AC 2007-506: SENSORS AND SYSTEMS IN A FRESHMAN DESIGN COURSE

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Sensors and Systems in a Freshman Design Course

Abstract

The second design course taken by all engineering Freshman was recently revised to build upon a first semester design course project in which sensors and programming (C++) are introduced in a robot challenge. In the second design course the students now have their programming knowledge extended to a graphical environment by learning LabVIEW™ through a series of assignments in which they interface various sensors to their laptop computers. Applications include a simple motor speed control using a shaft encoder. Students then use their knowledge in a team design project that incorporates data acquisition from sensors to a laptop computer, display of the sensor data and its use to control some aspect of the system to which it is applied. Teams are provided with design project choices, each posed as a set of system requirements. This together with mini-lectures and assignments continue a thread started in the first design course to develop systems concepts in the context of design. Development of students' comfort and capacity with sensors and systems as a core thread early in their education provides an important foundation for future engineers.

Background

Following a major revision in 1998, the engineering curriculum at Stevens Institute of Technology includes a design course in each of the eight semesters. This is collectively referred to as the Design Spine[1]. The first five are core design courses taken by students from all intended disciplines; the last three are taken in the discipline - a junior course followed by a 2-semester capstone senior year project. In most cases the core design courses are linked to concurrent engineering science courses, thus providing context for the latter. The Design Spine is a key vehicle to develop a number of threads that build both technical and so-called "soft" competencies. The latter include communications, creative thinking, teaming, economics of engineering, problem solving, project management etc. It should be noted that the first four design courses have been taught by adjunct engineers, either practicing or recently retired. They bring the benefit of their design experience into the classroom. A further curriculum revision in Fall 2005 provided the opportunity to completely revise Engineering Design II, taken in Freshman Year second semester. An objective for the revised course was to build upon the use of programming and sensors that was introduced to the Freshmen in Engineering Design I in the context of a robot project. It provided an opportunity to introduce graphical programming through LabVIEW which had previously not been addressed until the fourth design course in the sequence and then somewhat superficially. In providing this early emphasis on sensors and their interfacing through LabVIEW in a core design course it is intended to impress upon students the ubiquitous nature of sensors and systems for monitoring and control across the engineering spectrum. The revision of Design II also provided an opportunity to continue developing concepts of systems thinking initiated in Design I as described below and to further enhance other threads in teaming, creative thinking and communications.

Introducing a Systems Approach

Commencing with the students who entered in Fall 2005, the design sequence was revised to introduce concepts associated with systems thinking from the start of the design sequence. This reflects the recognition that engineers are called upon to practice in a global socio-economic environment increasingly dominated by engineering systems and the design of engineering systems. Engineering curricula, with their focus on the disciplinary contributions to design, encourage a mindset in which students seek technical solutions often rooted in a specific engineering discipline with little regard for the context in which their product, system, or service may be deployed, the societal or business need it may fulfill or even its relations to all the other engineering, business or 'environmental' domains that can contribute to success.

To address these issues of "partial design" it was decided to introduce the comprehensive design approach known as Total Design, after Pugh[2]. "Total Design" is the systematic activity necessary from the identification of a market/user need, to the selling of the successful product/process/service to satisfy that need – an activity that encompasses product, process, people and organization. In fact, total design encompasses approaches, methods and tools of system design and systems engineering. The major aim of systems engineering is to develop an operational model of the system for all phases of the life cycle, the model is then used as a basis for detail design. It is this top-down approach to design that has been missing from engineering curricula and that will be increasingly needed in the design of future systems. Systems thinking involves applying the common tools of analysis and synthesis to form new conclusions[3].

Engineering Design I and Introduction to Programming

In pursuing the goal to develop the total design approach throughout the Design Spine, basic concepts are now introduced in the Freshman year to establish the foundation, recognizing that they may not resonate with students there but provide the needed basis to revisit through the sequence to capstone design. In Engineering Design I the second week includes a product disassembly exercise using a cordless screwdriver. This now provides the vehicle to introduce the first steps in developing total design by consideration of market needs and stakeholder requirements. A detailed overview and linkages of the total design process appears in Figure 1. Each phase in the life cycle of a product, system or service, as shown in the sidebars, would include essentially the same ten steps. Students are given an overview of the complete process in Week 2 of Engineering Design I and then asked to address the first two stages in the context of the cordless screwdriver, for example, by being asked to identify the stakeholders and their requirements, something that presents them a challenge if they are pushed to go beyond the customer/user.

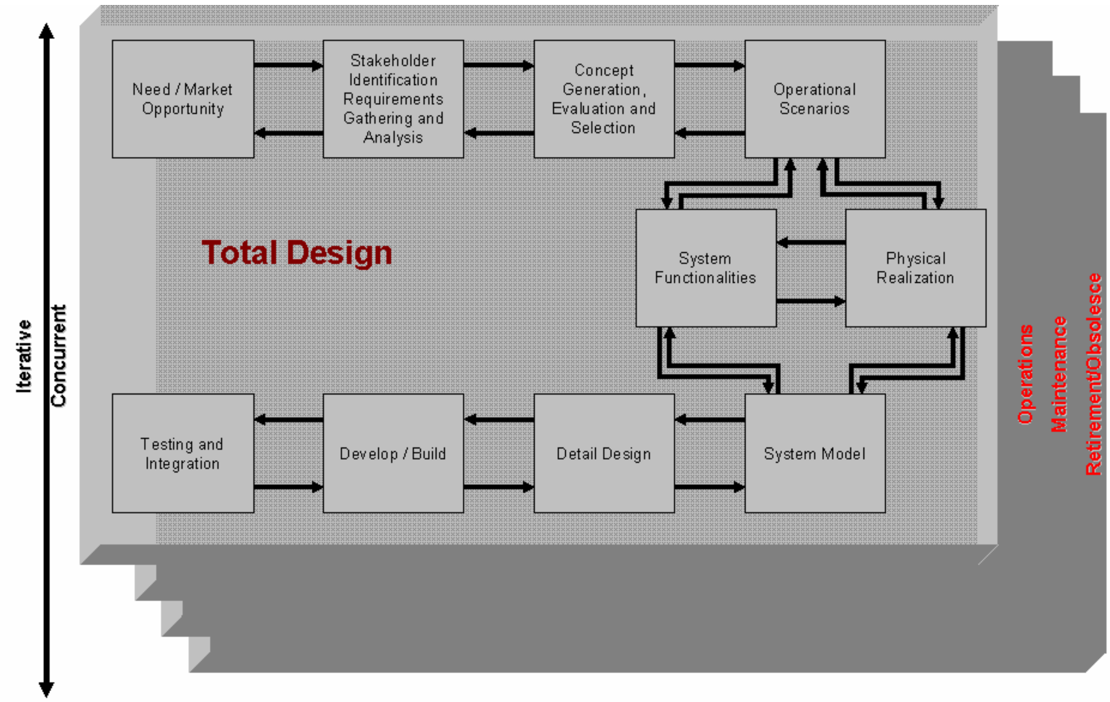

Fig. 1 Representation of Total Design (after Ref. 3)

These first two stages are reinforced in the context of the major design project that occupies Weeks 6-14. This project is an autonomous wheeled robot competition, which gives students an early example of a system; one that combines various disciplinary aspects such as mechanical design, electrical circuits, sensors and programming of a microprocessor. In this project they also engage in the third stage of the total design process, namely concept generation, but this is not developed in a systematic manner. It is revisited in more depth in Engineering Design II. The total design process in the context of introducing a systems approach to undergraduate design together with our initial experience in implementing it in Design I was described in a paper at the 2006 ASEE Annual conference [4].

It should also be noted that the robot design project provides a link and a context to concurrently build on the Introduction to Computer Programming course that is also taken in the first semester. The programming course uses C++ as the language, although it is mostly focuses on procedural aspects of programming within this environment. In the design course robot project, students use a PIC microprocessor (PIC 16F877A - Microchip Technology Inc.) on a custom - designed circuit board. The board has been designed for great flexibility to allow use for later courses up to senior design and exploits the full capabilities of the PIC chip. The board has pre-wired interfaces for two motors, a number of sensors and micro switches and a set of additional analog and digital I/O connections as well as extension capabilities through daughter boards. The PIC can be programmed in C++. In the design laboratory the student groups undertake a series of programming tasks early in the project that are common sub-programs for the project irrespective of the final design, such as motor control and bumper response. This provides a means to link knowledge from the programming course to real applications in a project-based learning mode in the design course, with instructor and teaching assistant support. These sub-programs then help in building the final software design.

Engineering Design II

Engineering Design II, which is the focus of the paper, was completely revised in Spring 2006 and now focuses on sensors and data acquisition, building on the Engineering Design I experience and continuing the development of systems thinking through the "Total Design" approach. The graphical programming language LabVIEW™ is employed to connect sensors to the students' laptop computers via a USB data acquisition module (National Instruments USB-6009 with 14 bit resolution and a counter). The custom-designed PIC board used in the Design 1 project is also employed to provide interfacing for experiments and in the design projects. This board has advantages in providing built-in interfacing and power for motors, including motor speed control through pulse-width modulation in hardware and can power other devices. It also provides serial communications linkage with Bluetooth^{R} protocol to give wireless capability which students used for joystick control in some projects.

Students learn to program in LabVIEW via assignments to connect to and calibrate a light sensor (Experiment 1 - PIC board as interface) and in Experiment 2 to perform motor speed control using a perforated disc and optical interrupt sensor. For this the PIC is used for pulse width modulation and the NI USB 6009 is introduced for counting - shown in Fig. 2.

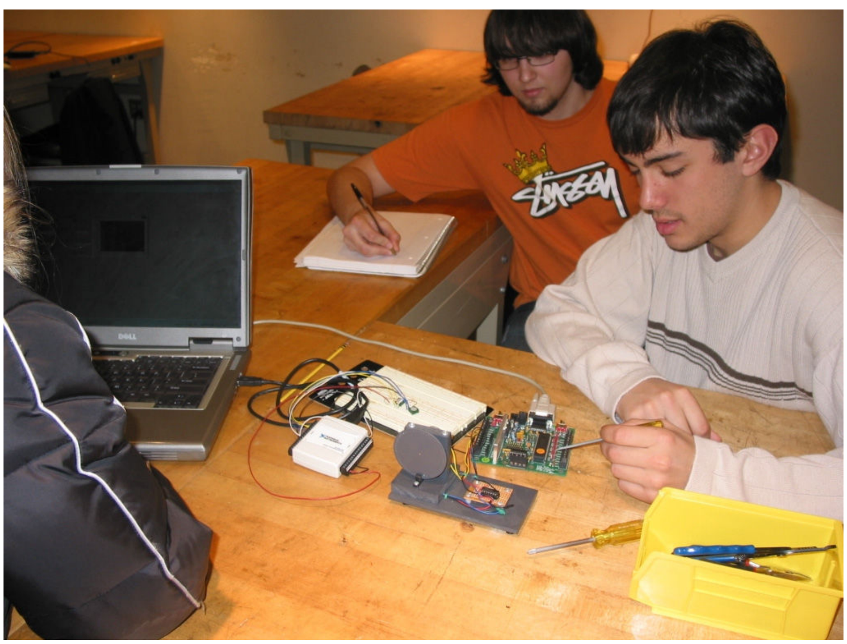

Fig. 2 Using USB 6009 DAQ and PIC board for motor speed control

The students apply this knowledge to their group's choice of one of three projects that require use of sensors, acquisition of sensor data and its use for a simple control function(s). Students are also required to develop a 'dashboard' on their laptop in LabVIEW to display the sensor data, etc. All students are required to develop their own LabVIEW program in the introductory assignments and so it is not just left to the "programmer" in the group. LabVIEW appears to provide a more intuitive route to programming, especially for students who were either not adept at C++ or not interested in programming in Term 1.

Total design is revisited early when a commercial fire alarm system (multiple units – one per group – connected across the design laboratory to a master monitoring panel) is evaluated and then the individual alarm units disassembled to reveal their sensors (temperature and optical smoke sensors which relate nicely to sensors used in the course). Stakeholder requirements for the alarm system are considered and then the 4th total design stage is introduced, namely Operational Scenarios, in which context diagrams and use case scenarios are developed. This requires a collection of scenarios to be established, one or more for each group of stakeholders for the particular phase of the life cycle – only the first design phase is considered in Freshman year. Each scenario addresses one way a particular stakeholder(s) will want to use, deploy or otherwise interact with the system; it defines how the system will respond to inputs from other systems to achieve the desired effect.

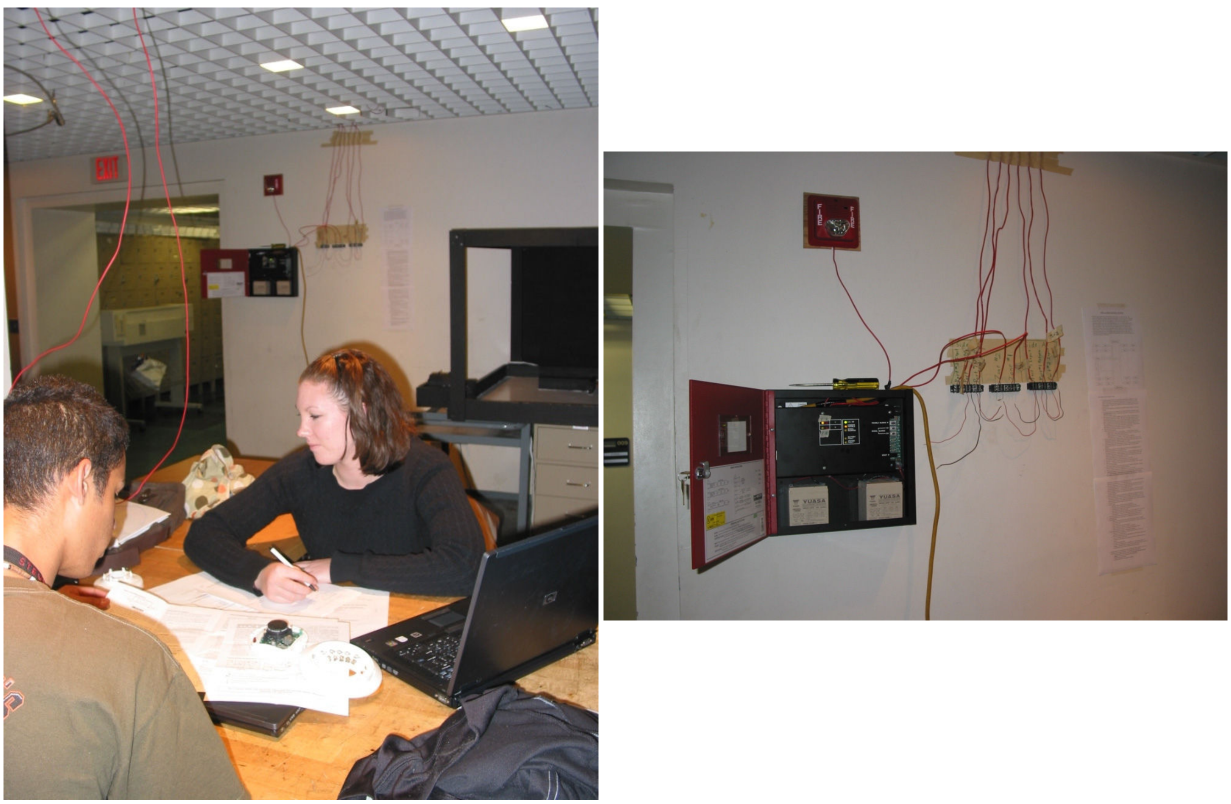

Fig. 3 Product Disassembly of a System (Commercial Multi-Zone Fire and Smoke Alarm)

The design projects are also used to reinforce the total design approach. Each project is presented in the form of a commercial Request for Proposal (RFP), groups choose an RFP to which they will respond. The projects include a search and recovery robot, which is based on the platform from Engineering Design I. This concept was inspired by a past project in the design program at Northern Arizona University[5]. The robot (not autonomous) is required to locate simulated victims (infra-red sources) in a debris field and place markers at a fixed distance from each. Infra-red and proximity sensors are used; many groups also used Bluetooth^{R} to provide wireless control of the robot via a joystick using an RS232 port on the custom-designed PIC circuit board used in the robot.

The second project (see example in Fig. 4) involves a gantry crane (built from LEGO). The project is posed as a retrofit with sensors for remote control. The team is required to use limit switches and sensors to remotely control, from a laptop computer, crane rotation through a defined angular range, hoist movement and the lateral positioning of a counter weight to balance the hoist. The third project (see example in Fig. 5) is a compact, deployable, environmental monitoring system that in principle can link to a wireless network and includes monitoring of temperature, wind speed and direction and a simulated hazardous gas (carbon dioxide).

Each of these projects is viewed as a system and groups are required to proceed through the first four stages of the total design process, developing context diagrams and use cases on their selected concept.

Fig. 4 Crane Retrofit Project

Fig. 5 Environmental Monitoring Station

For the conceptual stage, the use of a systematic evaluation of their ideas is encouraged through the use of a Pugh Matrix [2] in which concepts are plotted versus customer acceptance criteria and are each rated based on an assessment of whether the concept can meet, exceed or does not meet each of the criteria. The fifth stage would be to develop system specifications to guide the physical realization of the design. However, this has been limited to a basic response in the context of the RFP due to time limitations.

It should be noted that students are assigned to the groups in both Freshman design courses I & II to provide a diverse mix of disciplinary interest and background skills. Particularly in Design II, there is a focus on developing effective teaming skills. Each group is required to develop a team charter to guide their activities. This done in the context of the major design project and is also associated with the project management. Team members are asked to assess their own performance and that of their team members. This is done twice in the course, once midway to give feedback to the team, also at the end where these assessments are used by the instructor as input to determine individual participation grades.

Table 1 Weekly Schedule of Activities in Engineering Design II

WK	HOUR 1	HOUR 2	HOUR 3
1	Course Overview, Administrative Details, Grading Criteria, etc Review of Total Design Approach	Fire Alarm System Analysis Development of Stakeholder Requirements Product Disassembly – Smoke Detector and Fire Alarm Control Panel	
2	Team Membership Assignment Continuation of Total Design Process - Intro to Context Diagrams and Use Cases	Exercise - Context Diagram/Use cases for Fire Alarm System	Introduction to LabVIEW View On-Line LabView Video Homework Assignment – Complete Exercises 1 & 2
3	Using LabVIEW - Experiment 1 - Light Sensor Calibration Using PIC Data Acquisition		
4	Experiment 1 (Conclusion), Report Due Next Week		
5	Understanding Sensors (Types, Technologies, Applications)	Using LabVIEW - Exercising Basic Sensors with PIC DAQ	Introduction to USB-6009 DAQ – Exercising Basic Sensors with USB DAQ
6	Using LabVIEW - Experiment 2 - Motor Speed Control using USB-6009 DAQ & PIC		
7	Experiment 2 (Conclusion), Report Due Next Week Homework Assignment – First Team Self Assessment		
8	Establishment of Team Charter for the Design Project	Issue Design Project RFP's, Groups Choose Project, Identify Stakeholder Requirements and Develop Initial Design Concepts Including LabView Front Panels, Research/Identify Sensors Required – Order Sensors/Material	
9	Creative Thinking Workshop	Experiment 3 (Begin) - Design/conduct an experiment to evaluate a critical component(s) of your Design Project based on Analysis/Simulation or Test ; Finalize Context Diagrams and Use Cases Complete Design Project Plan (WBS/Gantt Chart) - Order Sensors/Material	
10	**Written Proposal Report Due** - Report to be Evaluated for Completeness of Design Using Total Design Process Conclude Experiment 3, Report Due Next Week Begin Design Project Implementation According to Approved Plan – Final order for Sensors/Material		
11	Design Project (per your program plan)		
12	Design Project (per your program plan)		
13	Testing of Completed Designs	**Final Design Oral Reports to be Presented** Homework Assignment – Second Team Self Assessment	
14	Final Project Evaluations		

Table 1 shows the week by week Engineering Design II schedule. It can be seen that in Week 9 time is set aside for a Creative Thinking Workshop. Techniques for creative thinking (brainstorming etc.) and concepts of team dynamics are discussed in the context of the conceptual design phase of the major design project. The workshop is part of a thread in developing creative thinking through the design course sequence. Communications skills are also seriously addressed and assessed through the various assignments as part of an overarching Communications Plan for the engineering curriculum.

Assessment

Assessment of the course included surveying the students to gauge their perceived learning associated with a number of course outcomes. These course outcomes are listed below. The design course outcomes map to Program Outcomes, in this case providing Core Engineering contributions to the Program Outcomes of the various engineering programs (hence the numbering system) which in turn align with the ABET (a thru k) outcomes in the ABET 2000 Criteria for accreditation. The table below shows the survey results averaged over 15 sections of the course that accommodated 340 students in Spring 2006.

Design II Course Outcomes that were surveyed to assess associated student perception of their learning experience in the course:

4E1 - You are able to apply creative thinking techniques to the design process.
5E1 - You are able to establish stakeholder requirements and translate these into design concepts as part of the total design process.
6E1 - You can apply the graphical programming language LabVIEW to interface various sensors to a computer data acquisition system to collect and use the sensor information.
3E1 - You are able to design and conduct an experiment and interpret the results to evaluate the characteristics of a sensor.
9E1 - You are able to work effectively with other members of a team to create and adhere to a team charter in order to successfully complete a team project.
10E1 - You are able to deliver an effective oral presentation appropriate to a particular audience.
10E2 - You are able to write a technical report that is appropriate to a project client or advisor.

		LEARNING EXPERIENCE				
Outcome	**Mean**	**Great**	**Signif**	**Some**	**Little**	**None**
Weighting		**4**	**3**	**2**	**1**	**0**
4E1. Avg	2.7	30%	32%	26%	8%	4%
5E1. Avg	2.5	25%	29%	26%	14%	5%
6E1. Avg	2.7	37%	25%	16%	13%	8%
3E1. Avg	2.9	34%	32%	21%	10%	3%
9E1. Avg	2.6	27%	26%	31%	8%	8%
10E1. Avg	2.4	22%	29%	25%	14%	10%
10E2. Avg	2.6	25%	34%	21%	11%	9%

Table 2 Survey results showing percentages of students choosing a particular rating and the mean scoring on the zero to 4 weighting scale applied to the ratings.

The results indicate that for all outcomes, over 50% of students judged that they had a significant or great learning experience. For most outcomes less than 20% judged that they experienced little or no learning. In the case of the communications-related outcomes this may have been because this was merely reinforcement of what had been already seriously addressed in Design I. Students did find the identification of stakeholders and their requirements (especially beyond the immediate customer) to be difficult. The limited experience of most students and their maturity level are contributors. However by addressing this early and returning to it through later design courses we hope to reinforce this important aspect of systems thinking. Team work is always a challenge with students but the result is actually somewhat encouraging as we attempted to build teaming skills through specific means such as the team charter.

Student comments (encouraged in the survey) were a revealing complement to the survey data. Two threads emerged:

1. A better introduction on how to use LabVIEW was desired and
2. Students wanted more time to do the final project.

Item 1 has been addressed with the second iteration of the course in Spring 2007. The adjunct engineers teaching the course now have experience teaching with LabVIEW (not all did prior to this course – training was provided by National Instruments before the course started). They have sample Experiment and Project solutions available to them, and additional guidance to assist students with learning LabVIEW.

Item 2 may be typical in that students always want to spend more time, or need more time, on their project. It was decided that sufficient time was already provided for the final project but in future to provide project RFP's earlier with better guidance on an experiment to do for each (this activity contributes to the ABET requirements for experimentation competency).

Some other minor themes:
- During Experiment 1, the procedure calls for each student to address their own set of LabVIEW programming requirements. The experiment is simple enough to do this. During Experiment 2 suggestions are provided on how the programming effort should be divided within the group. The goal for both is that all students learn LabVIEW programming. However in the final project some groups fell back on the "programmer" in the group to do this part. Greater instructor oversight is indicated to avoid this natural tendency of student groups. While such specialization might be expected in later years on multi-disciplinary projects, it runs counter to the goals of this course.
- Students have low interest in presentations in the design laboratory and would rather be doing hands-on activities. However, presentations are a necessary evil given that this environment is most appropriate to delivering material that is associated with developing design-related competencies. This result reaffirmed that presentations need to be short and relevant to the laboratory activities.
- Some students expressed dismay at Design II being more programming and more electronics etc. similar to the robot project of Design I. There are students for whom programming is uninteresting and who do not consider it relevant to their planned major. The challenge is to persuade them that this is core knowledge for an engineer and recognize the ubiquity of intelligent systems throughout engineering that use sensors and software.
- On the positive side many students commented on enjoying the diverse experiences in the course and the ability to choose their own project.

Conclusions

A core engineering design course has been developed and implemented for second semester Freshmen engineering students to help develop their understanding and facility with sensors and their application in data acquisition systems as a foundation for realizing applications across the engineering spectrum. The course provides a vehicle to continue building systems thinking as a key competence for engineers. It also contributes to threads in teaming, communications, project management and creative thinking that permeate the design course sequence. Assessment shows that students' perceptions of their learning associated with key outcomes of the course are encouraging with respect to the goals of the course and its contribution to those of the design course sequence. Based on assessment, changes have been made for future operation of the course to try to improve teaching of LabVIEW, increase students' recognition of the relevance and importance of the content of the course and to further develop the effectiveness of introducing systems thinking early in the curriculum with its associated challenges for students with little contextual knowledge and experience.

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