AC 2009-2146: SUPPORTING AN EMPHASIS IN PRODUCT DEVELOPMENT: INTEGRATING ELECTRONICS CAD TOOLS ACROSS THE CURRICULUM

Jay Porter, Texas A&M University

Jay R. Porter joined the Department of Engineering Technology and Industrial Distribution at Texas A&M University in 1998 and is currently the Program Director for the Electronics and Telecommunications Programs. He received the BS degree in electrical engineering (1987), the MS degree in physics (1989), and the Ph.D. in electrical engineering (1993) from Texas A&M University. His areas of interest in research and education include product development, analog/RF electronics, instrumentation, and entrepreneurship.

Joseph Morgan, Texas A&M University

Joseph A. Morgan has over 20 years of military and industry experience in electronics and telecommunications systems engineering. He joined the Engineering Technology and Industrial Distribution Department in 1989 and has served as the Program Director of the Electronics and Telecommunications Programs and as the Associate Department Head for Operations. He received his BS degree in electrical engineering (1975) from California State University, Sacramento, and his MS (1980) and DE (1983) degrees in industrial engineering from Texas A&M University. His education and research interests include project management, innovation and entrepreneurship, and embedded product/system development.

Wei Zhan, Texas A&M University

Dr. Wei Zhan is an Assistant Professor of Electronics Engineering Technology at Texas A&M University. Dr. Zhan earned his D.Sc. in Systems Science from Washington University in 1991. From 1995 to 2006, he worked in the automotive industry as a system engineer. In 2006 He joined the Electronics Engineering Technology faculty at Texas A&M University. His research activities include control system theory and applications to industry, system engineering, robust design, modeling, simulation, quality control, and optimization.

George Wright, Texas A&M University

George Wright is a Senior Lecturer in Electronics and Telecommunications Engineering Technology at Texas A&M University. He has been with the Programs for over 25 years. His research and education interests include software development for embedded systems and product development.

Supporting an Emphasis in Product Development: Integrating Electronics Design, Simulation and Implementation CAD Tools Across the Curriculum

Introduction

Over the past several years, several institutions of higher learning have developed courses and emphases in product development to introduce their students to entrepreneurship.[1,2,3] In this same spirit of "doing" versus "lecturing", the Electronics and Telecommunications (EET/TET) Programs at Texas A&M University have been developing an emphasis in electronics product design. To this end, the curriculum has been augmented to include topics such as electronics manufacturing, system integration, innovation, project management, and entrepreneurship. An initiative to team engineering technology students with business students who understand marketing and small business plan development has also gained substantial momentum over the past three years.[4] Finally, all students are required to participate in a capstone design sequence where they work in teams to develop the concept for a product and implement a fully functional prototype.[5]

In addition to changes in the curriculum, the faculty also recognizes that most of the applied research being done in the Programs also centers on the development of product prototypes for industrial partners across a range of market sectors including RFID, medical, security, communications, and power. While the particular focus area of research can be quite different between faculty members, the goal of most funded research products is quite often a product or a system that provides an application solution for the customer. For these reasons, the Programs recently decided to ask industry to help guide them in formalizing this new direction.
This led to the recent "Product Development Summit" held by the Programs on the Texas A&M campus. In this meeting, industry was asked to help answer the following questions:

- What does product/system development mean to your organization? (ie, is it focused on internal or external customers, is it focused on software/hardware or something else, what might the final product/system look like)
- What product/system development methodologies are used within your organization? (ie, interfacing with the customer, project management tools, idea generation techniques, system planning tools, documentation requirements)
- What does the career path of an individual in product/system development look like? (what would be the progression of promotions, what internal/external training would be required)
- What attributes are necessary to be a successful product/system developer? (ie, technical skills, "soft" skills, personality)
- What educational components would serve the future product/system developer best? (While we know that companies will probably not hire new graduates directly into product/system development roles, we want to prepare them with an interest in this area, and the skills to maximize the likelihood of success.)

An immediate action that resulted from working with these industrial experts was the need to develop a more holistic approach to product development. It was recognized that for students to be successful in the capstone design experience at the level required by the faculty, they need to have true expertise with the hardware and software design tools used in product prototyping and development. In fact, it has been observed on multiple occasions that teams with one or more members having prior experience (over and above their education) with design tools required for their specific project, have a more successful final deliverable. While the Programs already expose the students to a variety of tools by introducing them in individual courses, it was recognized the students needed repeated exposure throughout their curriculum in a real-world environment to develop their proficiency. Thus, efforts have and are being made to give the students multiple opportunities to use different tools through classroom, laboratory and project experiences.

These efforts have led to a pair of papers at the 2009 ASEE conference. This paper discusses which tools the faculty has chosen for the students to use in their product development efforts and how these tools are introduced in the flow of the curriculum. The specific tools discussed here include electronics simulation software, printed circuit board layout tools, multiple microcontrollers and their respective development environments, programmable device development environments, and electrical/mechanical assembly tools. A second paper that discusses a real-world course project that the programs use to bring together these tools in a product development effort can also be found in these proceedings.

Choice of Tools

As the Programs have moved forward with creating an emphasis in Product/System Development, it has quickly become obvious that if the students are going to be expected to "live" a meaningful product development experience, they must be provided with the necessary tools and knowledge to be successful. To this end, four essential areas of technology for electronic product and system development have been identified:

- Programmable device development environments
- Embedded hardware and associated development environments
- Electronics schematic capture and simulation environments
- Implementation tools for printed circuit board layout/manufacturing and electrical/mechanical assembly

Over a period of several years, the faculty have selected and refined a set of tools for use by the students. This selection process has been based on several things including cost, broad industrial use, required learning curve, and appropriateness for an educational program. This section discusses in detail the experiences and processes associated with selecting the tools that are currently made available to the students.

Programmable Devices

As most of the product/system development projects that are undertaken by EET/TET students will include some form of embedded intelligence, the Programs seek to provide all students with a wide range of both hardware and software development environments in which to work. For many years this was restricted to microcontrollers using both assembly and high-level languages.

Recently, the Programs have developed new relationships with two major Field Programmable Gate Array (FPGA) manufacturing companies. Through their support and the addition of a new faculty member with expertise in this technology, the programs have reoriented two of the sophomore-level courses to include FPGA technology and devices. Although other educational programs have chosen to include FPGAs in more advanced courses, the EET/TET Program faculty members believe strongly that this technology can serve a major role in providing a development/laboratory environment that is conducive to rapid design iteration. Being able to focus on the design, implementation, debugging, testing and documentation processes instead of the wiring/rewiring processes allows the students to learn more while exploring multiple options and/or answering more “what if” questions. Moving any technology such as this to the sophomore level includes a series of risks. One of the more critical risks is will the students be able to handle the learning curve associated with the technology and be able to effectively utilize the associated development tools.

After discussing the implementation strategy being considered with both manufacturers and users of the technologies, the EET/TET Programs decided to move forward with a two-course implementation approach. Once the approach was determined, the course directors of the two courses interacted with representatives of the university-relations department in a number of FPGA manufacturing companies to see what level of support could be provided for the new strategy. The EET/TET Programs were interested in building a long-term relation with a company that would include continued support in both hardware and software development environments. In addition to these laboratory resources, the course directors were very interested in training/short course support for laboratory assistants and other faculty members as well as potential student motivation support. Based on these decision factors, the EET/TET Programs chose Xilinx[6] as its industry partner. Xilinx has been involved in all aspects of the redirection of the two courses and has provided outstanding support.

Microcontrollers and Associated Development Environments

When teaching applied microcontroller development, the Programs have found that the establishment and maintenance of the laboratory infrastructure (hardware, software, and test equipment) is both expensive and time consuming. Therefore, the first requirement associated with picking a microcontroller environment is ensuring that the manufacturer will partner in order to support teaching and education. A second decision factor is making sure that the chosen environment is a leading industry standard. Finally, the selected family of microcontrollers must be complex enough that students can easily migrate to other families when necessary.

With this in mind, the faculty started by selecting the Freescale Semiconductor family of microcontrollers. Not only is Freescale an industry leader, but they maintain a wide range of controllers ranging from 8 bit to 32 bit families. In addition, the Freescale software tools support the full range of processors. Finally, not only is Freescale willing to partner with academic programs to support education, there are also numerous sources for third party development boards and reference designs as well as third party development software. Once the manufacturer was chosen, a particular family/architecture had to be chosen and after careful consideration the Programs decided to focus on the PowerPC architecture.[7]

The PowerPC is a RISC 32-bit Reduced Instruction Set (RISC) architecture that has five processing units including a hardware floating point processor. The low end processors in the Freescale PowerPC family provide a wide array of input/output devices that give the student broad exposure to a wide variety of standard as well as non-standard peripheral devices. Before making a decision, the following pros and cons were considered:

- Pros: State of the art technology, complexity, high quality hardware, reliable, high quality software development tool suites from multiple sources.
- Cons: Cost and complexity. As the word size and clock speed increase, the cost of hardware, software and test equipment increase. With the PowerPC, it will be necessary to obtain support from vendors for the hardware and software through donations and /or discounts. Also, it is difficult for individual students to purchase personal development systems because of the relatively high cost.

One will note that the processor's complexity was considered both as an advantage and disadvantage. Ultimately, the faculty decided that the difficulty of teaching a processor as complex as the PowerPC was justified since the concepts will serve the students well as they are required to transfer the knowledge to other architectures and processor families. This has been proven true as the students in the Program often chose to use other microcontrollers in their Capstone design projects. These other devices include microcontrollers from Microchip, Atmel, Texas Instruments, and Silicon Labs. In addition, our students report that they have opportunities to apply the knowledge of the PowerPC directly to existing projects as they start their career.

Analog and Digital Simulation

For analog and digital device design and analysis, software that can be used to capture electronic schematics, simulate the design, and design the PCB layout is needed. There are many software options that meet most or all these requirements including MultiSIM/Ultiboard, Cadence OrCAD, EAGLE CAD, EDWinXP, KiCad, gEDA, AutoTRAX , and PCB123. From the standpoint of cost, these packages vary anywhere from free to well over $1000 a seat. The Programs' decision on the choice of the software was mainly based on the following factors:

- Must run under the Windows operating system. This requirement is based on the fact that all of the Programs' computing facilities and laboratories are currently using WindowsXP.
- Cost to deploy the software must be reasonable. Specifically, figures of merit included optional maintenance fees, reasonable discounts for academic use, and the availability of student licenses.
- Compatibility with virtual instrumentation environments such as LabVIEW.
- Must provide the look and feel of electronic CAD packages used in industry. It is important that any tool used in the Programs provide the students with a "real-world" experience similar to what they will experience in industry.
- Must have a rich feature set. Specifically, the environment should support extensive industry device libraries, multilayer PCB design, autoplacement/autorouting, and

customizable design rule checking. In addition, creation and sharing of new devices must be straightforward.

Based on these criteria, the MultiSIM/Ultiboard[8] environment from National Instruments was selected. MultiSIM/Ultiboard is a product from National Instrument that runs in Windows. While the professional version of this package was required and is typically expensive, National Instruments was willing to work with the Programs to provide academic pricing. This was important since the educational version did not meet the necessary requirements. In addition, the total cost of a combined student license for MultSIM/Ultiboard and LabVIEW was approximately $70, allowing students to purchase the software for use at home. Since LabVIEW is being used in several courses, this combined license is very cost-effective. Finally, National Instruments and Texas A&M University have established a good relationship over the past decade and overall support provided to the Programs has been excellent.

Implementation

An important part of the Electronics and Telecommunications curriculum is the emphasis placed on the actual implementation of hardware/software systems. This includes not only printed circuit board manufacturing but also product packaging. For this reason, tools are required that allow the students to: layout and have printed circuits board manufactured; populate the boards they design; and design and build custom packaging as required. From the standpoint of PCB layout and construction, the Programs have looked into three different options.

The first option involves having the students lay out their boards in software and then actually manufacturing the boards in house. The obvious issue associated with this option is the cost of purchasing and maintaining the appropriate equipment. In fact, the Programs have supported the option in the past through two mechanisms. First, both the Physics and Electrical Engineering Departments support their researchers with PCB fabrication facilities. Engineering Technology has leveraged these resources by negotiating for the limited use of these facilities to support student capstone projects. Unfortunately, the drawbacks to this process were three-fold and included continual price increases, the low-priority given to student projects, and the limitation of only being able to manufacture double-sided boards. The second mechanism involved the purchase of facilities within the Department. In 2004, Engineering Technology purchased an LPKF PCB Prototyping system[9] that used a high-precision milling machine to create boards and that could build up to six layer boards. While this system has been used and is still functional, it also suffers from several issues including a high-cost per board, maintenance and disposal of chemicals, and the learning curve associated with using the machine.

The second option uses existing third party, web-based software tools to lay out a board and have it manufactured. An example of a company that does this is ExpressPCB.[10] The Programs have used this option multiple times and it works well. The cost of having a board made using facilities such as these are reasonable ($59 for three copies of a single board) but again, this process has disadvantages. First, because proprietary, web-based software is used to create the board layout, the students cannot migrate their files to another design environment later if necessary. Thus, they are limited to ExpressPCB as their source for boards unless they are willing to pay for the design files each time they make a change to their board. Second, the $59 charge restricts the students to a particular size PCB and to two layers.

A final option is to purchase in-house PCB layout software for use by the students that can generate the necessary design (Gerber) files. Once the students have designed their boards, they can generate Gerber files and then send their files over the web to one of the many design houses that can build their boards for them. Again, this option has been used with good success. Many students have used Advanced Circuits[11] and have had both two and four layer boards of varying sizes built for under $100. Of the three options discussed this in the one that the Programs now use on a regular basis. Using the Multisim/Ultiboard[8] tools discussed previously, students can design boards with almost any level of complexity and then have them manufactured off site. While the boards can cost up to $100 (and even more in rare cases), student projects are typically supported through grants and donations so students do not incur any out-of-pocket expense for their projects.

Once the students have printed circuit boards manufactured, they must populate them. In the days of thru-hole parts, this was a simple process easily doable in an educational laboratory. However, with today's surface mount technology (SMT), the process of populating a printed circuit board is more complex and tedious. Like before, the Programs have come up with two options for solving this problem. First, the students have been asked to look outside the Programs for third-party vendors that will populate the boards for them. An example of this is a company called Screaming Circuits[12] that will actually provide a quote through an online utility. Again, the drawback to this option is cost. The students quickly find out that using a service to populate a single board is not economical. However, they can also see how the cost per board rapidly decreases with quantity. A second option, and the one that is currently supported, is the creation of a facility with SMT soldering equipment. The Programs have a laboratory for use by the students that has SMT soldering/desoldering and reflow stations. Most of the equipment in this lab was purchased from Xytronics[13], a company that makes low-cost but good quality equipment.

Finally, once the students have built their PCBs, they typically need to create "professional" enclosures for their projects. Until a couple of years ago, this was left to the students' creativity and ingenuity. The students did have access to the Programs' in-house technicians and to the equipment available in the Department's metal, wood, and plastics machining labs. However, the results varied greatly based on the student team's prior experience with mechanical design. In order to improve this part of the design process, the faculty now demands that all mechanical packaging designs are documented in CAD software before production. At this time, no specific software environments are required but most students use one of three packages: Sketch-up, Autocad, or ProE. The package chosen depends on their personal experience but because of the documentation requirement, the department faculty recently jointly invested in a 3D Printer capability that allows students with electronic drawings, to produce custom packages on site. At least one student group has used this capability successfully.

Integrating Tools into the Curriculum

It is important to ensure that the students are competent with the tools necessary to be successful product developers, especially when they enter their rigorous capstone design course sequence. For this reason, continual efforts are made by the faculty to make certain that the students are exposed to the important tool sets multiple times in their curriculum. Table 1 shows a snapshot of the curriculum as of Spring 2009 and the different courses that use each of the different tools.

Table 1 – Flow of how individual tools are taught throughout the curriculum

<table>
<tr><th rowspan="2">Year</th><th rowspan="2">Course</th><th colspan="4">Tool</th></tr>
<tr><th>Programmable Devices</th><th>Micro Controllers</th><th>Capture and Simulation</th><th>Implement</th></tr>
<tr><td rowspan="4">2</td><td>Circuits I</td><td></td><td></td><td bgcolor="green"></td><td></td></tr>
<tr><td>Circuits II</td><td></td><td></td><td bgcolor="green"></td><td></td></tr>
<tr><td>Digital Logic</td><td bgcolor="green"></td><td></td><td bgcolor="green"></td><td bgcolor="green"></td></tr>
<tr><td>Adv. Digital Des.</td><td bgcolor="green"></td><td bgcolor="green"></td><td></td><td></td></tr>
<tr><td rowspan="5">3</td><td>Electronics</td><td></td><td></td><td bgcolor="green"></td><td bgcolor="green"></td></tr>
<tr><td>Emag</td><td></td><td></td><td bgcolor="green"></td><td bgcolor="green"></td></tr>
<tr><td>Microprocessors</td><td></td><td bgcolor="green"></td><td></td><td bgcolor="green"></td></tr>
<tr><td>Instrumentation</td><td></td><td bgcolor="green"></td><td bgcolor="green"></td><td bgcolor="green"></td></tr>
<tr><td>Software Design</td><td></td><td bgcolor="green"></td><td></td><td></td></tr>
<tr><td rowspan="3">4</td><td>Controls</td><td></td><td bgcolor="green"></td><td bgcolor="green"></td><td bgcolor="green"></td></tr>
<tr><td>Data Comm</td><td bgcolor="green"></td><td bgcolor="green"></td><td></td><td></td></tr>
<tr><td>Capstone Design</td><td bgcolor="green"></td><td bgcolor="green"></td><td bgcolor="green"></td><td bgcolor="green"></td></tr>
</table>

One can see that apart from programmable devices, the students see the different packages/devices on at least four different occasions throughout their sophomore and junior year technical courses. (The freshman year is dedicated to general core curriculum.) The use of programmable devices, a relatively new emphasis in the Programs, is currently being expanded.

Programmable Devices

The Programs' implementation strategy called for utilizing FPGA technology as the basis for the first two courses in digital design. The first course focuses on digital logic design principles, and the second course then builds on this knowledge to include microcontroller architectures and the HDL programming language. Xilinx agreed to provide Spartan 3E development boards and their ISE Design Suite 10.1 to support both of these courses.

In the first digital design course, students learn to design and implement both combinatorial and sequential logic circuits. Instead of having to implement their designs in discreet logic on protoboards using an assortment of wires or just simulating their designs using computer software, EET/TET students are now able to transfer classroom learning directly into the laboratory where they can implement, debug, and test their designs. Initially, the student learned how to use the ISE Design Suite 10.1 to input their digital designs. However, through a project underwritten by National Instruments, a summer intern was funded to work with EET/TET faculty to develop a LabView toolkit that would provide a more intuitive graphical user interface for the digital design students. This toolkit was developed during the summer 2008 semester, evaluated and improved during the fall 2008 semester, and is now the preferred development environment for this first course. Because LabView has been selected by the EET/TET Programs as its graphical programming language, sophomore-level students get a better feel for this software environment early in their educational careers. Another paper being presented at the 2009 ASEE National Conference provides detailed information on the new LabView toolkit and success the EET/TET students have had in using it.

The digital design course also provides an opportunity for the students to work in a team, on a project that integrates facets of each of the course labs, and to do so in a friendly, yet competitive environment. Specifically, the two-person teams must build a digital controller so that a mobile platform can operate autonomously over both a drag race (straight and long) and a road race (lots of sharp turns) that is delineated with electrician tape on the floor. The team with the lowest total time is declared the winner and maintains programmatic bragging rights until the next group of students compete. Known now as the Xilinx Race of Champions, this competition serves to reinforce many of the digital design fundamentals, provides a true appreciation for rapid design using FPGA technology, and encourages the students to move up a little higher on the learning curve. Beginning in the fall 2008 semester, Xilinx has provided cash prizes to the first, second, and third place winners. Figure 1 and 2 provide examples of the mobile robots that the teams build and the race course they must successfully negotiate.

Figure 1 – Race Entries

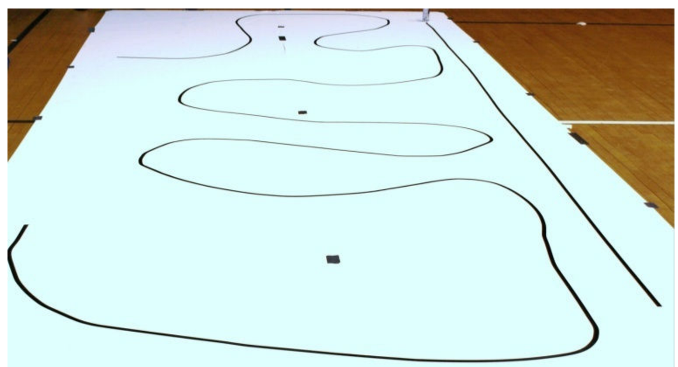

Figure 2 – Course for Xilinx Race of Champions

The LabView toolkit for the digital design course was built utilizing the HDL capability provided by National Instruments. Although there were other methodologies that could have been employed to create the toolkit, the HDL approach was selected specifically to support the following course in microcontroller architectures. In the second course in the sequence, students are allowed to "open up" one of the sequential logic flip flop devices they utilized in the first course to see that all functionality was been provided using the VHDL development language. Throughout this second course, the students learn and use VHDL to complete their laboratory assignments. In the first half of the course, a small microcontroller is designed and implemented in the Spartan 3E device. In the second half of the course, the students learn how to embed a PicoBlaze microcontroller into the FPGA device and then how to develop and download operational code that the microcontroller executes.

At the completion of the two course sequence, students appreciate the design power of FPGA technology to: create an embedded combinatorial/sequential logic, implement VHDL solutions, and to embed a fully functional microcontroller. These skills add to their design capabilities while allowing them to reinforce their classroom learning with successful laboratory implementations and demonstrations. The success of this approach to digital design and microcontroller architectures is now caused other FPGA manufacturers and users to become more interested in our students and graduates. At least one of the EET/TET students received an intern opportunity from a small company because of the appreciation he had for the Xilinx FPGA design environment. Likewise, another FPGA manufacturer is seeking information on how the programs have successfully integrated this technology into an undergraduate curriculum. In addition to partnering with and potentially expanding the EET/TET FPGA solutions and resources, the company hopes to disseminate this model to other institutions.

Microcontrollers and Associated Development Environments

The curriculum for teaching microcontrollers includes a two course sequence that focuses on microcontroller principles, concepts and programming. The first course, Microprocessors, concentrates on microcontroller architecture and programming. In this course, assembly language is taught since it forces the student to understand the basic architecture of the device. To accomplish this, course software products from Premicro System are used as tools. Their software includes:

1) Integrated Development Environment
2) Text Editor
3) Assembler
4) Debugger
5) Flash Programmer

The Premicro toolset has proven to be a very effective toolset for the teaching environment. The vendor provides an array of tools for the Freescale family of microcontrollers and the software runs on Windows-based computers. In the second course, Embedded Software Systems, the student experience is extended with a focus on product and system development using the C programming language.

Finally, while these two courses truly focus on the development of software and interfacing, microcontrollers are used elsewhere in the curriculum. For example, the course project in Instrumentation requires that the students use a Microchip[14] PIC24 series device to develop a "smart sensor". By this time, they have completed at least their first class in microcontrollers and the C programming language and are expected to extend their current knowledge to a new platform and development environment. The idea is to help build the students' confidence in their ability to interpolate as well as extrapolate their skill set. This process works well as evidenced by the fact that by the time students start their capstone project, they are willing to move to whatever microcontroller and development environment makes sense for their specific application. This is in contrast to several years ago, when all students would only use devices they had worked with in previous courses.

Analog and Digital Simulation

MultiSIM/Ultiboard is vertically integrated in the curriculum of the electronics engineering technology program. It is first introduced in Circuit Analysis II, a sophomore level technical course. It is then re-enforced in sequential courses such as Applied Electromagnetics and Analog Electronics. Students are required to use MultiSIM/Ultiboard in laboratories and for their course projects in junior-level courses such as Electronic System Interfacing. MultiSIM/Ultiboard is also extensively used by senior design project teams for electronic hardware design, simulation, and building of prototypes. Through the process of learning and using the software in multiple courses, students become highly competent with these design and simulation tools. The benefits in learning the course material and improved efficiency in conducting experiments and designing circuits are tremendous. Potentially, the software can be introduced in Circuit Analysis I. But introducing the software too early may cause students to rely too much on the software and negatively impact the learning of the fundamentals of circuit analysis. This is something that is worth looking into in the future.

Implementation

As previously discussed, implementation tools currently used by the Programs include tools to: have PCBs manufactured, build and populate electronic systems, and design and build packaging for final prototypes. To ensure students are ready to apply these tools professionally in their capstone project, they are given multiple opportunities to use them in the curriculum.

Starting with their Digital Logic course, students are given an opportunity to assemble motor drive circuitry for an autonomous robot course project. Here, they begin to learn about basic thru-hole and SMT soldering and assembly. While they have not yet produced a printed circuit board, they do learn how to use perf boards for building simple circuits. While the circuitry is fairly basic, they do learn how to do basic hardware troubleshooting as well. To follow this up, the first semester junior course in Electronics has a more complex project associated with it that requires assembly. In this class, students must identify and purchase a project kit (typically from Ramsey Electronics) that has a substantial analog/semiconductor component in its design. These kits typically have 30-50 parts and often use SMT technology. Again, as part of the project, the students must document a structured approach to assembly and test. They are taught to build their system in modular, test-as-you-go fashion. This experience, while tedious for many students reinforces the importance of good soldering and troubleshooting techniques. A similar experience is also provided in the Microprocessor course, where students fabricate cables and hardware to use with their development boards. While cable fabrication seems trivial, it teaches the students an excellent lesson in how simple things like good connections cannot be taken for granted.

Next, in the Electromagnetics course, students are required to design their first printed circuit board and have it manufactured. The goal of the project is to design a circuit board using impedance controlled, microstrip techniques. The students learn how to calculate highfrequency trace impedances and the importance of ground planes. Equally important, the students use ExpressPCB.com's proprietary software to layout their boards and send them off for manufacturing. ExpressPCB works well for this project since each member of the team can receive three copies of their PCB for a total cost of $59 (~$20/student). In addition, the company website provides the students with the technical specifications (dielectric constant, metal thickness, board thickness, etc) so that the students can make impedance calculations. While the ExpressPCB system has drawbacks, it is a very straightforward approach to introduce students to the PCB layout process.

The first real experience the students receive in an end-to-end prototype design comes in the Instrumentation course (details about this experience are published in a second paper at this conference). In this class, the students are asked to build a professionally-packaged prototype of a "smart sensor" to be used in an existing process control application. For this project, the students must create a set of requirements, design, layout, and test a complete solution, package their prototype, and document their intellectual property. For this experience, they are asked to use the Multisim/Ultiboard environment by National Instruments to capture their schematic, simulate its functionality and then transfer it to a PCB layout. Through this process they learn how to create footprints, indentify appropriate device package styles for their design, use design rule checkers to make sure their final layout is "manufacturable", and generate and validate Gerber files for manufacturing. It should be noted that they work with faculty to go through a formal schematic, and PCB layout reviews before submitting their files to a board house. Once the faculty is satisfied their layout is functional, they use Advanced Circuits to have their board built. Because Advanced Circuits has substantial discounts for educational projects, the cost is very reasonable. Once the students receive their boards, they must build them using professional SMT soldering/desoldering stations and then package them professionally. While the students do not take any manufacturing/mechanical courses, they do have access to staff technicians and professional manufacturing equipment.

Finally, through these experiences, the students are ready for more open-ended projects that have less faculty guidance. In their senior year, they first work on a design project for the Controls course. Then, in the semester before graduation, they implement their Capstone design project. This design is, in almost all cases, very complex and requires all of the implementation tools and skills they have acquired to date. In fact, as the flow of implementation tools in the curriculum is tweaked and becomes more complete each semester, the results in the Capstone course have become increasingly more professional. To help improve the quality of the prototypes, the Programs have established a on-line knowledge base of how-to documents and videos.

One area that still needs improvement is mechanical design/packaging. There is little formal coursework in this area. One improvement that has been made is that teams are now required to create mechanical drawings associated with packaging using tools such as Sketch-up, Autocad, or in rare cases, ProE. In fact, these electronic designs have led some teams to use the Department's rapid prototyping facilities to produce complex, custom packaging for their prototypes. A second change that is currently being formalized is encouraging students who know they are going to have a substantial mechanical design component, to take a CAD course for their technical elective.

Results of Integration and Conclusion

Over the past five years, the Electronics and Telecommunications faculty have moved the focus of their programs towards product/system development. While the Programs will always deliver a well-rounded curriculum that prepares students for general careers in the Electronics and Telecommunication industries, the faculty believes that the future of engineering and engineering technology in the United States depends on graduates that understand innovation and entrepreneurship as well as the technical/engineering fundamentals. For this reason, the curriculum has been changed over time to provide students with the requisite technical expertise and a strong background in project management that allows them to understanding the planning process behind product and system development.

Since 2002, the Programs have refined their capstone design course sequence to require all students to: form a team that will function as a small startup company; identify an idea for a product or system; locate sponsorship and find a faculty advisor; plan their efforts using project management principles and develop a formal proposal to sell their idea; and finally implement their design through a working prototype and complete documentation package. This process encourages the students to use their education to innovate and solve a complex, real-world problem. Feedback from both graduates and their employers indicate that this experience makes them extremely valuable employees. For example, a small Dallas-based firm that develops embedded-based systems recently hired two of the students who have been through this process. While their usual hiring practice was to only hire seasoned, experience engineers, they indicate that these "fresh-out" graduates are an excellent fit for their company. In fact, one of the two students won this year's Employee of the Year award. Also, the Programs' industrial advisory board evaluates the graduating seniors each spring and has indicated on numerous occasions that this capstone course sequence exposes the individual to real-world demands in a mistake-tolerant environment.

To this end, the establishment of a standardized toolkit for all students has resulted in significant improvements in the prototype development required in the capstone design sequence. The student teams that form companies and plan, implement, test, and document their transition from an idea to a fully functional prototype now have a common reference plane in which to communicate their designs to stakeholders, faculty and other students. This common platform provides the ability to host and maintain a knowledge base of technological solutions that can be leveraged by follow-on teams; thus the level of design capability increases with each new semester. Through these knowledge base solutions and lessons learned, design, fabrication, and testing errors are being reduced such that teams are becoming much more efficient and productive by capitalizing on the experience of preceding teams.

A good example of this value-add process can be seen in a recent capstone design team, FourTel. This team was able to utilize the toolkit together with several knowledge base topics to improve and expedite their development efforts. FourTel produced a prototype of a system that utilized the HD Radio infrastructure available on both the public broadcasting system as well as most university radio systems to integrate a wide array messaging system for both fixed and mobile digital signage. A conceptual diagram of this system is shown in Figure 3.

These included hardware interfacing and software development for their embedded microcontroller; a unique process of populating fine pitch parts on a PCB; and the implementation of the I2C communications protocol between the microcontroller and the RF transceiver. Because FourTel was able to bring their design to fruition in a timely manner, the team was able to provide an operational demonstration of their prototype during a campus-wide Ideas Challenge competition. This demonstration clearly set FourTel apart from other students that entered the contest. In addition to winning the $3000 grand prize, Fourtel also received a voucher for $2000 of legal assistance by a Houston-based patent attorney to file a provisional patent for their idea. The provisional patent has been issued, and a small company is in the process of licensing the intellectual property for commercialization. The success of this student team is, in part, attributable to the adoption and integration of a standardized design, simulation, and implementation toolset across the curriculum.

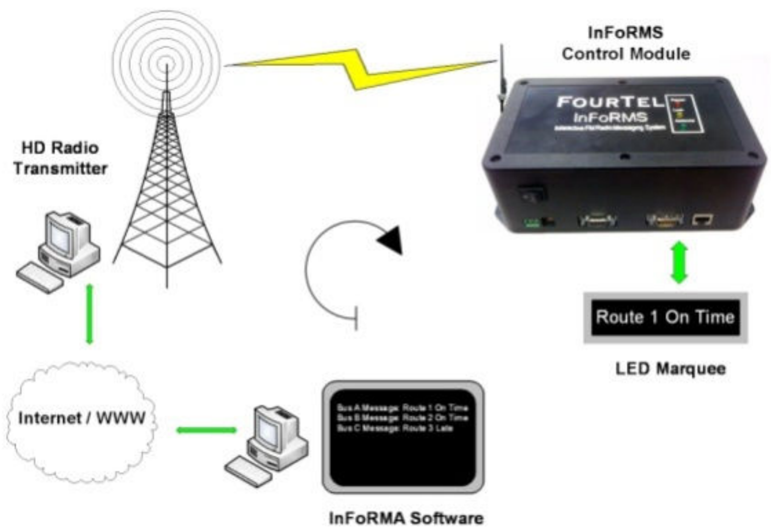

Figure 3 – Fourtel Capstone Design Project

As the capstone design process continues to evolve, the addition of the recently added FPGA tools will begin to add value. Because these tools have been introduced in the sophomore-level courses, students have not yet entered the capstone design sequence with this experience. Replacing multiple devices and circuitry with a single FPGA, being able to embed the processor/microcontroller within the device, utilizing VHDL and digital design tools that can be compiled and downloaded to the target FPGA device will continue to improve the quality and reduce the production-level costs of the prototypes the student teams create. Finally, all students will have experience with industry-grade tools and several opportunities to apply those tools to solving real-world problems in a team environment. The value of this type of educational experience is now being appreciated by those companies that hire the graduates of the EET/TET Programs as entry-level employees.

Bibliography

1. L. Richards, "Creativity and New Product Development: Bringing Entrepreneurship into Engineering Design Classes," 2007 ASEE Annual Conference and Exposition, Honolulu, HI, United States, 2007.
2. W. Birmingham, B. Allison, J. Dupree, "Entrepreneurship via Multidisciplinary Product Development," 2007 ASEE Annual Conference and Exposition, Honolulu, HI, United States, 2007.

3. A.J. Marchese, J.L. Schmalzel, T.R. Chandrupatla, S.A. Mandayam, "A Venture Capital Fund to Encourage Entrepreneurship and Rapid Product Development With Multidisciplinary Teams," 1999 ASEE Annual Conference and Exposition, Charlotte, NC, United States, 1999.
4. J.A. Morgan, J.R. Porter, "Embedding Business Students into Engineering Entrepreneurship Educational Experience," 2008 ASEE Annual Conference and Exposition, Pittsburgh, PA, United States, 2008.
5. J.R. Porter, J.A. Morgan, "Engineering Entrepreneurship Educational Experience (E4) Initiative: A New Model for Success," 2007 ASEE Annual Conference and Exposition, Honolulu, HI, United States, 2007.
6. http://www.xilinx.com
7. http://www.freescale.com/powerpc
8. http://www.ni.com/multisim
9. http://www.lpkf.com
10. http://www.expresspcb.com
11. http://www.advancedcircuits.com
12. http://www.screamingcircuits.com
13. http://www.xytronics.com
14. http://www.microchip.com