# Embedded Systems Education: Future Directions, Initiatives, and Cooperation

David Jeff Jackson and Paul Caspi

*Abstract*—**In this paper we present the summary of and results from the 2005 Workshop on Embedded Systems Education (WESE2005). This workshop was held in conjunction with EMSOFT 2005, the leading conference for research in embedded systems software. The workshop focused on presenting experiences in embedded systems and embedded software education. Workshop sessions included a diverse set of international presenters leading discussions on embedded systems curricula and content; teaching experiences; and labs and platforms used in embedded systems education. A summary panel discussion concluded the workshop.**

*Index Terms*—**embedded systems education.**

## I. INTRODUCTION

Embedded systems represent a major fraction of the digital systems market as indicated by the fact that embedded systems represent a key technology in the automotive, consumer electronics, industrial automation, military/aerospace, office automation, telecommunication and data-communication industries [1-3]. As much as 98% of all 32-bit microprocessors currently in use worldwide are used in embedded systems [4]. Thus, it is a very strategic domain from an economic point of view. However, most computer engineering programs teach programming and design skills that are appropriate for a general-purpose computer operating under control of a commercial operating system rather than for the more specialized embedded systems [5]. Moreover the field is fragmented into many application domains, e.g. aerospace, automotive, railways, telecommunications, consumer electronics, which all have their own design methods and philosophy.

Additionally, instruction in embedded systems can increase opportunities for breadth in a curriculum as these systems naturally involve hardware and software components that interface to various electrical, mechanical and chemical processes. Thus embedded systems education is an excellent example of an area of study that requires depth and rigor while maintaining breadth required for meeting emerging workforce and education needs of worldwide industry [6,7].

David Jeff Jackson is with The University of Alabama Department of Electrical and Computer Engineering, Tuscaloosa, AL 35487-0286 USA (phone: 205-348-2919; fax: 205-348-6959; e-mail: jjackson@eng.ua.edu).

Paul Caspi is with the French CNRS at Laboratoire VERIMAG, Gieres, France (e-mail: paul.caspi@imag.fr).

The rapid proliferation of embedded systems requires an increasing number of engineers trained in microcontroller-based systems, real-time concepts, hardware/software co-design, distributed processing, hardware-software integration, and system-level issues in embedded systems design. Instructional material is just beginning to appear in this area from around the world and the development of this focus area, associated instructional materials and evaluation materials will allow us to better train our students and hopefully help in bridging the methodological gaps that exist between this large variety of application fields.

## II. BACKGROUND AND WORKSHOP ORGANIZATION

It is in this spirit that we organized the first workshop on embedded system education associated with the 2005 EMSOFT embedded software conference [8]. This is one of the first workshops specifically devoted to systems and software and we believe this is an important field that deserves to be addressed. Two invited speakers from the University of California, Berkeley and the Royal Technology Institute of Stockholm discussed some of their most advanced experiences in embedded system and software education. Multiple sessions focusing on embedded systems curricula and content; teaching experiences; and labs and platforms used in embedded systems education were conducted during the workshop. The sessions gave matter to lively, animated and enriching discussions. The panel discussion that concluded the workshop allowed us to delve deeper into the subject and raise useful questions concerning future directions, initiatives and cooperation in developing robust embedded systems education programs and curricula.

The remainder of this paper is organized as follows. First, a summary of invited presentations is given. These presentations provide an international viewpoint of the state of embedded systems and address the need for a new education paradigm and a didactical perspective on embedded systems education. Second, embedded systems curricula and contents from selected international universities are presented. Third, a sample of teaching experiences is given. Finally, a presentation of labs and platforms for embedded systems education is given.

## III. INVITED PAPERS

In [9], Sangiovanni-Vincentelli and Pinto present guiding principals for the embedded systems teaching and research agenda at the University of California at Berkeley. The principal goal is to bring closer together the fields of system theory and computer science. Both graduate and undergraduate considerations are presented with an overview of the graduate curriculum and a detailed presentation of EECS249: Design and Embedded Systems: Models, Validation and Synthesis. Multidisciplinary courses in computer science, civil engineering and mechanical engineering are described.

A description of the undergraduate program is given with emphasis how embedded systems concepts are used to marry the physical and computational world and how students are educated in critical reasoning about modeling and abstraction. Understanding of mathematical models, their limitations and their power was a significant motivator for the development of much of the undergraduate curriculum. Laboratory experiences and future directions are also given.

Grimheden and Törngren [10] present embedded systems using a didactical approach together with some educational implications. The way embedded systems education was originally implemented at the department of machine design, mechatronics lab, at the Royal Institute of Technology (KTH) in Stockholm, Sweden is presented. Currently, embedded systems at KTH is treated as a subject within machine design, with a heavy focus on product development, development of intelligent products and a treatment of that subject is presented.

Embedded systems at KTH is taught as a case of the Conceive, Design, Implement and Operate (CDIO) initiative with a focus on the CDIO implementation being in the fourth and final year of the specialization in embedded systems. Laboratory exercises, results, and international collaboration with capstone design courses are also described.

## IV. EMBEDDED SYSTEMS CURRICULA AND CONTENTS

Example embedded systems curricula and contents are given by Pak [11], Yamamoto [12], Marwedel [13], and Muppala [14]. Pak describes how the Korean government has designed and driven the innovation of undergraduate curriculums to meet increasing industrial demand for quality IT experts in the computer-software field including embedded systems. A spiral model for curriculum development is described that includes requirement analysis, design, implementation and realization phases. Specialized field tracks and industry demand for these tracks are summarized. Finally, a demand driven curriculum for meeting these industry-determined skills is given.

Yamamoto describes an effort at Nagoya University involving an extension program on embedded software, called NEXCESS (Nagoya university EXtension Courses for Embedded Software Specialists) [12]. The goal of this program is the education of engineers in industry with financial support by the government. This continuing education program involves faculty members, practicing engineers and an advisory committee overseeing an eight course offering of introductory, intermediate and advanced courses in embedded systems. Course materials and a description of the program including results are presented.

Marwedel introduces a common introductory course for embedded system education at the University of Dortmund [13]. An emphasis of the course is putting the different areas of embedded system design into perspective while avoiding early over-specialization. The course is used for motivating students for attending more advanced theoretical courses. The content, the structure and the prerequisites of the course are described. Suggested follow on courses and experiences are also presented.

Muppala [14] describes experience with designing and offering a senior undergraduate course on Embedded Systems Software in the Department of Computer Science at the Hong Kong University of Science and Technology. Course topics, hands-on laboratory experiences and course projects are presented in detail. Finally, an analysis of the course, including student feedback is given.

## V. EMBEDDED SYSTEMS TEACHING EXPERIENCES

In [15], Weiss identifies the needs of a practical course in microcontroller programming at the Vienna University of Technology, with respect to course structure and grading. Solutions and experiences are discussed. Details are given with respect to high level course goals and different teaching techniques and their impact on different aspects of the course. Educational materials, course structure, lab organization, personnel, and grading issues are also described in detail.

Legourski describes a system for the automated testing of embedded software in undergraduate study exercises [16]. The paper describes a system that can carry out black-box tests to verify whether the embedded software running on a target system meets predefined requirements. The software is intended to minimize workload associated with grading software when a large number of students are enrolled in a course. A special meta-language is used to describe the correct behavior of the tested program.

## VI. EMBEDDED SYSTEMS LABS AND PLATFORMS

In [17], Edwards introduces experiences teaching an FPGA-based embedded systems class at Columbia University. This course requires students to learn low-level C programming and VHDL coding to design and implement an embedded systems project. Challenges faced by students include design complexity, learning interfaces and protocols, time management, and developing design team skills. Details are given concerning the course structure, laboratory, and design projects including audio- and video-based design examples. Student feedback and course evaluation data are also presented.

Ricks presents an evaluation of the VME architecture and its use in embedded systems education [18]. General characteristics of the VMEbus architecture are described and these are then related to aspects of embedded systems education included as components of the IEEE/ACM CE2004 computer engineering model curriculum. The evaluation is intended to identify the strengths and weaknesses of the VME architecture as a general-purpose embedded systems educational tool. Embedded systems topics and learning outcomes form the model curriculum are presented and the characteristics of the VME architecture are considered with respect to how well the architecture can be used to address the considered topics.

In describing a diverse set of hardware platforms, Salewski presents a general view of embedded systems in the way that it is always a programmable hardware platform (CPU based or reconfigurable hardware) which has to be programmed in a suitable programming language [19]. Various means of implementing embedded systems, including microcontrollers and programmable logic devices, are presented. Students are required to implement the same design using multiple platforms. A lab course and experiences are described. Student assessments of the effectiveness of using the various platforms are also given.

## VII. CONCLUSION

The panel session that concluded the workshop allowed the participants to summarize to results presented, address future directions for embedded systems education, suggest initiatives that might be undertaken to advance the field of embedded systems education, and suggest models of cooperation between members of the worldwide community whose interest is in embedded systems.

The observation was made that institutions worldwide share many of the same concerns with respect to embedded systems education. Some of these concerns involve appropriate course, curriculum, and laboratory development and proper experiences for students. It was also recognized that embedded systems education often develops in many different ways. Often the development begins in computer engineering or computer science disciplines. However, the embedded systems field is highly multidisciplinary and there are many instances where the development is from a mechatronic viewpoint. Also, there are often pronounced differences in embedded systems education between the United States, European, and Far East countries.

It was a consensus opinion that continued sharing of experiences through workshops, email distributions, seminars, and other dissemination mechanisms were critical. Initiatives that were suggested for continued growth in this field were formation of a subgroup that focuses on embedded systems education within SIGBED and continued workshops associated with the major conferences on embedded systems.

Finally, it was also a widely held viewpoint that embedded systems education as a field should continue to develop and formalize while maintaining rigor and formalism with respect to proper system design, test, and debug methodologies. This is especially true considering the number of embedded systems engineers that will be needed during the coming decades and the pervasiveness of embedded systems within the worldwide culture and that improved models of cooperation within the international embedded systems education community will be necessary to sustain this.

We feel this first workshop has been a great success. There are many things that remain to be done on the subject and there is room for significant improvements that will be the task of future editions of the workshop and our successors in their organization.

## ACKNOWLEDGMENT

We would like to acknowledge the efforts of the program committee for their insightful reviews and participation in making this a successful first workshop. We would also like to thank Dr. Wayne Wolf for extending the invitation to conduct this workshop and Dr. Walid Taha for his extremely valuable assistance as EMSOFT workshops chair.

## REFERENCES

[1] Turley, J., "The Two Percent Solution," Embedded Systems Programming, December 2002, www.embedded.com.
[2] Gannod, G. C., Golshani, F., Huey, B., Lee, Y. H., Panchanathan, S., and Pheanis, D., "A Consortium-based Model for the Development of a Concentration Track in Embedded Systems," 2002 Proceedings of the American Society for Engineering Education Annual Conference and Exposition, session 1532.
[3] Wolf, W., "Rethinking embedded microprocessor education," Proceedings of the 2001 American Society for Engineering Education Annual Conference and Exposition, Albuquerque, NM, 2001.
[4] Wolf, W., Madsen, J., "Embedded systems education for the future," Proceedings of the IEEE, 88(1), pp. 23-30, January 2000.
[5] www.computer.org/education/cc2001/.
[6] Neilsen, M. L., Lenhert, D. H., Mizuno, M., Singh, G., Zhang, N., and Gross, A. B., "An Interdisciplinary Curriculum on Real-Time Embedded Systems," 2002 Proceedings of the American Society for Engineering Education Annual Conference and Exposition, session 1526.
[7] Caspi, P., Sangiovanni-Vincentelli A. et al, "Guidelines for a Graduate Curriculum on Embedded Software and Systems," ACM Transactions Embedded Computing Systems, August 2005, to appear.
[8] www.emsoft.org
[9] A. L. Sangiovanni-Vincentelli and A. Pinto, "Embedded System Education: A New Paradigm for Engineering Schools?," Proceedings of the 2005 Workshop on Embedded Systems Education, pp. 1-10, September 22, 2005.
[10] M. Grimheden and M. Törngren, "How should embedded systems be taught? Experiences and snapshots from Swedish higher engineering education," Proceedings of the 2005 Workshop on Embedded Systems Education, pp. 30-35, September 22, 2005.
[11] S. Pak, E. Rho, J. Chang, and M. Kim, "Demand-Driven Curriculum for Embedded System Software in Korea," Proceedings of the 2005 Workshop on Embedded Systems Education, pp. 11-15, September 22, 2005.
[12] M. Yamamoto, H. Tomiyama, H. Takada, K. Agusa, K. Mase, N. Kawaguchi, S. Honda and N. Kaneko, "NEXCESS: Nagoya University Extension Courses for Embedded Software Specialists," Proceedings of the 2005 Workshop on Embedded Systems Education, pp. 16-20, September 22, 2005.

[13] P. Marwedel, "Towards laying common grounds for embedded system design education," Proceedings of the 2005 Workshop on Embedded Systems Education, pp. 21-24, September 22, 2005.
[14] J. Muppala, "Experience with an Embedded Systems Software Course," Proceedings of the 2005 Workshop on Embedded Systems Education, pp. 25-29, September 22, 2005.
[15] B. Weiss, G. Gridling, and M. Proski, "A Case Study in Efficient Microcontroller Education," Proceedings of the 2005 Workshop on Embedded Systems Education, pp. 36-43, September 22, 2005.
[16] V. Legourski, C. Trodhandl, and B. Weiss, "A System for Automatic Testing of Embedded Software in Undergraduate Study Exercises," Proceedings of the 2005 Workshop on Embedded Systems Education, pp. 44-51, September 22, 2005.
[17] S. Edwards, "Experiences Teaching an FPGA-based Embedded Systems Class," Proceedings of the 2005 Workshop on Embedded Systems Education, pp. 52-58, September 22, 2005.
[18] K. Ricks, D. J. Jackson, and W. A. Stapleton, "An Evaluation of the VME Architecture for Use in Embedded Systems Education," Proceedings of the 2005 Workshop on Embedded Systems Education, pp. 59-65, September 22, 2005.
[19] F. Salewski, D. Wilking, and S. Kowalewski, "Diverse Hardware Platforms in Embedded Systems Lab Courses: A Way to Teach the Differences," Proceedings of the 2005 Workshop on Embedded Systems Education, pp. 66-70, September 22, 2005.