The Embedded Software Consortium of Taiwan - A Progress Report of Educational Activities

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Abstract

To meet the challenges brought by recent advancement on semiconductor manufacturing technology to develop system-on-chip (SoC) techniques, the Ministry of Education (MOE) of Taiwan has been running the VLSI Circuits and Systems Education Program since 1996. This program is currently at its third phase of revision, which starts at 2006 and ends at 2010. The Embedded Software (ESW) Consortium is one of the 8 domain-specific, inter-collegiate consortia funded by the MOE under this program. The goal of ESW is to address the challenges of embedded software development for SoC systems. This paper first introduces the VLSI Circuits and Systems Education Program. The organization and activities of ESW is described next. Finally, we present an execution summary of ESW in the past three years.

Keywords: embedded software, integrated circuit design, educational programs

1 Introduction

The continuous advancement in nanometer semiconductor manufacturing, integrated circuit (IC) design, and system-on-chip (SoC) techniques has made practical to place on a single chip a complete computing system. The key to the success in the development of a SoC industry depends on a large number of well-educated engineers on IC design, embedded software, and system integration, in addition to supporting personnel in business, management, and law. The Ministry of Education (MOE) of Taiwan has been running the VLSI Circuits and Systems Education (CSE) Program since 1996. The program is to provide our local semiconductor industry with its needed technology and engineers, both in quality and quantity. Phase I of this program began in 1996 and ended at 2000. The objective of this phase was primarily to establish fundamental IC design environments at universities in Taiwan to promote IC design research and new educational curricula. Phase II of this program continued at 2001 and ended at 2005. To make its decision process and execution efficiently, Phase II adopted a top-down approach by forming six domain-specific, inter-collegiate consortia. This consortium architecture is further expanded into eight consortia in Phase III that begins at 2006 and will end at 2010.

The ESW Consortium, established in February 2004, is the latest consortium founded by the MOE under the VLSI CSE Program to address the challenges of embedded software development for SoC systems. A SoC system, different from a traditional board-level system, places on a single chip all system components, including one or more microprocessors, cache, memory, and communication modules. Traditional board-level system software cannot fully utilize the resources of a SoC system if directly ported. In addition, these software are often developed to support a wide variety of platforms. In contrast, a SoC system software is mostly designed for a specific platform. The ESW Consortium intends to achieve its goal by integrating resources from the government of Taiwan, domestic and foreign academic societies, and local semiconductor industry. The programs of ESW include academic and industrial forums, international collaborations, student activities and promotion, and a new embedded software curriculum.

The VLSI CSE program of Taiwan and the ESW Consortium was formally introduced in [1]. We described the Phase II of the CSE program, the supply-demand analysis of the local semiconductor industry, the six-consortia architecture, and an execution summary of ESW in 2004. In this paper, we update the recent progress of the CSE program and the ESW Consortium. We first briefly describe the Phase III program and the eight-consortia architecture. We next provide an ESW execution summary in 2006. The execution report focuses on the 2006 Embedded Software Design Contest (ESDC) and the ESW hands-on lab map. The ESDC, hosted by the MOE of Taiwan, is an annual event in which students compete with their constructed embedded systems in both creativity and advanced technology. This event has been used by ESW to evaluate and demonstrate the performance of their reformed ESW curriculum. A number of hands-on labs are produced during the development of the ESW curriculum. We started a new project in 2005 to classify and integrate all these labs into a comprehensive map of labs. This map serves both as a handbook for professors to select labs suitable to their courses and as a guide for ESW to advance its curriculum. Finally, due to the space limit, we skip the update on the ESW curriculum that includes more courses than its shape in 2004.

The rest of the paper is structured as follows. Section 2 introduces the Phase III of the CSE program. Section 3 presents the latest results of ESDC. Section 4 describes our efforts in constructing a comprehensive map of hands-on labs. An execution summary of other ESW activities is reported in Section 5. Finally, Section 6 concludes this paper.

2 The VLSI CSE Program

The VLSI CSE program was initiated in 1996 by a group of senior professors and industry leaders who envisioned that high-quality IC design engineers will be essential to its local semiconductor industry. The execution of the VLSI CSE program can be divided into three phases. The Phase I executed from July 1996 to December 2000. Its primary goal was to establish advanced VLSI design curricula in around 20 research-oriented universities. The Phase II executed from January 2001 to December 2005. Recognizing that SoC is a must-have technology, Phase II took an aggressive top-down approach to form a six-consortia architecture. A top-level office named the SOC Consortium [6] hosts all cross-consortia activities while each sub-level consortium manages its own domain-specific events. Along with the execution of the CSE program, the MOE founded the Chip Implementation Center [3] that offers its service of manufacturing chips designed by students. Total funding for Phase I and Phase II are US$3M and US$15M, respectively. In addition, there are around 1,000 chips fabricated and tested by the CIC each year.

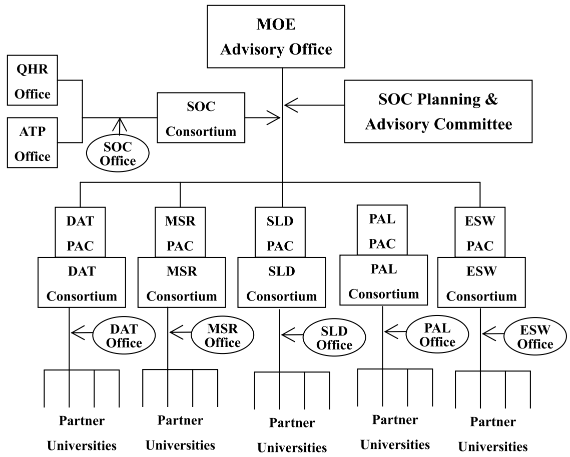

Figure 1: The eight-consortium architecture

Phase III starts at January 2006 and will end at December 2010. Its purposes are two folds: to continue what we have achieved and to make our results visible to international communities. To adapt to its fast growth in scope and impact, Phase III expands its consortium architecture to an eight-consortia one, as shown in Figure 1. There are four levels of administrations. The advisory office of the MOE defines general guidelines and approves budget planning. The SOC Consortium coordinates and monitors activities among all consortia. The DAT (Design Automation & Testing), MSR (Mixed Signal & Radio Frequency), SLD (System-Level Design), PAL (Prototyping Application & Layout), and ESW (Embedded Software) are domain-specific consortia, each of which has a group of partner universities to define its curriculum and activities. Both the QHR (Quality Human Resources) and ATP (Advanced Teaching Platform) consortia are added in Phase III to coordinate cross-consortia activities. QHR hosts all programming contests, invites international speakers, and sponsors cross-consortia activities. These contests are the IC Design Contest, the Silicon IP Authoring Contest, the EDA Programming Contest, and the Embedded Software Design Contest. Each contest is held annually to provide a platform for student competition and performance evaluation. ATP promotes new curricula developed in all consortia by providing the financial support needed to adopt a new curriculum. The total funding for Phase III is increased to US$20M proximately.

The organization of the ESW Consortium remains much the same as we reported in [1]. The ESW office is currently based at National Tsing Hua University and chaired by Professor Chung-Ta King. Professor Tai-Yi Huang serves as the executive secretary since ESW was first founded in February 2004. Its planning and execution is supervised by an independent Planning and Advisory Committee (PAC) consisting of one senior researcher and four industry leaders. Its programs are classified into five main categories: embedded software forums, student activities and promotion, international cooperation programs, industrial strategic forums, and the embedded software curriculum. There are totally 22 partner universities of which 46 professors are involved in planning and executing ESW activities. All information and promotions are published and accessible at its official web site [5].

3 The Embedded Software Design Contest

The annual ESDC event is sponsored by the MOE and organized by the QHR Consortium. The first ESDC was held in 2003 for the purpose of demonstrating the capability of embedded software design and development. Since 2006, ESDC is organized by Professors Tei-Wei Kuo and Shih-Hao Hung at National Taiwan University. A full ESDC schedule spans over four months. Each team can have no more than three students, with no restriction on undergraduate and graduate students. Each team registers by submitting a proposal describing its project scope and working list. Each proposal is reviewed by the program committee to provide early feedback and suggestions. There is a period of two months for students to complete their working list. A final report is due two weeks prior to the final on-site demonstration. The score of a project is based on its final report (30%), its oral presentation (20%), and the system demonstration (50%). We evaluate a project by its software originality and creativity, soundness of software engineering, and system performance, depending on which category of competition it is registered for. A winning team is financed as an award to attend one international conference related to embedded system and software.

Figure 2 shows the total number of registered teams from 2003 to 2006. There were only 30 teams

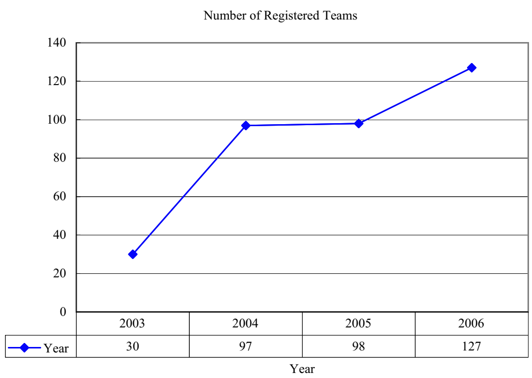

Figure 2: The number of registered teams

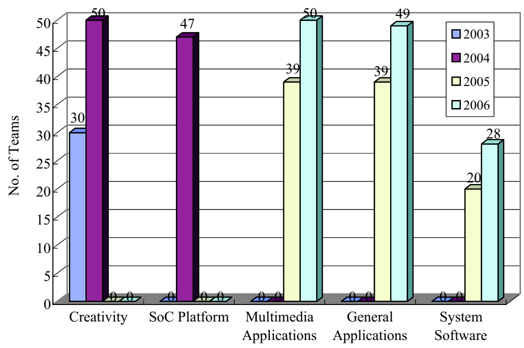

Figure 3: The number of teams in each category

in 2003 when ESDC first took place. This number increases significantly to 97 in 2004 when the ESW Consortium was founded. As the ESW curriculum continues to develop and be deployed in more universities and colleges of technology, this number reaches a record-high of 127 in 2006.

In 2003, there is only one contest category of Creativity. In 2004, ESDC added a new category of SoC Platforms to attract more hardware-centric students. Each team is allowed to register only in one category. Figure 3 shows the number of registered teams in each category. A team registered for Creativity has an open choice of embedded platforms, and their work was evaluated on its software originality and creativity. A team registered for SoC Platforms can only work on a list of designated platforms and was evaluated on its software efforts in design tradeoffs and resource optimizations. Starting in 2005, we made ESDC as a thee-category contest based on areas of applications. The category of Multimedia Applications is there in response to the ever-growing inter-

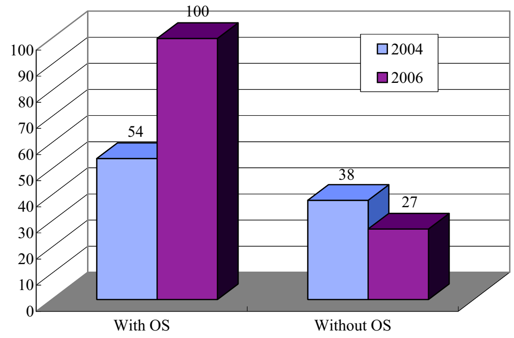

Figure 4: The types of embedded systems

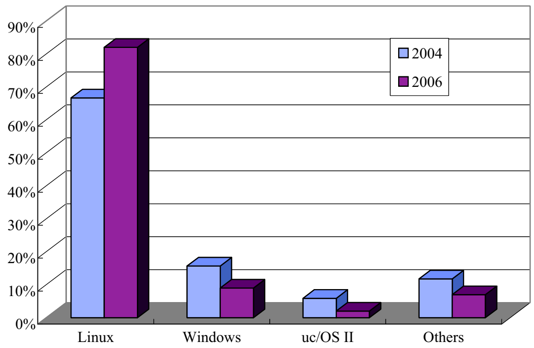

Figure 5: Classification by operating systems

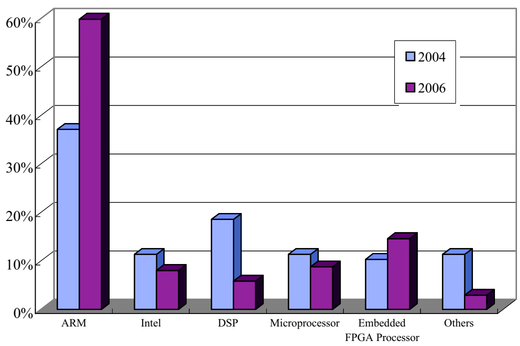

Figure 6: Classification by processors

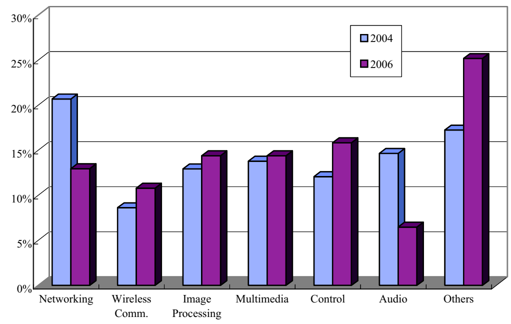

Figure 7: Classification by topics

ests and ideas in multimedia. The category of General Applications provides the arena for students to showcase their creativeness and skills without limit of topics and platforms. Finally, the category of System Software is designed to encourage the research and development efforts in embedded system software such as the operating systems, middleware, compilers, and device drivers.

Figure 4 shows the number of projects that are managed by an operating system or by a mere loop scheduler in 2004 and 2006. It is an interesting observation that more students choose to work with an operating system to implement complex applications, manage real-time tasks, and handle sophisticated embedded platforms. It is also an indication of stronger competition and more advanced skills of participated students from 2004 to 2006. Furthermore, Figure 5 breaks down the types of operating systems adopted by students. In 2006, 82% of participated teams chose Linux, higher than the 67% adoption in 2004. This shows the dominance of Linux in our academic society of embedded software. This dominance results from the flexibility and availability of Linux-based development kits and strong educational and industrial support behind Linux.

Figure 6 shows the classification by processors. The percentage of ARM-based processors increases from 37% in 2004 to 60% in 2006, well demonstrating the dominance of ARM-based processors in the local market. There are more network and multimedia applications developed with FPGA prototyping in 2006 while there are less projects utilizing DSP processors. If we classify projects by user-mode and kernel-mode, about 80% of projects are user-mode applications while 20% of them are kernel-based modules including operating systems, device drivers, and system-related tools. We noticed this distribution since 2004 and have made a strong effort to encourage and promote the development of kernel-level software. In fact, the category of System Software is created to address this need. The improvement of technology and skills demonstrated by projects in this category is considered superior to what we observed in the other two categories.

Figure 7 further classifies user-mode projects by domains of applications. Generally speaking, net-

Year	Category	Project Topics
2005	Multimedia Applications	An integrated design of OSGi gateway and DVB interactive platform
		An intelligent digital camera with adjustable power and performance
	General Applications	e-Housekeeper
		Realization of human-robot interaction via vision capturing
	System Software	Software-less SCAN sensor
		A memory protection mechanism in an embedded OS
2006	Multimedia Applications	An intelligent guide for emergency fire exit
		Embedded H.264 video streams
	General Applications	3G entertainment - Good, Great, General
	System Software	A low-power real-time operating system
		A fast multi-core simulation framework with synchronization IP

Table 1: The topics of winners in each contest category

working (including wired and wireless) applications and multimedia (including audio and image processing) applications are favored. The category of Others includes projects in the domain of security, health, and kernel-level topics. Finally, Table 1 lists the winners in each contest category of 2005 and 2006. Most winners of 2003 and 2004, available in [1], use multimedia applications to demonstrate their embedded software. On the other hand, many winners in 2005 and 2006 developed embedded systems that efficiently integrate system resources of hardware and software. The latter winner certainly requires more understanding and training on embedded software. This trend is again considered as an indication to the success of the ESW curriculum.

In summary, after four years of strong competition, our experience from ESDC confirms that this government-sponsored annual event has become a great force in promoting embedded software research and educational programs. In addition, it also helps to reveal the strength and weakness in our ESW curriculum. The program committee of ESDC continues to observe increased quality and complexity in the proposed projects. An active item of future work is to encourage more kernel-level embedded software and increase the number of teams in System Software.

4 The Hands-on Lab Map

The development of the ESW curriculum is to provide a set of lab-centric courses. Each course was first designed by a group of four professors and was later adopted by interested universities. An adoption of a course receives financial support by the MOE to setup a lab for its purpose. In return, each adoption is required to provide at least 4 sets of hands-on labs at its final review. The ESW office has collected 80 labs from 8 different courses. We label each lab with an index of *CourseNum-UnivNum-LabNum*. For example, a lab module with a label of 002-01-03 indicates that it is the third lab module developed by the first university for the second course.

For ease of reference, we classify these 80 modules by three categories: platforms, operating systems, and tool chains. There are currently 14 embedded platforms and 5 different operating systems. Due to the space limit, we only give out partial information of each classification table in the following. The complete tables are accessible at the official web site of ESW [5].

4.1 Classification by Platforms

Table 2 gives part of our classification by platforms. The first column lists the platforms used in each set of labs. The second column lists the operating system used by these labs. An empty slot of this column indicates that no operating system is installed. In contrast, if an operating system is ported as a lab, we provide its label for reference. The third column gives the topic of this lab and the fourth column gives its label. This table helps ESW professors to easily identify the platform suitable to their teaching needs. In addition, it serves as a map to develop unavailable modules for a selected platform, avoiding redundant efforts.

4.2 Classification by OS

There are 5 different operating systems used among all lab modules. Figure 8 shows the name of these operating systems and the number of labs installed with each operating system. Linux-based operating systems are strongly favored by these hands-on labs. Table 3 gives part of our classification by operating systems. The first column shows the name of the

Platform	OS	Topic	Label
Creator S3C2410	Linux 2.4 [001-02-02]	LCD Display	[001-02-01]
		MP3 Player	[001-02-03]
		RT-OS module FireLinux	[001-02-04]
NET-Start!W3001 ARM S3C4510B	uClinux 2.0 [001-03-04]	Bootloader	[001-03-03]
		Switch and 7-segment	[001-03-05]
		Interrupt Handlers and Time Delay	[001-03-06]
		DMA	[001-03-07]
	uC/OS [001-03-08]	Scheduler: Priority-inversion Issue	[001-03-09]

Table 2: The classification of labs by platforms

OS	Platform	Topic	Label
Linux	Creator S3C2410	Porting Linux 2.4	[001-02-02]
		MP3 Player	[001-02-03]
		RT-OS Module FireLinux	[001-02-04]
	TI OMAP 5910	Porting Linux 2.4	[001-04-01]
		IPC (Share Memory & Semaphore)	[001-04-01]
		PThread Programming	[001-04-01]
		Embedded GUI Programming	[001-04-01]
		Networked Digital Camera	[001-04-01]
uClinux	NET-Start!W3001 ARM S3C4510B	Poring uClinux 2.0	[001-03-04]
		Bootloader	[001-03-03]
		Switch and 7-segment	[001-03-05]
		Interrupt Handlers and Time Delay	[001-03-06]
		DMA	[001-03-07]

Table 3: The classification of labs by operating systems

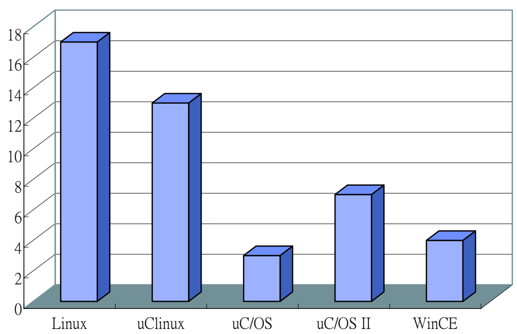

Figure 8: The number of labs with each OS

Topic	Label
ARM Development Suite	[001-03-01]
	[001-03-02]
	[001-07]
	[001-08]
ARM SDT	[001-05]
Hitool	[001-10-02]
	[003-01-01]
ARM GCC Cross-compiler	[002-01-01]
	[003-01-01]

Table 4: The classification by tool chains

operating system and the second column shows the platform. The third and the fourth columns show the topic of a lab and its label. By this table, an interested professor can easily find out the topics of labs and platforms for her favored operating system. Similarly, a new course on embedded operating systems or related topics can enhance this table by developing unavailable lab modules.

4.3 Classification by Tool Chains

One major category of courses in the ESW curriculum is to develop tool chains for embedded platforms. These tool chains are mainly compilers and debuggers. There are totally 16 labs related to the development of tool chains. We classify these labs by its developed tool. Table 4 gives partial information about this classification.

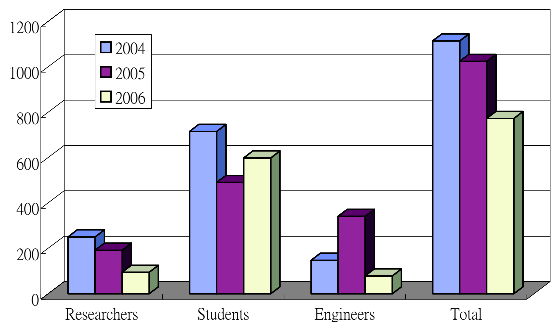

Figure 9: The attendance summary report

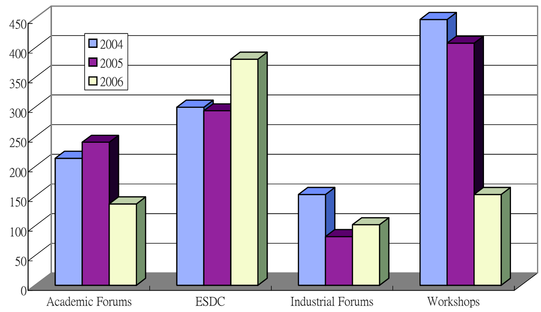

Figure 10: The attendance report by events

5 Execution Summary

Figure 9 shows the attendance report of ESW activities in the past three years. There are totally 1115, 1025, and 773 persons in 2004, 2005, and 2006, respectively. We further break down this number by two different categories. Figure 9 also lists the attendance by roles: academic researchers, students, and industrial engineers. On the other hand, Figure 10 breaks down this number by events: academic forums, ESDC, industrial forums, short courses or workshops. In the following, we analyze this data by events and show some interesting observations. Our comparison mainly focuses between 2004 and 2005. Because the calendar of 2006 is still in its early July dates, no direct comparison will be made.

5.1 Academic Forums

We held four academic forms in both 2004 and 2005. The number of academic forums will be reduced to 3 in 2006 and each forum will have a limit of 40 persons to foster more focused discussions. The attendance increases from 214 in 2004 to 241 in 2005. There are two reasons behind this increase. First, we were only exploring topics when ESW was first founded in 2004. When entering 2005, we had better ideas about what will interest academic researchers. The selection of topics is therefore more customer-oriented. The topics of the forums in 2005 are "Quality of Services and Care for the Elderly", "Building Structurally Stable Embedded Software", "Compilers and Software Development Toolchains for Embedded Systems", and "The Promotion of Embedded Software Research and Education in Taiwan". The other reason of having a better attendance is to co-locate a forum with a short course or a workshop. This strategy proves to be successful for both forums and workshops since an interested audience can attend two events in one trip.

5.2 International Programs

In 2004, we executed the international cooperation program by inviting renowned international scholars to Taiwan to give a short course or a tutorial and exchange research ideas with local researchers. In 2005, we added one more item by sponsoring researchers to attend foreign events such as an international conference or an education program held by an academic institute or a company. We extend this vision in 2006 to actively participate in international activities of embedded software research or education. In fact, this submission, along with other submissions of ESW, to this workshop is part of this effort. At the invitation of international scholars, we invited Professor Lui Sha [4] from the University of Illinois at Urbana-Champaign to talk about the construction of reliable and stable embedded software in September 2005. We also invited Dr. Stephen Kent [2] from BBN Technologies to give a short course about the issues, practices, challenges, and opportunities of VoIP security in July 2006.

5.3 Industrial Forums

The industrial forums of 2004 addressed on subjects that interest both academic researchers and industrial engineers. Starting in 2005, we executed industrial forums to discuss more industrial-focused subjects. As a result, less researchers attended these forums while more engineers were attracted to participate. We considered it a positive change and continue to execute likely in 2006. The forums of 2005 featured two panel discussions, one on the subject of providing the embedded software engineers needed by industry and another one on the subject of constructing profit-oriented business models. We held one industrial forum so far in 2006. This forum featured a panel discussion of research and development of turn-key technology in embedded software.

5.4 Short Courses and Workshops

To promote ESW events and attract more audience, we co-located academic forums with a short course in 2005. This short course presents a 6-hour content describing the bootstrapping process of Linux, the $O(1)$ scheduler introduced in 2.6, and a couple of hands-on lab to construct a multi-tasking embedded operating system. This short course was held three times, each of which drew more than 100 students and engineers to attend. The success of this short course and its high attendance encourages us to bring together multiple events of similar audience in 2006. In addition, we also held one workshop during the period of ESDC to provide the training required for platform adoption as well as share some successful stories from previous ESDC winners.

The ESW curriculum now consists of 12 courses, 9 of which completed its design in 2005 and another 3 of which were newly added in 2006. The courses that are completed by 2005 have been adopted by 11 universities already. To introduce and promote these courses, we hold at least 2 workshops each year to briefly go over the content and structure of each course. These workshops also provide a platform for interested professors to exchange their teaching experience. In 2006, we further expand this effort to have an overview workshop of all courses and a lab-centric workshop for each course. All these workshops are planned and will be held in August 2006. Finally, the ESW curriculum for technical colleges is currently under development. It is expected to be ready for adoption by September 2006.

6 Conclusions

The MOE of Taiwan has been running this VLSI CSE program since 1996, in order to provide well-trained students both in quality and quantity for its local semiconductor industry. Over the past 10 years, the previous two phases of the CSE program have successfully achieved its educational goal. This program has made Taiwan stayed in a leading role in many sectors of the semiconductor industry. The ESW Consortium, the last consortium founded by the MOE during Phase II, is to address challenges and opportunities in embedded software for SoC systems. Starting 2006, the CSE program enters its third phase of revision. The importance of cultivating talents for embedded software is commonly recognized by senior researchers and industrial leaders in a number of meetings. Accordingly, more resources will be placed on the ESW Consortium during Phase III.

ESW has created a series of events to promote both research and educational reforms of embedded software. These events include academic forums, international collaboration, industrial forms, and student activities. The annual ESDC event has been used to demonstrate and evaluate the execution of ESW. The number of participated teams increases each year and reaches a record-high in 2006. Furthermore, the quality of code developed by the winners is also better than ever. To organize all hands-on labs and make easy future planning, we create a map of labs by classifying all labs by platforms, operating systems, and tool chains. The future work is to continue our efforts in providing high-quality education for more students. Also, we will promote our results in international communities and share our experience.

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