

AC 2008-1422: CHAMPIONING HIGH-TECH RENAISSANCE: SENSOR AND CONTROLLER SYSTEM INTEGRATION COURSE

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Championing High-Tech Renaissance: Sensor and Controller System Integration Course

Abstract

With rapidly advancing and evolving technologies, the primary challenges in engineering product development have shifted from creating well defined components to producing complex, interdependent systems. Innovating and adapting to this new, complex environment is critical to surviving in the global economy. The challenge is to generate “good” ideas and rapidly convert them to viable commercial products. In the product development process, proof-of-concept systems are built to determine the feasibility of products or processes. It is essential for today’s engineers and scientists to understand systems engineering principles and have the knowledge and experience in integrating systems to test the efficacy of their ideas. To this end, we have developed the Sensor and Controller System Integration course that enables students to rapidly metamorphose their ideas to proof-of-concept systems for high-tech applications using commercial-off-the-shelf (COTS) components. This paper presents the course philosophy, curriculum, instructional strategy, preliminary assessment results and the teaching tools employed to enhance the students’ entrepreneurial experience.

Introduction

Frans Johansson, in his book *The Medici Effect*¹ recounts the story of the Medicis, a banking family in Florence who were patrons in a wide range of disciplines. Due to the Medicis and a few other like-minded families, sculptors, scientists, poets, philosophers, financiers, painters, and architects from all over Europe and as far as China converged upon the city of Florence. There they found each other, learned from one another, and broke down the barriers between their disciplines and cultures. Together they formed a new world based on new ideas—what became known as the *Rinascimento* or the Renaissance. As a result, the city became the epicenter of a creative explosion and one of the most innovative eras in history followed. Johansson calls this phenomenon the “Medici Effect.”

The maximum probability of groundbreaking and revolutionary advances is at the convergence of concepts, disciplines, countries, and cultures and is accelerated by modern computational power, communication infrastructure, and easy access to information for everyone. Can we recreate the scenarios that preceded and propelled the Renaissance in our quest for promoting entrepreneurship education? Using modern technology, can we bring together wildly different ideas from various disciplines and rapidly explore the potential of the resulting numerous unique concept combinations to become radical innovations? Are we on the verge of a new high-tech renaissance?

With advancing and evolving technologies, the primary challenges in engineering product development have shifted from creating well defined components to producing complex, interdependent systems. Innovating and adapting to this new, complex environment is critical to surviving in the global economy. Successful organizations, including universities, indicate that the real source of power in a knowledge-based economy is in combining technical prowess with

entrepreneurship². The challenge is to generate “good” ideas and rapidly convert them to viable commercial products. Most of the successful high-tech and serial entrepreneurs have a systems engineering approach to their entrepreneurial ventures³. The economy in which the Engineers of 2020 will work will be strongly influenced by the global marketplace for engineering services and a growing need for interdisciplinary and system-based approaches⁴. Innovation in product/service design and commercialization that enables entrepreneurship can be successfully leveraged by applying systems engineering principles and techniques alongside entrepreneurial activities related to the context of the innovation⁵. Proof-of-concept systems are built to determine the feasibility of products or processes. It is essential for today’s engineers and scientists to have an understanding of system-based approaches to problem-solving and experience in rapidly integrating systems to test the efficacy of their ideas.

The Pennsylvania State University is one of the largest research universities in the United States. Fundamental and applied research is carried out at its numerous research centers and laboratories. As the dynamics between technological know-how, engineering talent, and challenges change, paradigm shifts are necessary in the way research is conducted, as well as the way in which products and processes are designed and developed. Advances in electronics have enabled a whole gamut of laboratory automation techniques that cut costs, improve quality and productivity, and enable the rapid testing and evaluation of ideas leading to innovative products. Laboratory automation is gaining ground in industry but has reached fewer academic research circles. Applying a systems-based approach and modern technology in the lab environment offers tremendous entrepreneurial opportunities⁶.

The Sensor and Controller System Integration (SCSI) course exploits the power of virtual instrumentation to promote lab automation and accelerate the idea evaluation and product development processes. This is an intensive laboratory-based course that covers interfacing computers of various form factors to a wide array of sensors, actuators, instruments, and sub-systems. The course encompasses essential engineering concepts, which include the following: using virtual instrumentation, integrating sensor networks, collecting/processing signals, defining system response, and controlling actuators. The concepts are covered in a just-in-time manner and focus on solving real-world systems problems and demonstrating product evolutionary steps of concept, research, design, and production. Hands-on technical sessions are accompanied by weekly workshops on entrepreneurship related topics.

This comprehensive course aims to:

- Foster entrepreneurship, invention, and innovation by enabling students to metamorphose their ideas to proof-of-concept systems for high-tech applications.
- Promote lab automation and intrapreneurship to facilitate rapid migration of ideas from the concept to product stage and increase the quality and productivity of research centers.
- Accelerate the internationalization of products using automated test systems for localized/tropicalized (adapted for the huge markets in countries with tropical climate) prototypes to ensure that they meet design constraints and performance requirements. The emphasis is on leapfrogging technologies for developing and underdeveloped communities.
- Create awareness of the commercialization process, i.e., the long winding road from an idea to a marketable product. A risk management perspective is employed.
- Improve student learning with hands-on experimentation.

Course Genesis and Market Positioning

Enterprising students with original product ideas need the resources to evaluate the practicality of their ideas, develop their products, and perform thorough tests to realize robust marketable products. Researchers working in labs and research centers use lab automation tools, such as National Instruments' LabVIEW⁷, to automate experiments. Connecting different types of instruments to computers to control experiments and acquire/analyze data is crucial to performing some experiments. In other cases, it speeds up the experiment significantly, resulting in increased productivity. A large number of engineering and science students involved in professional project-based organizations like Network of Entrepreneurs, Engineers for a Sustainable World, Student Space Programs Lab, Hybrid and Hydrogen Vehicle Research Center, etc., perform various experiments and integrate systems as part of their projects. However, most researchers and students lack the training in computer interfacing, experiment control, and system integration that would be crucial to the success of their endeavors.

An informal survey of these students and faculty members across various disciplines and colleges was conducted to assess their needs. Students involved in entrepreneurial activities and projects were also interviewed. The results indicated that the students required a hands-on course that would cover interfacing computational systems of various form factors to various sensors, transducers, and sub-systems. It was also desired that the course cover some of the fundamental engineering concepts of instrumentation, control, and signal conditioning. Concepts surrounding interlinking various programming languages and application programs were also frequently requested. Essentially, the students were alluding to an electro-mechanical system development sandbox.

At most universities, Engineering Entrepreneurship is usually taught as an entity within itself and does not involve cross-disciplinary activities⁸. This is almost true for Penn State, which offers a minor in Engineering Entrepreneurship. According to the Director of the minor, "The Engineering Entrepreneurship (E-SHIP) minor prepares undergraduate students to be world-class technology business innovators. We want students to complete the minor with an 'entrepreneurial mindset,' meaning they are more creative, better at handling ambiguity, better at teamwork and see themselves as product leaders much more than when they entered the minor⁹." Resources like the Center for Engineering Design and Entrepreneurship¹⁰ (CEDE) and the Learning Factory¹¹ provide the physical space and numerous resources to enterprising students interested in prototyping their designs.

Most research activities take place at the graduate level and design activities are largely viewed as undergraduate activities. With the inclusion of entrepreneurship with design, there are greater opportunities to consider the links between marketable design activities based on engineering research activities¹⁰. A significant gap (commonly called the "Valley of Death"^{12, 13}) exists between technology creation (having its genesis in sponsored research) and a viable early-stage company capable of bringing the technology-based product to market. Faculty and graduate students can attempt to productize the fruits of their research by engaging in entrepreneurial design that culminates in a proof-of-concept prototype. The prototype makes a much more convincing case to potential funders for commercialization than a journal article.

This was the motivation for developing a course that equips innovative students from diverse disciplines with the knowledge, skills, and experience to integrate proof-of-concept prototype systems using commercial-off-the-shelf components. This course serves as the vehicle to rapidly transport ideas from the concept stage to product stage and to revolutionize the way research is conducted and products are designed and adapted for different markets.

Course Philosophy

The SCSI course employs a challenge-based instruction philosophy in an “Indiana Jones” style journey filled with Adventures, Quests, Ventures, Pitches, and numerous fictional and non-fictional characters. Challenge-based education is a category of problem-based education^{14, 15} in which problems are posed as a series of interesting challenges that require the students to search for and acquire knowledge and expertise, as needed, to solve the challenge^{16 - 19}. The challenge-based, team approach to learning stimulates the students to develop a deep understanding of the material and, at the same time, to build problem-solving, teamwork, and communication skills²⁰. These skills are vital for aspiring entrepreneurs and world-class engineers.

The SCSI course employs a prototype-based model as opposed to a specifications-driven model. Specifications are used only as a roadmap. The emphasis is on product development rather than product design and a systems-based approach is employed. Transparency, freedom, and innovation are woven into the fabric of the course. Most conventional courses are designed around systems of compliance and control, which stifles the creative and entrepreneurial instincts of students²¹. In this course, the students are given ample room (and better grades) for exercising creativity and “rebellious against the system.” They are offered the opportunity to negotiate alternate assignments and grading schemes throughout the course. A two-hour session towards the end of the semester is devoted to Course Quality Control. All the material covered in the class is revisited and students are asked to redesign the course for the next semester. This activity results in valuable insights to the instructor and also benefits the students as they look back and truly understand the significance of certain sessions.

Entrepreneurs should be comfortable working in an environment fraught with chaos, uncertainty, and ambiguity²². Toward this end, structured chaos is added to the course in various ways. The Quest teams change every two weeks—they are more like “flash teams” (extending the concept of “flash mobs”²³) and, one could argue, that they are not “teams” anymore! Multidisciplinary teams are flung into a completely unknown complex problem and asked to come up with a solution in two weeks’ time. The scenarios chosen for the various Adventures, Quests, and in-class exercises are wildly different—ranging from hospitals to long-wall mines to breweries to “Love Detection and Support Systems” (explained later). Using judgment to deal with novel and complex problems is a key characteristic of entrepreneurs²⁴. Preparing students to quickly find and use resources and extract necessary information from dispersed, fragmented, and sometimes unreliable sources for identifying and solving complex problems is emphasized throughout the course.

The course is open to students from all disciplines with virtually no pre-requisites except an open mind and a time commitment of 14 hours/week. There is no textbook for the course. Course material is derived from a wide range of sources and provided as PDF’ed PowerPoint

presentations. Students typically end up with a 400+ page binder of course material. There are guest lectures on the entrepreneurship-related topics backed up by reading assignments and podcasts. Hands-on sessions are peppered with numerous audio and video clips from resources including STVP Educators Corner²⁵, Cornell eClips²⁶, commercials, speeches, etc.

Course Educational Objectives

The course educational objectives were developed such that, by the end of this course, students should be able to

- Identify processes and tasks in their research lab that can be automated and ideas stemming from their research that have market potential.
- Define product requirements and formulate specifications.
- Determine how to simultaneously meet system and physical design constraints and identify effective trade-offs to optimize system performance.
- Determine the hardware and software resources required to interface various kinds of sensors and actuators to a computer.
- Integrate small computer-based testing, measurement, and automation systems.
- Work in a team environment to develop innovative products/processes or optimize an existing product/process.
- Be aware of what it takes to advance their proof-of-concept system to a commercially marketable product.

Course Mechanics

Sensor and Controller System Integration is a 4-credit course that includes two 3-hour labs and a 1-hour workshop. Hands-on sessions on various essential topics are held during the first eight weeks of class. The concepts explained in class are reinforced by in-class exercises as well as homework assignments. Taking a cue from management guru Tom Peters²⁷, the homework assignments are called “Adventures” and team labs are called “Quests”. There are two individual adventures and two team adventures during the first eight weeks. The course schedule is shown in Table 1.

The 3-hour sessions and Adventures are described briefly below.

Electrical and Computer Engineering Fundamentals: This is an optional session held during the first week of class that reviews fundamental concepts including voltage, current, resistance, Ohm’s law, analog (AC/DC) signals, digital signals, concept of ground, sensors and transducers, parts of a personal computer, number systems (decimal, binary, hex, and converting between them using Windows calculator) and familiarization with various lab equipment including digital multimeters (DMMs), power supplies, function generators, and oscilloscopes. This session is critical for non-engineering students and a good review for engineering students. This session is intimidating for the non-engineering students and follow-up helps to boost their confidence.

LabVIEW Programming: The course uses National Instrument’s LabVIEW⁷ graphical development environment to develop the proof-of-concept systems. The first three weeks focus on getting familiar with the LabVIEW environment and developing applications using standard

Table 1: Course meeting schedule for Fall 2007 semester

Week	Lab 1: Monday (3 hours)	Lab 2: Wednesday (3 hours)	Lecture: Wednesday (1 hour)
Week 1	Course Orientation Fundamental Concepts	LabVIEW Basics Modular Programming	Course Venture Orientation
Week 2	No Class	Data Structures File Operations F1	Entrepreneurship Workshop
Week 3	Program Architectures Design Patterns E1	Systems Engineering Advanced LabVIEW	Elevator Pitches
Week 4	Data Acquisition Design Review Process E2	Software Interfacing C, SQL, ActiveX, .Net	Identifying Markets for Products & Services
Week 5	Functional Verification System Characterization	Controlling Devices & Sub-systems	Venture Value Propositions P1
Week 6	Instrument Control Device Drivers E3	Human Factors, Usability Operating System Issues	Intrapreneurship Workshop Consensus Building
Week 7	Proof of Concept Systems Rapid System Integration	N/W and Distributed Apps Internet Integration	Social Entrepreneurship
Week 8	Signal Processing Signal Conditioning E4	FPGAs, Other Platforms Quest Orientation	Venture PDR P2
Week 9	Quest 1		Invention & Innovation
Week 10	Quest 2		Teamwork & Leadership
Week 11	Quest 3		Triple Bottom Line International Issues
Week 12	Quest 4		Venture CDR P3
Week 13	Quest 5		Patents & Intellectual Property Issues
Week 14	POC to Product Technical issues	Reflection on Course, Ventures, Ideas	POC to Product Non-technical Issues
Week 15	Course Quality Control	Final Prototype Demos	Final Presentations P4
Exam Week	Final Report Due F2		

Key: Technical Adventure: Ex
 Non-Technical Adventure: Fx
 Presentation/ Venture Design Review: Px

design patterns. Some advanced LabVIEW concepts are also covered. The first three weeks of the course are the most difficult and the students are provided with numerous external resources to learn LabVIEW.

First Adventure: Includes problems like designing the interface for a calculator similar to the windows calculator (in simple mode), a thermistor temperature calculator and datalogger, and reverse engineering a function generator's controller simulator and designing a testbench for it.

Second Adventure: Consists of two problems—the students develop the code to make the calculator they designed in the first Adventure functional and they develop the code for a state-machine based simulation of a real-world process. A washing machine simulator and a brewery simulator have been developed in the past.

Systems Engineering: Introduces the class to systems engineering, traits of system engineers, and various lifecycle models employed in industry. Practical tips on course venture management are offered.

Data Acquisition: Introduces the students to the basic jargon associated with instrumentation and data acquisition systems. It includes various exercises on acquiring and generating analog and digital signals. The students are introduced to the engineering design process in preparation for the Venture design reviews.

Software Interfacing: Covers the interlinking of various programming languages and application programs like LabVIEW, C/C++, MATLAB, SQL, MS Office, ActiveX, .Net, etc. Students also learn how to access and develop Dynamic Link Libraries (DLLs) and spawn external applications.

Functional Verification and System Characterization: Deals with topics like technical risk identification and management, verification and validation, and developing test plans and implementing them using automated testing equipment.

Controlling Devices and Sub-systems: During this session, the students learn concepts like current sourcing and sinking; button debouncing; pulse width modulation (PWM); control techniques; proportional, PI, and PID control; and they play with devices like LEDs, relays, and DC motors.

Third Adventure: For this group Adventure, students interface and characterize various sensors and develop one-page datasheets for them. They are also challenged to identify and articulate innovative applications for the sensors. The students develop a 'Love Detection and Support System" where they control images for a boy and girl on the screen using physical sliders and detect whether it's day or night (using a light sensor) and whether or not they like each other (using pushbuttons) when they meet on the screen. Based on these inputs, they do different things like play music, launch a game of Solitaire, play a game of Hearts, open a website with dating tips, launch a movie, have fireworks (on LEDs), etc. This Adventure covers a lot of different concepts (data acquisition and control, software interfacing, graphics and animation), needs good teamwork and has significant room for creativity. In the next Adventure, the students

convert this game to a distributed application where the boy and girl (or other combinations) can be anywhere in the world.

Instrument Control and Device Drivers: Students learn how to communicate with lab instruments and devices using various protocols including serial communication (RS 232), GPIB (useful for communicating with lab instruments), and USB at various levels of abstraction. Also covered are the fundamentals of Standard Commands for Programmable Instruments (SCPI), Virtual Instrument Software Architecture (VISA), and finding and using device driver Application Programming Interfaces (APIs).

Human Factors, Usability: With help from video clips including Dow's Human Element commercial²⁸ and David Kelly (IDEO) talking about creating user experiences²⁹, students are encouraged to think about the larger context surrounding their innovative products and moving beyond designing products to designing experiences. Jakob Nielsen's usability heuristics³⁰ are discussed with various examples from www.baddesigns.com³¹.

Operating System Issues: Fundamentals of multithreaded architectures and the advantages and issues with the Windows XP operating system are dealt with in this session. The need for alternate computer architectures and real-time operating systems for specific applications is emphasized. This is an advanced topic that appeals more to students with an electrical/computer engineering background.

Proof-of-Concept (POC) Systems and Rapid System Integration: The design process followed for the Segway Human Transporter³² is discussed from the industrial design, prototyping, and reliability perspectives. NASA's Inflatable Wing Airplane project³³ is discussed to explain the concept of proof-of-concept systems. The students are shown a machine vision-based sorting system and challenged to come up with a POC system for it. The POC is developed and demonstrated in class. Then the students are shown a functional POC for an RFID-based parking system and challenged to design the final system for a local parking garage.

Networked and Distributed Applications & Internet Integration: This session covers fundamental computer networking concepts including TCP/IP, Datasockets, LabVIEW Shared Variables, Webservers and remote applications, and programmatically sending email and SMS (text) messages. All the computers in the classroom are on a network and the students get an opportunity to convert their single-computer applications to distributed applications and programmatically send emails with system status updates.

Signal Processing and Signal Conditioning: This session starts with a review of time domain and frequency domain concepts and covers various signal processing (signal manipulation in software) and signal conditioning (signal manipulation in hardware before it is digitized) techniques essential for teasing out the information from the raw data. The students develop a software audio graphic equalizer in class.

Fourth Adventure: There are two problems—design of a touchscreen-based game to entertain 4–8 year-old kids and design of a POC system for a fairly complex application. While developing the POC, the students need to understand the complex scenario, separate the essential

and non-essential parameters, and make a number of decisions to come up with the optimum solution. The students need to calculate the Recurring Engineering (RE) and Non-Recurring Engineering (NRE) costs for their solution. The team that instills maximum confidence (by way of their POC) and provides maximum value for money is declared the winner and gets bonus points.

Introduction to Other Architectures: This session covers the basics of computer architecture and contrasts temporal processing with spatial processing to introduce Field Programmable Gate Arrays (FPGAs). The differences in the architectures of Personal Digital Assistants (PDAs), Digital Signal Processors (DSPs), and FPGA-based architectures (National Instruments' Compact RIO) are discussed to prepare the students to work on those systems. During the second half of the session, the five Quests are introduced to the students.

Proof-of-Concept to Final Product—Technical Issues: Once the Quests are completed, there is one session dealing with the various technical issues encountered in taking the POC prototype to a final product. Topics including functional verification, validation, industrial design, design for manufacturability, design for testability, etc. are revisited with the help of real-world examples. Since students are nearing completion of their overarching course Ventures, they tend to appreciate and delve deeper into these topics at this point in time. Course Quality Control and redesign is done in one session and the remaining sessions are given to the students to complete their course Ventures.

Quests

Quests are team labs with certain objectives and significant scope for exercising creativity. Students work on the Quests in a round-robin manner and they are sequenced to help students with their Ventures (if they are related to any of the Quests). Quests are graded as a team (statement of work is required) and the teams change every two weeks. The Quests are designed so that they require the students to study various concepts, sensors, actuators, protocols, and technologies in various labs. Some Quests are fairly difficult and require careful planning and division of labor to ensure that the minimum requirements are met. The five Quests (in the two semesters so far) are described below.

Open Lab: Students interface various sensors and actuators, develop drivers for a certain sensor (changes every session), and develop an innovative POC prototype and pitch it to the class. Students have access to more than 40 different sensors and actuators, laptop computer, PDA, Erector sets, etc.

Camera Control: The objective of the Camera Control Quest is to control a web camera mounted on a servomotor-based pan/tilt system using a joystick and stream the video captured by the camera to the computer (see Figure 1). The next step is to make the camera controllable over the internet and have the video streamed to a webpage. The students are also given a specific image processing task, like reading a barcode, counting the number of needles, or sorting objects of different sizes using the webcam. Students have found a lot of very innovative applications of a \$10 (free after rebate) webcam.

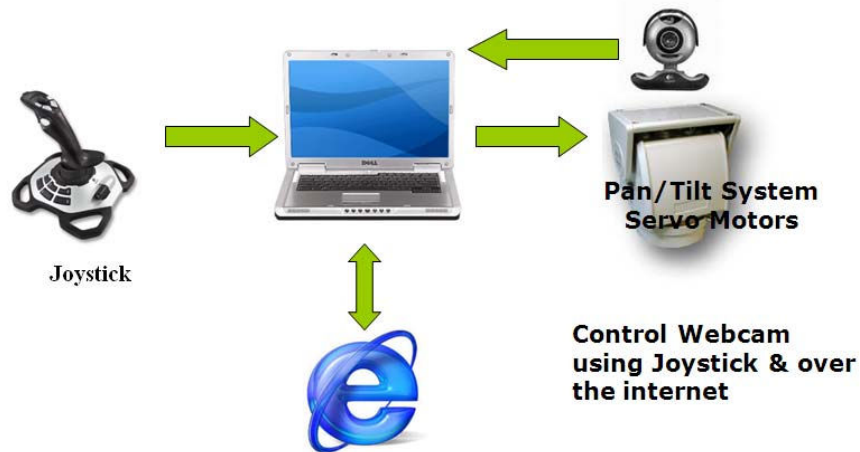


Figure 1: Camera Control Quest block diagram

Automated Test Station: The objective of this Quest is to develop an Automated Test System (ATS) to test and characterize a Device-under-Test (DUT). The DUT for this quest is an amplifier that is packed in a black box and identified by a unique barcode. The ATS controls a power supply, function generator, and digital multimeter over the General Purpose Interface Bus (GPIB) to provide various stimuli to the DUT and log its response (see Figure 2). The ATS performs various tests for functionality and characterizes the amplifiers by finding their cut-off frequency and gain–bandwidth products. The characteristics of the amplifier (identified by the barcode using a barcode scanner) are written to a specific kind of file from which they can be read back easily when necessary.

This Quest familiarizes the students with test planning and automated test systems, which are essential for performing exhaustive testing on new products to reduce the technical risk or performing routine testing for Quality Control. Students working in lab environments benefit significantly from this Quest because they can go back to their labs and automate their experiments, thus increasing their productivity significantly.

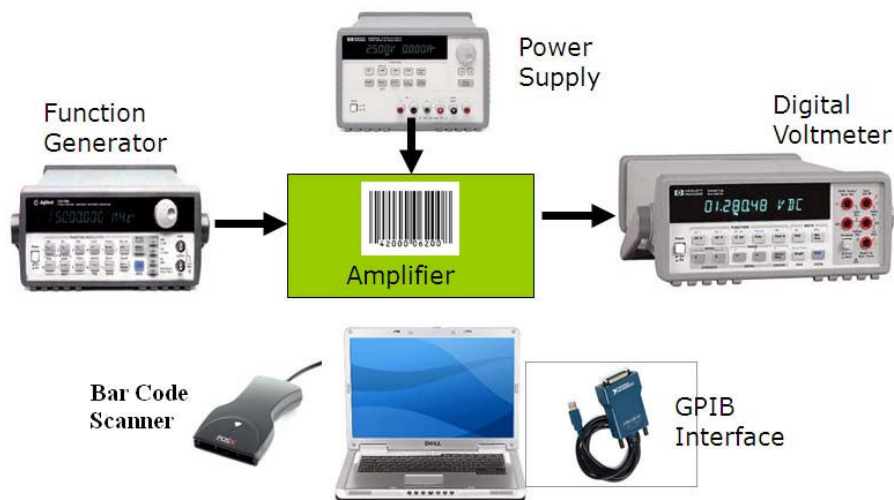


Figure 2: Automated Test Station Quest block diagram

Compact RIO–based System: This is one of the more complex Quests in which students develop an application on the National Instruments Compact RIO³⁴ system. The Compact RIO (cRIO) is a ruggedized Programmable Automation Controller that has a real-time microcontroller and FPGA working together. The cRIO needs to be programmed to control the position of a stepper motor. A laser pointer is mounted on the stepper motor and there are four light sensors mounted on a wooden board. When any of the light sensors is obstructed, the cRIO is required to reposition the stepper motor to shoot the laser back at the obstructing device (see Figure 3).

The students are challenged to develop an application on a very different computer architecture, which presents some unique problems. Partitioning the system between the host computer, real-time microcontroller on cRIO, FPGA on the cRIO, and the user is a major decision. The system requires a lot of wiring and very careful planning because the code takes about 30 minutes to compile and hence a limited number of code iterations are possible. 80% of the teams successfully complete this Quest.

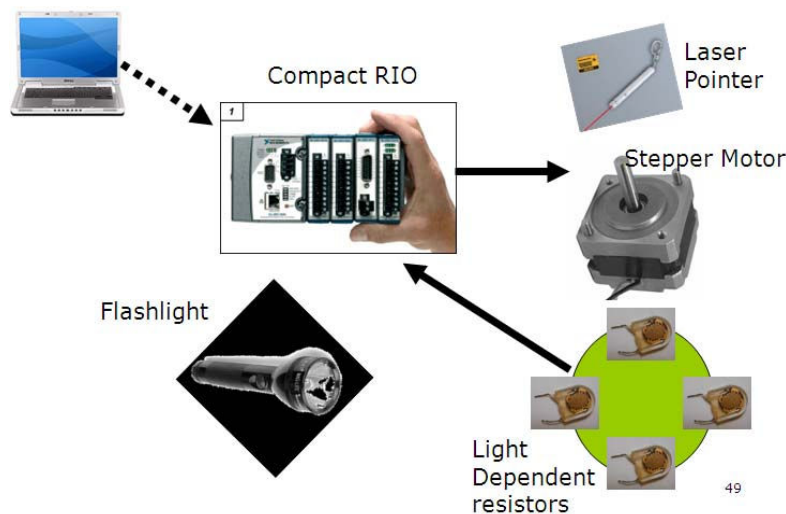


Figure 3: Compact RIO–based System block diagram

Hospital 2010: This is one of the most complex Quests in which students assemble a networked system for a futuristic hospital. Students set up a Bluetooth Personal Area Network (PAN) with three nodes: a Personal Digital Assistant (PDA), a Pulse Oximeter, and a laptop with a weighing scale and blood pressure monitor connected to it (see Figure 4). The PDA accumulates information like body weight, blood oxygen concentration, pulse rate, and blood pressure over the Bluetooth PAN and displays it on the screen. The PDA also displays basic patient and doctor information (name, sex, notes, etc.). It is envisioned that each patient will have his or her own PDA (and PAN) that will transmit data to the Central Station over a Wi-Fi link (i.e., an ad-hoc network with TCP/IP). The central station can serve as an internet gateway to make the information accessible to authorized personnel. RFID scanners track patients inside the hospital and are connected to the Central Station.

Similar architectures are being used for telemedicine and mobile hospital applications. In spite of being a tough and often times frustrating Quest, the students tend to enjoy it because of its

uniqueness and the sense of accomplishment that comes with getting all the sub-systems to work at the same time. This Quest has inspired and directly helped two entrepreneurial teams that have received seed funding from multiple sources.

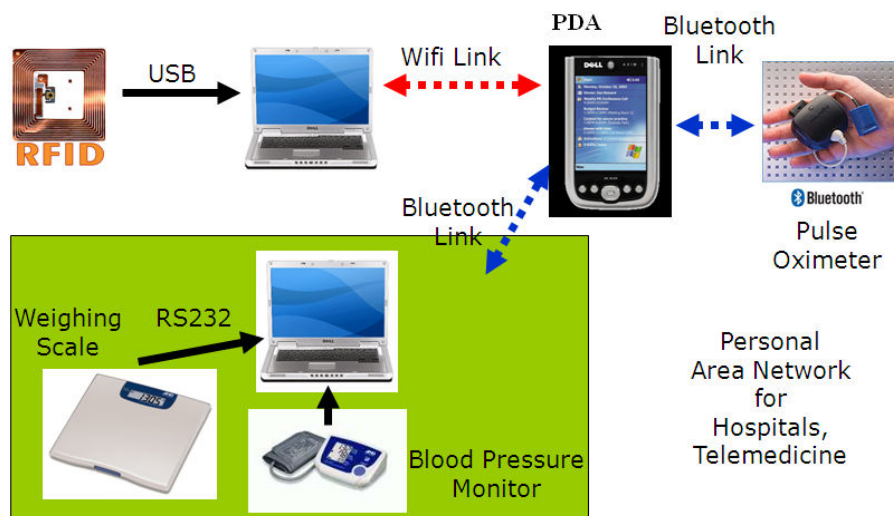


Figure 4: Hospital 2010 Quest block diagram

Entrepreneurship Workshops Parallel Track

A one-hour workshop on non-technical topics is held every week. This constitutes one-credit of “non-technical” material partnered with the three credits of “technical” material, which combined make for the total of four credits in this course. The various workshops are briefly discussed below.

Course Venture Orientation: The objectives and logistics of the overarching course Venture are discussed with examples and demonstrations of Ventures from previous classes.

Entrepreneurship Workshop: The basics of technology-based entrepreneurship and traits of successful entrepreneurs are discussed.

Elevator Pitches: The art of making elevator pitches is presented with examples and students are challenged to pitch their ideas to recruit their Venture teams.

Identifying Markets for Products and Services: Market research, identification, and positioning are discussed with numerous real-world examples. Techniques like SWOT analysis and House of Quality are presented.

Intrapreneurship Workshop: This workshop presents Pinchot’s Principles³⁵ for intrapreneurship and gives students another opportunity to practice elevator pitches.

Information Gathering and Consensus Building Exercise: Gathering information (or expectations) and reaching consensus on important issues between stakeholders is vital to making effective decisions. Consensus building skills are critical for social entrepreneurs

working in developing countries. We use a wisdom wheel approach to get various perspectives on an issue from the stakeholders (students) and reach consensus on a certain topic.

Social Entrepreneurship: The elements of social entrepreneurship and stories of successful social entrepreneurs are discussed with the help of video clips.

Invention & Innovation: This session focuses on finding innovative applications for products and the elements of Business Planning.

Teamwork & Leadership: Various methods to enhance the capabilities of the team are discussed and experimented with.

Triple Bottom Line: The Triple Bottom Line³⁶ (TBL) concept is discussed and debated with examples of companies that espouse the TBL concept and the metrics used for the bottom lines.

International Issues: The social and economic challenges of working on entrepreneurial projects in developing and underdeveloped communities are discussed.

Patents & Intellectual Property Issues: The concept of intellectual property and related topics (patents, trademarks, trade secrets) are discussed.

Funding Your Ventures: Various funding sources for entrepreneurial ventures and their pros, cons and expectations are discussed.

Course Venture

The course Venture is the *raison d'être* for this course and runs from week 1 to week 15! Over the course of the semester, E-Teams develop a POC prototype for an innovative product or system with a specific “endpoint”. The Venture is actually executed outside class times and students have access to numerous resources including money provided by a National Collegiate Inventors and Innovators Alliance³⁷ (NCIIA) course development grant.

It is essential that the Venture be useful (solve a real problem), usable, implementable, desirable, affordable (at least at POC level) and allowable (from an intellectual property and course spirit perspective). The Venture can be revolutionary—in which case it should pass the Five-Minute Google Test (FMGT) for originality and have value to one or more target audiences. The Venture can be evolutionary—in which case it should undercut all competition and not infringe on external IP. It should have excellent commercialization potential and real value. Revolutionary (intersectional) Ventures are preferred over directional Ventures and the students are strongly encouraged to venture into innovative leapfrogging systems for people living at the Bottom of the Pyramid³⁸ in developing and underdeveloped countries. It is desired that the significant time, money and energy expended on this project by the students and their mentors lives beyond the end of the semester and hence the students are required to identify “endpoints” for their Ventures. Potential Venture endpoints include:

- New venture: Commercializing the product by way of entrepreneurship
- Participate in a National/Global Competition

- “Sell” your product to a company or a non-profit
 - Applying the project (with minor changes) to their research lab and publishing the initiative
- Experts are consulted as required to chime in on the Venture. Venture Value Propositions, Preliminary Design Reviews (PDRs), Critical Design Reviews (CDRs) and Final Design Reviews (FDRs) are held over the course of the semester. The functional prototypes are showcased at the college-wide Design Expo held at the end of the semester. This forces the students to hone their product pitch and, more importantly, discover and define that fine line separating necessary information to get their Venture concept across and giving away their unprotected Intellectual Property. Students have generally done some patent searches while trying to get their Venture concept approved (by FMGT) and have a general idea about what IP can be protected. They are pointed to the right resources to protect their Intellectual Property.

Sample Course Ventures

Described below are a few of the innovative products that have been developed as part of this course to date.

BlueToe: The BlueToe ski performance analysis and improvement system uses various sensors to record performance data about ski tilt, inclination, vibration, flux, and position. Data is transmitted wirelessly through Bluetooth technology to an audible readout attached to the skier for immediate feedback and also to a cell phone or PDA for post-descent analysis. The team developed a fully functional POC prototype during the course and showcased their product at the Global Idea to Product competition. This Venture concept was developed by a three-member team including the captain of the Penn State Ski team and chair of the Penn State Ski club. The team is working on patenting their technology and developing a compact prototype that can be fixed on to skis and tested on the slopes.

Buzby Networks: The Buzby Networks team is trying to address critical problems related to informational needs in the healthcare industry with facility-wide, low-power wireless sensor networks. Wireless sensor networks (WSNs) can be used to connect sensors throughout an entire healthcare facility to collect and interpret data in order to provide valuable information to healthcare professionals. The team proposes the development of products that apply the new ZigBee wireless sensor network technology in ways that address specific information problems in such facilities. This team has expended significant time and effort in understanding the needs of the various stakeholders in the complex healthcare industry and developed a POC prototype in this course. They have already received seed funding from The Technology Collaborative³⁹ and have submitted an NCIIA Advanced E-Team³⁷ grant proposal.

Shot Caller: This team demonstrated the feasibility of an automated target scoring system for target shooters. This system can be used by recreational shooters, police, and the military to automatically score targets in real-time, with capabilities for both visual and audio feedback. The system uses a high-resolution webcam to capture video from a spotting scope trained on a target downrange. LabVIEW software running on a laptop PC is then used to acquire and process camera images to determine the miss distance after each shot. Shot-correction feedback is then given by visual feedback on the laptop’s display, and by audio feedback of the miss distance from the PC speakers.

COSMOS: The Contact Sport Monitoring System (COSMOS) is a system of sensors designed to fit inside a helmet or mouth guard that communicates wirelessly with a coach's computer on the sideline. Through equipping athletes with a temperature sensor and a three-axis accelerometer, the athlete's body temperature and impact to the head are monitored and relayed to a PDA over a Bluetooth network. The system is updated in real time and assists coaches in making decisions on player exit based on an established severity index for heat strokes and head injuries. The COSMOS team is targeting high school football teams initially.

High-Tech Social Entrepreneurship

The majority of the world's designers focus their efforts on developing products and services exclusively for the richest 10% of the world's customers. A revolution in design is needed to reach the other 90%⁴⁰. The National Academy of Engineering wants engineers to be leaders in the movement toward use of wise, informed, and economically sustainable development and has asked engineering educators to prepare students with a strong foundation and new knowledge toward innovative technologies that advance society and creative applications of these technologies with broad considerations⁴. There is a growing trend towards internationalizing the curriculum at various universities. The focus on experiential, cross-disciplinary, international education with an entrepreneurial flavor can be harnessed to develop high-tech, high-impact products that help disadvantaged people living in extreme poverty in developing and underdeveloped countries.

Dedicated sessions on Social Entrepreneurship, Triple Bottom Line, and International Issues as well as demonstrations and success stories help create an atmosphere that advocates social entrepreneurship and harmony between the environment, technology, and society. Students are strongly encouraged to engage in social entrepreneurial Ventures that seek to improve the Quality of Life of people in the (developed and) developing world by advancing high-tech, high-impact products and services.

Mashavu⁴¹ is one example of a high-tech system being advanced towards a pilot implementation in Tanzania for Summer 2008. Mashavu enables medical professionals to e-adopt children in the developing world using modern technology and communications infrastructure. Trained operators at Mashavu stations in developing communities collect essential medical information including images, body temperature, lung capacity, blood pressure, and stethoscope rhythms for each child on a regular basis. Web servers aggregate this information from various Mashavu stations over a cell-phone link and provide it to medical professionals through an online portal. Medical professionals log on to this portal to supervise the health of the kids they have "adopted" and provide medical feedback to the relevant Mashavu station operators, who can forward that information to the child's caregiver.

An E-team comprising of students and faculty from Engineering, Liberal Arts, Business, and Medicine is working with Mt. Meru Peak School and Good Hope orphanage in northern Tanzania on this project. A functional POC prototype was developed in the SCSI course and improvements based on expert feedback are in progress. Mashavu stations can also provide health information to adults for a small fee. This increases the health consciousness of the people

and provides a revenue stream to make the project economically sustainable. A team of business students is working on a detailed business commercialization plan. Mashavu employs a networked healthcare system that also can be extremely valuable during emergencies and disaster situations. Mashavu means “chubby cheeked” in Swahili, the national language of Tanzania.

Student Evaluation

The grading categories for the course are given in Table 2. All the Adventures and Quests have points specifically allocated for creativity and innovation. Venture-related deliverables are co-graded by peers (50%) and referees (50%). Success and failure are both rewarded—inactivity is not. There is an emphasis on class participation and attendance because, given the intense nature of the class, it is extremely difficult for students to catch up. Nearly 100% attendance has been observed.

Table 2: Summary of grading categories

3-credit technical component:

Laboratory related:	Adventures (4)	20%
	Quests (5)	30%
	<i>Subtotal:</i>	<u>50%</u>
Venture related:	Venture Value Proposition (PDR)	5%
	Venture CDR	10%
	Venture FDR + Report	15%
	Teamwork & participation	10%
	<i>Subtotal:</i>	<u>40%</u>
Leadership:	Leadership and Innovation	10%
	<i>Total:</i>	<u>100%</u>

1-credit non-technical component:

Adventures:	Adventures (2)	30%
	Venture Value Proposition	10%
Venture related:	Venture CDR	10%
	Venture FDR + Report	10%
Surveys:	Surveys 1 → 3	5%
Participation:	Class Participation	35%
	<i>Total:</i>	<u>100%</u>

Class Activities Employed to Enhance the Entrepreneurial Experience

A number of class activities were specifically developed to enhance the entrepreneurial experience. Short descriptions of these activities are presented below.

Multi-perspective opportunity assessment and team building: This is the first non-technical Adventure. Students engage in an online role-play to evaluate Venture ideas from various perspectives and connect concepts with the objective of finding collaborators and closing in on a Venture. Students post Venture ideas on an online discussion forum and respond to their peers' ideas from various perspectives:

- **Dexter:** Dexter is a genius imaginer and concept originator. There can only be one Dexter on a thread.
- **Jimmy Neutron:** Concept collaborator, checks for originality, helps refine ideas, critiques ideas, and plays devil's advocate
- **Superman:** Enters with groundbreaking ideas and solutions...and leaves right away. Superman helps Dexter and Jimmy solve technical problems and refine ideas. However, he is often mistaken for a bird or airplane! (Sound arguments are required to prove that the student is actually Superman!!!)
- **Top Cat:** Hails from Manhattan and is the leader of the gang. Looks at the business side of things including market potential, market identification, financial issues, legal issues, policy and regulatory issues.
- **Homer Simpson:** Represents the customer and consumer. Looks at affordability, aesthetics, usability, ergonomics, and affective design issues. Homer does have occasional bouts of astonishing creativity and foresight (think: lead users)!
- **Captain Planet:** Ensures harmony between technology, society, and the environment. Looks at environmental issues, social implications and issues, professional and ethical issues, and globalization related issues for the Venture concept.

This method encourages the students to think from the various perspectives and openly provide constructive criticism because they are responding to their peers' roles. The student's real identity is still visible to all and aids in team building. Though students find this exercise "cheesy" in the beginning, they tend to truly enjoy it once the online discussions start. The instructor also participates in this exercise—generally in the role of Captain Planet.

The Venture concepts and Venture teams eventually bubble up from this exercise. The phrase "Venture concept" is used because a prototype-based model is employed and the Venture concept provides a general idea of what problem the team is trying to solve or opportunity the team is trying to discover and shape. The course instructor subjects the Venture concept to the Five Minute Google Test (FMGT). The premise is that if the course instructor can find a similar product, service, or an infringing patent by Google searches in five minutes, the Venture concept is disqualified and needs to be refined. It is observed that passing the FMGT on Dexter's first ideas is very difficult. However, as students collaborate, explore and refine a Venture concept and consider specific markets, they come up with Venture concepts that pass the FMGT.

Peer evaluation using bonuses: Students distribute (virtual) bonuses to their peers towards the end of the course. Each team member is given \$10,000 that they have to distribute between themselves. The bonus distribution is zero-sum; if someone makes more money, someone has to lose money. This bonus is then converted into peer-evaluated teamwork points that constitute 5% of the final grade. It is observed that, although the students tend to grossly inflate points during

the design reviews or even give everyone a full score, they are very thoughtful in distributing bonuses. The bonus distribution is in line with the instructor’s observations of the team members’ contributions. The efficacy of this technique for an entrepreneurial product development course is shared by Carlson and Sullivan⁴².

Gross dramatization: Lots of videos, audio clips, etc. are used to gain the attention of the students and drive home points. During the explanation to the multi-perspective opportunity evaluation exercise described earlier, the theme music for a character is played as the slide comes up to encourage the students to think about the character’s perspective and gain their attention. One of the major objectives of this course is to encourage students to venture into a brave new world and overcome the fear of failure and fear of the unknown. Motivational clips like an excerpt from Teddy Roosevelt’s famous “Man in the Arena” speech are played to motivate the students. On a continual basis, students are encouraged and challenged to think about how their ideas can be put into action to change the world.

Reflective Essays: The second non-technical Adventures requires students to write one-page reflective essays on three topics – (1) their entrepreneurial traits and journey over the semester (2) the non-technical topic(s) covered in the class and (3) relationship(s) between the technical and non-technical material covered in the class. Self-assessment and reflection on their personal and professional goals helps the students to determine whether or not entrepreneurship is for them and revisit what they have learnt in the class.

Student Demographics for First Two Offerings

The SCSI class has been offered in the Spring 2007 and Fall 2007 semesters. 27 students have enrolled in the course so far. A majority of the students were self-selected and knew why they wanted to sign up for this class. However, most of the students were not aware of the significant entrepreneurial flavor of this course until the course orientation. The breakdown of the majors of the students is shown in Table 3.

Table 3: Demographics of the class

Major	Undergrad	Grad
College of Engineering		
• Electrical Engineering	8	1
• Mechanical Engineering	1	0
• Industrial Engineering	2	0
• Chemical Engineering	2	0
• Engineering Science and Mechanics	1	1
• Computer Science and Engineering	1	1
• Biomedical Engineering	0	1
• Acoustics	0	2
College of Earth and Mineral Sciences		
• Earth & Geo-Environmental Engineering	0	1
• Material Science	0	1
Eberly College of Science		
• Astrophysics	0	1

Smeal College of Business		
• Business Administration & Economics	1	0
Professionals		
• PSU Related	0	1
• Non-PSU	0	1
Total:	16	11

Assessment Plan and Preliminary Assessment Results

A three-phase survey instrument (pre-semester, mid-semester, and end-of-semester) was designed to study the effectiveness of course curriculum, structure, and instructional strategy in meeting the objectives of the course and the students' expectations. Effectiveness of multidisciplinary teams (composed of undergraduate and graduate students and professionals) in identifying problems and opportunities and developing innovative solutions is also being studied to devise optimum ways of team formation, mentoring, and management. After receiving approval from the Institutional Review Board, online course surveys were administered to the students on the first day of class (after orientation), at mid-semester (after Quest orientation), and at end of semester (after the final design reviews).

The questions were answered by the students on a Likert scale of 0 to 5 (0 = none, 1 = very low, 2 = low, 3 = average, 4 = high, 5 = very high). The sample size is 27 students across the two semesters. We are considering the average score for the class to study the impact. Some questions were asked three times and some questions were asked only at the end of the semester. The preliminary results from these assessment instruments are presented here. We intend to consult assessment experts and conduct in depth analysis of this data in the near future.

Basic knowledge of how to advance your system to a commercially marketable product:

Pre-semester mean: 2.33

End-of-semester mean: 3.66

Confidence in complex problem solving:

Pre-semester mean: 3.81

Mid-semester mean: 3.80

End-of-semester mean: 4.03

One of the basic problems with this question is the definition of “complex problem solving.” Students knew why they wanted to sign up for this course but had no idea what kind of problems they would solve and learn to solve on their journey!

Confidence in using a computer to solve problems:

Pre-semester mean: 4.0

Mid-semester mean: 4.0

End-of-semester mean: 4.33

Similar issue with the question—the students don't know what kind of problems they will be solving with a computer.

Confidence in LabVIEW programming:

Pre-semester mean: 1.03
Mid-semester mean: 3.35
End-of-semester mean: 3.59

Confidence in your ability to apply the knowledge and skills acquired in this class to your discipline or research area:

End-of-semester mean: 4.23

25 students answered high or very high for this question. This is extremely important for this course.

Confidence in your ability to identify, formulate, and solve engineering problems (within the domain of this course):

End-of-semester mean: 4.11

Confidence in your ability to identify, analyze, and improvise on sub-optimal implementations of systems:

End-of-semester mean: 3.89

Confidence in applying knowledge of computers and systems to solve engineering problems:

End-of-semester mean: 4.3

23 students answered high or very high

Understanding of the importance of harmony between technology, society, economy, and the environment:

End-of-semester mean: 3.81

Other Interesting Observations: This course generated significant interest in social entrepreneurship and the Triple Bottom Line concept. Engineering students were especially excited to see the human dimension to their profession. The session on Human Factors was really appreciated by the students and *all* the teams went back to their Ventures and made some changes to make it more usable. Most teams had one highly motivated champion who contributed most to the success of the team. Typically this person was not an electrical or computer engineering student. For example, the Mashavu project is championed by a chemical engineering undergraduate student and COSMOS was championed by a material science graduate student. An astrophysics graduate student claimed that this course was the first time he was working in a team environment! On two occasions, the words “how can you even think like that?” were heard in the lab.

Course Challenges

The primary challenge for the course is that it is very intense and very demanding of faculty time as well as student time. Co-teaching the course is not practical because of the specialized knowledge and skills, although experts are brought in to present some of the entrepreneurship topics. This course is currently offered through the Continuing Education program at Penn State as a senior-level special topics course in Engineering Design. Efforts are underway to institutionalize the course and get a permanent course number. This will help market the course

and have a steady student stream. However, funding challenges still remain because the course is taught by a staff member and the Continuing Education program does not pay the instructor's department adequately to buy out his time. A more sustainable funding model needs to be worked out to sustain the course in the long run. Efforts are underway to simplify some of the sessions and Adventures to make them less time-consuming and maintain the rigor at the same time.

The course is an accepted elective for most disciplines in engineering, the Engineering Entrepreneurship minor, and the Certificate program in Engineering Design. Students from other Colleges are a little apprehensive in signing up for an 'engineering' course. Co-listing the course might solve this problem but does raise other administrative issues.

Students own the intellectual property they develop in this course. The university has no stake in it and this also implies that University IP officers cannot and will not pro-actively help students secure their IP. Currently, the students are pointed to the right resources to protect their IP. Most students do not pursue this further and don't take pro-active steps to protect their IP. We are trying to develop a more aggressive approach to address this concern.

Road Ahead

Student and faculty response to this course has been extremely encouraging. A number of E-teams formed in the class are working on advancing their products towards commercialization. These students serve as excellent role models to infect others with the entrepreneurship bug. Continued support to the teams is provided by various resources on campus including a brand new student business incubator. A very successful Invention 2 Venture workshop⁴³ was held in Fall 2007. An Idea Pitch competition is being organized for Spring 2008 and a new partnership between the local Small Business Development Center (SBDC) and Ben Franklin Technology Partners⁴⁴ is offering \$25,000 in seed money to aspiring entrepreneurs.

A unique partnership between the College of Engineering and the College of Liberal Arts is being developed to provide the support structure for the pilot testing and commercialization of leapfrogging technology-based social entrepreneurial ventures in Tanzania. Entrepreneurship at Penn State has achieved the critical mass and reached the tipping point. We are hoping to harness the energy and passion generated by this movement in this course and hoping to transform the students from myopic discipline-focused individuals to creators, entrepreneurs, problem-solvers, activists, leaders, and co-conspirators with a burning passion to change the world to a freer, friendlier, fairer, and more sustainable planet.

This course could be very beneficial to the Life Sciences. An entire book has been written on how lab automation is critical to fighting infectious diseases and bioterrorism⁴⁵. There is a growing interest in entrepreneurship in the life sciences and lab automation in the research lab to get products to market faster⁶. We intend to adapt and market this course to students in the life sciences to introduce them to the fascinating world of entrepreneurship by dangling the lab automation carrot.

This course has rekindled the “Medici Effect”. An international team with a biomedical engineer, industrial engineer, and geo-environmental engineer combined concepts from their disciplines to develop an innovative wireless sensor network management system called Sensowi. An astrophysicist, computer engineer, and electrical engineer combined concepts from their respective disciplines to develop a simple and inexpensive way to control a computer mouse with their eyes. A material scientist, economist, and computer engineer developed the COSMOS system by bringing together various concepts from their fields. These students are very confident of taking the concepts, knowledge, and skills acquired in this course back to their discipline and infecting others with the entrepreneurship bug.

Under the auspices of this course, students from various colleges, disciplines, and cultures came together on a wild safari where they attempted to break down the barriers between them, truly collaborate, create value, and exploit the power of modern technology to develop innovative products and services and try to change the world in their own little way. Championing similar hands-on, multidisciplinary, design-focused entrepreneurship education opportunities might help fuel a new high-tech renaissance—and we need to shape it so that it truly benefits all of humanity. Maybe Indiana Jones will jump across the Valley of Death!

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