	Flow measurement by measuring velocity and pressure	Uncertainty estimation from multiple measurements
Gas Chromatography	Data collection and analysis	Data analysis (peak identification) using MATLAB

Table 3. Frequency distribution of responses for Q1 to Q6.

Response	**Q1***		**Q2**		**Q3***		**Q4**		**Q5**		**Q6***	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Strongly Agree	1	10	15	21	3	17	2	9	2	3	2	7
Agree	7	15	9	4	15	8	9	11	7	14	5	12
Neutral	10	0	0	0	6	0	9	5	9	4	14	6
Disagree	6	0	1	0	1	0	5	0	7	4	4	0
Strongly Disagree	1	0	0	0	0	0	0	0	0	0	0	0
Mean Score	3.04	4.35	4.52	4.73	3.80	4.65	3.32	4.08	3.16	3.58	3.20	3.96

Q1. I can define and differentiate between sensor and control.

Q2. I can define precision and accuracy and explain the difference between the two.

Q3. I understand the importance of controlling a biological system is for getting maximum benefit from the system.

Q4. I can define the term sensitivity and know its importance with measurement and control

Q5. I feel my previous exposure to MATLAB in previous years have prepared me to use the tools for this class and others

Q6. I feel that skills I learned with respect to MATLAB have broader use to my future courses, and my career?

* Post-test response significantly different from pre-test

Table 4. Frequency response for questions related to ability to do specific tasks using MATLAB

Scale		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Mean**
Importing*	Pre	2	2	3	0	3	5	3	0	0	3	5.29
	Post	0	0	0	0	1	1	3	3	5	8	8.62
Vectors	Pre	1	0	0	3	3	5	3	2	0	4	6.43
	Post	0	0	0	0	1	1	2	6	3	8	8.57
Data Analysis	Pre	0	0	0	1	6	3	3	3	0	5	7.00
	Post	0	0	0	0	0	0	3	4	4	10	9.00
Plotting*	Pre	0	0	2	1	5	7	1	2	0	3	6.19
	Post	0	0	0	0	0	1	0	3	0	17	9.52
Fitting*	Pre	1	1	0	4	6	3	2	2	1	1	5.52
	Post	0	0	0	0	1	0	0	6	1	13	9.14
Script Files	Pre	2	1	3	2	3	3	3	1	1	2	5.33
	Post	0	0	1	0	2	1	6	3	2	6	7.76
Documentation	Pre	4	1	2	2	3	1	3	1	1	3	5.19
	Post	0	0	0	0	0	1	2	6	3	9	8.81
Publishing	Pre	3	1	3	0	3	4	0	4	2	1	5.38
	Post	0	0	0	0	2	1	1	4	1	12	8.76
Connection*	Pre	12	4	0	1	4	0	0	0	0	0	2.10
	Post	0	0	3	0	3	2	4	3	3	3	6.90

Scale 1 to 10, where 10 is best

* Post-test response significantly different from pre-test