Selection of Processor, Language, and Labs in Introductory Microprocessor/Microcontroller Courses

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Abstract:
The hardware and software used in introductory microprocessor/microcontroller courses in electrical and computer engineering (ECE) and in electrical and computer engineering technology (ECET) curricula is of general interest to faculty in these disciplines. Information on processors, languages, and laboratories used in teaching fifteen ECE and eleven ECET courses was collected using university/college syllabi and other material available via the Internet. The choices made are presented in tables and similarities and differences between and among the two disciplines are discussed. The result is a comparison of the material taught in introductory embedded processor courses.

Introduction:
An introduction to microprocessors (uP's), microcontrollers (uC's), or embedded computing is an essential part of ECE, ECET and other similar curricula. Four, eight, and sixteen bit embedded processors are ubiquitous in modern life and the billions used annually far exceeds the number of 32/64 bit general purpose processors used in desktop and portable computers. Embedded computing devices are built into essential devices such as automotive airbags, appliances, cell phones, and security systems. They are also included in widely used items such as remote controls, handheld tools, PDA's, motor controls, computer peripherals, and educational and entertainment devices. While their importance is well established, selection of the device(s) to be taught in introductory university courses is problematic because of the plethora of available choices. For instance, the most used embedded controllers are 8-bit devices; however, these often control peripherals or are connected to higher capacity processors in networks. As the capability of an embedded processor increases, the amount of available memory increases and higher level languages are used more often for programming. Thus, the selection of a processor is linked to selection of the programming language used in teaching the fundamentals of embedded computing. Introductory courses may teach assembly language for the particular processor or a high level language, such as "C", which is generally available, with libraries, for most uP/uC's. The many types of hardware available for interfacing with embedded processors, such as sensors, displays, keypads, and interface busses also make selection of laboratory exercises for an introductory course challenging.

With this in mind, information was sought concerning introductory courses in microprocessors, microcontrollers, or embedded computing. Internet sites containing sufficient information were found for fifteen introductory engineering courses and eleven introductory engineering technology courses. This survey, while not comprehensive,

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appears to be representative and is based on university instructors who chose to make their syllabi and other information publicly available on the Internet.

Universities and Courses:
Table 1 shows the institutions surveyed, course designations and titles, credit hours, and the most informative website used in compiling the material for each course. The appendix shows the approximate geographic locations of the 26 universities/colleges surveyed. The only universities surveyed which had ECE and ECET courses are Purdue University and the authors' university, Indiana University-Purdue-University Fort Wayne (IPFW), which is academically autonomous from Purdue. Information from other universities offering both ECE and ECET courses was not readily available. In both disciplines, most courses had a 4 credit hour content including an associated lab, either as part of the course or as a separate lab course. Where there was a separate lab course, it was included in the total number of credit hours shown in Table 1. For ECE courses, 8 of the 15 courses were junior or senior level and in ECET, 4 of 11 were junior or senior level. Historically, discipline specific EE/ECE courses began in the sophomore or junior year after intense preparation in mathematics and science, and microprocessors were introduced in the junior year. It appears that many ECE programs have moved the first course in uP/uC's into the sophomore and, in one case, into the freshman year. Also, historically, discipline specific courses in engineering technology began in the freshman year, with a uP/uC course, such as those surveyed, introduced in the sophomore year. Based on this survey, the ECET courses are still primarily in the sophomore year.

Table 1: The Fifteen ECE & Eleven ECET Programs surveyed

University	Course # & Title	CH$^+$	Website for Course Information
	ECE Courses		
U of Hartford (CT)	ECE-332: Intro to uP's	4	http://uhaweb.hartford.edu/jmhill/ee332/
Bilkent U (Turkey)	EEE-212: uP's	4	http://www.ee.bilkent.edu.tr/~ee212/
IPFW (IN)	ECE-362: uP Systems & Interfacing	4	http://www.engr.ipfw.edu/index.php
Iowa State U	CprE-211: uC's & Digital System Design	4	http://class.ece.iastate.edu/cpre211/
U of Mass (Amherst)	ECE-222: uP Lab	2	http://www.ecs.umass.edu/ece/ece222/
Mississippi State U	ECE-3724: uP's	4	http://www.ece.msstate.edu/~reese/EE3724/
Univ of the Pacific (CA)	ECPE-172: uP's	4	http://www1.uop.edu/eng/courses/ecpe/ecpe172/f04/
Purdue U	ECE-362: uP Systems & Interfacing	4	http://posserver.ecn.purdue.edu/eceugo/
Rice U (TX)	ELEC-226: uP & Embedded System Lab	3	http://cnx.rice.edu/content/m11681/latest/
U of Texas	EE-319K: Intro to uC's	3	http://www.ece.utexas.edu/~valvano/EE319KF04.html
U of Texas (El Paso)	EE-3376: Intro to Embedded Systems (uP's I)	4	http://www.ece.utep.edu/courses/web3376/ee3376.html
Vanderbilt U (TN)	EECE-218: uP's & uC's I	4	http://eecs.vanderbilt.edu/Courses/ee218/
Western Michigan U	ECE-251: uP's	4	http://homepages.wmich.edu/~zandim/ECE251Course.pdf
U of West Florida	EEL 4744: uP Applications	4	http://www.uwf.edu/mkhabou/

U of Wisconsin (Madison)	ECE-353: Intro to uP Systems	3	http://www.engr.wisc.edu/ece/courses/ece353.html
	ECET Courses		
Brookdale CC (NJ)	ELEC-242: Intro to uP's	4	http://www.brookdalecc.edu/fac/engtech/aandersen/obj/elec242.pdf
California U of PA	CET/EET-270: Intro to uP Design	4	http://www.aet.cup.edu/~jsumey/eet270/Welcome.html
IPFW (IN)	ECET-205	4	http://users.ipfw.edu/broberg/ECET205DownloadPg.htm
U of North Carolina (Charlotte)	ETEE-3275 (2213?)	3	http://www.coe.uncc.edu/~sjkuyath/ETEE3275/menu232.html
Penn State U (Hazelton)	EET-211	3	http://www.hn.psu.edu/faculty/kdudeck/EET211/ET211SY.htm
Purdue U	ECET-209	4	http://www.tech.purdue.edu/Eet/courses/eet209/
Oregon Inst. of Tech - Metro Campus	EET-327P/328P	5	http://www.almy.us/classes/eet327/general.html
Southern Polytechnic State U (GA)	ECET-2213 (3220)	4	http://ecet.spsu.edu/courseinfo/
Texas A&M (Corpus Christi)	ENTC-4418	4	http://www.sci.tamucc.edu/~entc/Syllabus4418.html
Utah State	ITE-3390	3	http://www.engineering.usu.edu/ete/documents/syllabi/ite_3390_hatch_fall_2004.pdf
Wentworth Inst. of Tech. (MA)	ELEC-240	4	http://public.wit.edu/~dilwalis/Elec_240_Spring04.htm

[+]Credit hours either includes a lab or a separate lab course

Processors:

Table 2 shows the choice of processors for the ECE and ECET introductory uP, uC, embedded processor courses. The most popular devices were from Freestyle Semiconductor[1] (formerly Motorola semiconductors with the spin-off completed in 2004). 6 of the 15 ECE courses and 3 of the 11 ECET courses used the Freestyle 8-bit MC68HC11/MC68HC12 uC's, while one ECE course used the 32 bit MPC555. PC-based Intel X86 uP's were chosen for 3 ECE courses and 3 ECET courses. One ECE course used a version of the Intel 80C188 16-bit uC and 3 ECET courses used versions of the 8051 uC (made under license to Intel by AMD, Dallas, Phillips, Signetics, Siemans and others). Microchip PIC (Peripheral Interface Controller) uC's were used in 3 ECE and 1 ECET courses. Several other devices were also used in these introductory courses, as shown in Table 2.

The choice of processor used shows considerable variation and is generally based on the expertise of the faculty member(s) responsible for the course, the learning objectives for the course, and how the course fits into the curriculum. There does not appear to be a significant difference between the choice of processors used for ECE or ECET courses. Intel is the world leader in supplying uP's for desktop and portable computers, so it is no surprise that 6 of the 26 courses chose to use X86 uP's to introduce uP's. Freestyle Semiconductor is the global market share leader for semiconductors for automotive applications and for communications processors, and has the fourth largest global market share for digital baseband semiconductors for cellular handsets[1] so, having 10 of the 26 courses use this chip is also reasonable. Microchip has been the number one supplier of 8 bit uC's in the world since 2002[2], so the use of PIC uC's in only 4 of the 26 courses may be less than expected, however, many PIC's use a simplified assembly language that may not translate well into higher level DSP courses. Eighteen of the 26 courses used uC's and 7 used uP's including the 6 Intel X86 uP's and 1 Freestyle MPC555, which is also referred to as a 32-bit uC.

Table 2: ECE (15) & ECET (11) Processor Choices

uP/uC	ECE #	ECET #	Comments
Intel uP	3	3	X86 based (including Pentium)
Intel uC	1	2	80C188 based/8051 based
Freestyle	7	3	68HC11/12 & 1-MPC555 based
PIC	3	1	12F675/16F84/16F877/18F452 uC's
TI	1		MSP430 16 bit uC
PLD	*		Part of one ECE course
Atmel		1	ATMega16 uC
Cypress		1	PSoC

Textbooks:

Table 3 shows the textbooks used in the courses surveyed. These textbooks varied greatly even for courses at different universities that used the same processor, which shows the large number of textbooks available. As shown in the Table, below, there are only 3 textbooks used in both ECE and ECET courses. Although, there is, generally, little mathematical theory involved in an introductory uP/uC course, the method and depth of coverage is usually different in each discipline. An example of this is that until two years ago, an ECET course at IPFW used the same text[3], using the Microchip PIC, as an ECE course at Georgia Tech. The difference in course coverage was primarily in the depth of theoretical coverage, for instance in Interrupt Timing considerations, which while not mathematically complex, requires a deeper understanding of assembly language and the operation of the microcontroller. 17 of the 32 textbooks used were published by Prentice-Hall (including Merrill). The next highest number from a publisher was 4 from Thompson (Delmar and Brooks-Cole). Three of the textbooks were from Oxford and 1 each from Elsevier (Newnes) and Phillips Inc. 6 of the courses used either no text or a local text by the instructor.

Table 3: ECE & ECET Textbook Choices

Textbook	ECE	ECET
Assembly Language for Intel-Based Computers, Irvine, Prentice-Hall	2	1
The Intel Microprocessors 8086/8088, 80186/80188, 80286, 80386, 80486, Pentium, and Pentium Pro Processor Architecture, Programming, and Interfacing, Brey, Prentice-Hall	1	
The 80x86 Family, Uffenbeck, Prentice-Hall	1	
Embedded uP System Design, Short, Prentice-Hall	1	
Microcontroller Technology: The 68HC11, Spasov. Prentice-Hall	2	
Introduction to Embedded Microcomputer Systems: Motorola 6811 and 6812 Simulation, Valvano, Brooks-Cole	2	
Microcontrollers and Microcomputers: Principles of Software and Hardware Engineering; and Software and Hardware Engineering: Motorola M68HC12, Cady & Sibigtroth, Oxford	1	1
68HC12 MCU Theory and Apps, Pack & Barrett, Prentice-Hall	1	
MC68HC11: An Intro, Software and Hardware Interfacing, Huang , Thompson-Delmar	1	
The Firmware Handbook, Ganssle, Newnes	1	
Digital Design Principles and Practices, Wakerly, Prentice-Hall	1	
The 80x86 IBM PC and Compatible Computers Volumes 1 and 2", Mazidi & Mazidi, Prentice-Hall	1	1
8088 & 8086 uP Prog., Interfacing, SW, HW & Apps & Lab Manual Triebel & Singh, Prentice-Hall		1
8051 uC and Embedded Sys. Mazidi, Prentice-Hall.		2
8051-Based Microcontrollers, Phillips Inc		1
The 8051 Microcontroller, MacKenzie, Merrill		1
Digital Designing with Programmable Logic Devices, Carter, Prentice-Hall		1
Software and Hardware Engineering: Motorola M68HC11, Cady, Oxford		1
Embedded C Programming with the ATMEL AVR, Barnett, Cox, & O'Cull, Delmar		1
Text by Instructor	1	1
No Text -Use Reference Manuals/Data Sheets	2	2
Total	**18***	**14***

* Three ECE and three ECET courses used two primary textbooks and both are listed

Language

Table 4 summarizes the programming languages used in these introductory uP/uC courses. The mix of languages is similar in both disciplines and it appears that an initial focus on assembly language is still preferred in most universities for the introductory course. This may be due to the depth of understanding of the physical structure and internal operation of uP/uC's required to learn and use assembly language. Use of assembly language with uP/uC's also requires students to study schematics and use a printed circuit development board or breadboard for interfacing devices. Thus, fundamental skills are developed that are useful in later studies involving computers and computerized systems. The capability and capacity of microcontrollers, in terms of memory and throughput is constantly increasing and there appears to be little use of assembly programming in industry. This is due to the time required to develop, troubleshoot, and maintain assembly language programs when compared to a "C" program. Generally, assembly language is only used when there is insufficient memory or another compelling reason not to use a higher level language. Higher level languages usually create much larger programs, in terms of lines of code, and are less efficient in memory usage. Based on this, it was somewhat surprising that "C" was not used in more introductory courses since it is apparently the language of choice for uC programming in industry. Another possible reason for the continued use of assembly language for introductory courses is that[4], "Assembly language is a must in DSP applications..." Two of the reasons for this statement are shown to be timing and data-type considerations for DSP chips in the EDN article[4]. This article also states that, while "C" compilers and development tools are improving, it is still necessary to read the intermediate assembly code for many DSP applications.

Table 4: ECE & ECET Languages

Language	**ECE #**	**ECET #**
Assembly	10	7
"C"	1	1
Assembly & "C"	3	2
HDL & "C"	1	
Assembly & VHDL		1

Hardware

Table 5 shows that 9 of the 15 courses in ECE and 8 of the 11 ECET courses use a development board. These printed-circuit boards usually have external interfacing devices such as LED's, LCD's, Keypads, temperature sensors, and serial interface devices included on the board. They also generally contain the uP/uC chip, a power supply connection, and a USB or other serial connection used for program downloading and other external communication. The use of a development board enables students to learn the software and how to interface the uP/uC with external devices without the laborious troubleshooting required when using breadboards. 3 ECE and 3 ECET courses use the Intel X86 processor built into most PC's. These courses generally do not use breadboards, but use interfacing devices such as the 82C55 Parallel Interface, or teach students how to interface the uP with built-in parallel, serial, and/or USB ports on the PC. The 3 ECE courses that use breadboards and discrete devices are quite varied and no general conclusion could be reached concerning course coverage.

Table 5: ECE & ECET Hardware

Hardware	**ECE # of courses**	**ECET # of courses**
Development Boards	9	8
Breadboards & Discrete Devices	3	0
PC & Interfacing Devices	3	3

Lab Exercises

Lab exercises were similar in both ECE and ECET courses as shown in Table 6 and generally focused on writing programs to interface and use various transducers and peripheral devices. As previously mentioned, the depth of theoretical coverage is a fundamental difference between ECE and ECET courses. This same basic difference exists between ECE and ECET lab exercises. Even though lab exercises in ECE and ECET may cover similar subject matter, one must look at individual requirements and the focus of the exercises to distinguish discipline specific characteristics. The many courses that also required students to complete a project were not specifically included in Table 6, although some portions of selected projects are shown as lab exercises.

Table 6: ECE & ECET Lab Exercises

Lab Exercises	**ECE**	**ECET**
I/O	All	All
ADC & DAC	All	All
Interrupts	Most	Most
Asynchronous Comm.	Many	Most
Keypad/Keyboard	Many	Most
PWM	Many	Many
Timers & Counters	Most	Most
Sensors	Most	Most
Motor Speed Control	Several	
Traffic Light Control	One	Two
FFT/FIR Filters	One	
Calculator	One	
Frequency Measurement.		One

Summary

The microprocessor/microcontroller industry is quite varied and the processors and languages used in ECE and ECET courses generally reflect faculty expertise and course and curriculum learning objectives. Most ECE introductory uP/uC courses are scheduled in the junior year while most ECET courses are scheduled in the sophomore year. A trend in some university ECE programs appears to be to move the generally popular, introductory uP/uC courses earlier in the curriculum, which may spur interest and increase retention. Microcontrollers were used in 18 of the 26 courses, while 7 courses used uP's including the Freestyle MPC555, which is referred to as a 32-bit uC. Only 3 ECET courses used the same textbook as an ECE course. A closer look at the textbooks should provide insight into the more how-to and hands-on nature of the ECET courses and the greater depth of theoretical understanding of fundamental uP/uC operation required in ECE curricula. The mix of programming languages, the use of development boards, and the general types of lab exercises performed were similar in both disciplines.

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1 http://www.freescale.com/ formerly Motorola Semiconductor
2 http://www.electronicstalk.com/news/ari/ari145.html
3 Peatman J, "Design with PIC Microcontrollers", Prentice-Hall, 1998
4 EDN.com, Dec 29, 2004: http://www.edn.com/article/CA56648.html

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Appendix: University/College Locations
(E=Engineering, T=Engineering Technology)