Developing Next-Generation Engineers – IMPACTS

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ABSTRACT

In the development of remote labs and virtual engineering tools the focus has rightly been on the technical challenges to be overcome to provide useful and usable tools and experimentation. However, the utilization of such facilities in educational settings is not simply a case of making students and faculty aware of their existence. In fact, there are significant pedagogical issues in the blending of remote and virtual facilities with cohort and location-based teaching and learning, and a number of research findings have highlighted student issues with both traditional teaching methods and the use of predominantly on-line materials. The authors have considerable experience in the development, production and use of eLearning materials in academic and industrial environments, and in tool virtualization and remote labs, and here propose a model for a distributed Masters program that supports students on a location-neutral basis utilizing online eLearning materials, virtual tools and remote lab facilities, combined with location-specific specialist teaching and learning facilities. The program described is already in operation between three European Universities, with the intention to expand both within Europe and beyond, utilizing the Erasmus Mundus scheme. The program is based on a constructivist pedagogic model that demands considerable independence of study and research on the part of the students, within a rich environment of high-quality specialist materials offered in a wide variety of modes. The authors believe that this approach optimizes the benefits of individual academic specialization in research and teaching, combined with effective use of eLearning materials, remote labs and virtual tools in a distributed environment, and thereby addresses a number of the issues identified from the research while also offering a high quality program to educate and develop next generation Engineers.

I. BACKGROUND

The development of new models, methods and tools to support distance and remote learning, in particular asynchronous learning environments and "Virtual labs and classrooms", has been significant over the last ten years. During this period many new standards have been defined, with those related to learning objects, such as IEEE LOM and IMS, having a major influence on this development. The authors have been involved in a number of projects and initiatives during this period that have contributed to the body of knowledge, most notably ASTEP [1][2] and MARVEL [3], and they have also produced a number of virtual, online and remote-use tools within these and other projects.

The known advantages of the constructivist approach to student learning, building structures that concentrate on the student developing and constructing their own learning with faculty and environmental support reducing as student experience and skill levels grow, are increasingly seen as most desirable in new course development. These build on the early work of Vygotsky [4], Piaget [5] and Bruner [6] and seek to develop the concept of cognitive apprenticeship [7][8]. Initial lessons in the development of such an approach for remote tutoring in the MANTCHI project [9] have been combined by the authors with the outcomes of a recent comparative study of models of support for lifelong learning [10], in developing a new model for a distributed Masters program.

However, if this model were to be focused purely as an online model, the established history of online courses does present issues in completion rates, as the dropout rate in online courses tends to be higher than with traditional education. A study by Arbaugh[11] found that as learners become involved in more online courses, their perception of learning changes little but there is a significant change in their satisfaction with the online format of course delivery. This is further supported by findings from the ASTEP project, where learners in workplace learning environments identified a preference for online practical skills-based training in the workplace, but for a separate classroom-based environment for theoretical, knowledge-based learning, leading to a significant change in the focus of the environment developed for that project [12].

On the other hand, recent studies of traditional engineering teaching in Universities and Technical Colleges have seriously criticised both traditional teaching models and the balance of techniques utilised [13][14]. These studies have focused on the significant benefits of tutorials, lab-based activities and practical projects over lectures and non-reified theoretical abstraction. The empirical evidence for these conclusions is based on student and graduate responses on the effectiveness of the different approaches for individual learning.

From the foregoing, the authors identified the need to develop a model for a distributed Masters program that offers an appropriate mix or *blend* of online, virtual, classroom and lab-based activities. Within the model the focus should be on supporting the individual development and construction of learning by the students, within a rich environment of high-quality specialist materials, offered in both physical synchronous and virtual synchronous and asynchronous modes, through a range of multimodal interfaces [15]. Consideration should be given to the utilisation of novel, but evidentially successful, technologies such as gaming environments [16] combined with successful traditional classroom-based, virtual and remote tools, techniques and technologies. Within such a model, the expertise available from each partner should be utilised to best effect to provide students with the opportunity to gain best possible experience. The outcomes of such a model should be next generation computer scientists and engineers, capable learners with a broad experience of utilising remote, virtual and local learning resources, a strong understanding of their own learning model and requirements, and a commitment to lifelong learning.

II. The IMPACTS Model

IMPACTS (International Masters Program in Advanced Computing Technologies and Systems) is a Bologna-compliant, 4 semester Master of Science distributed program, currently based on three European University partners – Buskerud University College in Kongsberg, Norway; The University of Porto, Portugal; and The University of Abertay Dundee, United Kingdom. The intention is to grow the consortium of partners, and there are already three other European partner Universities lined up to join the consortium. Additionally, the project will seek EU Erasmus Mundus support in due course to permit the addition of non-European partners, and there are already five potential partners, from four countries in Latin America, seeking to join the consortium.

Students are recruited on the basis of having completed a three year undergraduate degree in Computer Science, Software Engineering, Electronic Engineering or a similar degree with significant components in Programming, Mathematics and Abstract Design, to a threshold standard. Each semester contributes 30 ECTS (European Credit Transfer Scheme) credits to the student transcript, so students can take semesters from the course and use the credits towards other qualifications, and each semester offers an outcome certification, based on credit accumulation, for students. The first semester offers students a set of common core subjects, the materials having been developed and delivered online, in English, to ensure a relatively common experience for all students. Each student will follow this semester at their home institution, with the credit level for this module being set at SCQF level 10 (Scottish Credit and Qualifications Framework [17]), immediately sub-Masters level, on the basis of bringing students from a variety of different backgrounds to a common level of understanding of the core. There is a progression requirement at the end of this semester, based on the students producing individual research reports demonstrating both individual research capability and understanding of core concepts and research methodology. The remaining three semesters are set at SCQF level 11, Masters level, returning 90 ECTS credits for students successfully completing the program. For the second and third semesters, the students will follow two of the three programs of specialist expertise on offer at each of the partners, again taught in English – Embedded Systems/Realtime Programming at Buskerud, Configurable Computing at Porto, and Smart Systems at Abertay. In their final semester the students will undertake an individual dissertation project based at their home institution but utilising online and remote support from the other partner institutions as relevant. Degrees are awarded by the home institutions, ratified by a Coordinating Committee, and described by a European Diploma Supplement.

III. Embedded Systems/Realtime Programming

The Embedded Systems/Realtime Programming semester at Buskerud University College focuses on emerging technologies within this field of study. The last few years have seen the introduction of object-oriented technology being used more and more in embedded system design. Modelling using objects enables hardware and software co-design expressed in UML. This has led to new development processes where the system is modelled using platform independent object models that are later transformed into software using an object oriented language like C++ or Java, and into hardware using System C. The hardware may end up as FPGA code and the software may eventually be executed by a soft core processor also situated in the same FPGA as the rest of the system. The boundaries between hardware and software are fading and the methodology used in their development is converging.

Modelling using UML [18] has come a long way since the introduction of UML in 1997. The language has matured and new flavours or profiles have emerged. In our course we introduce the students to the UML Real Time profile. The real time profile for UML is an OMG standard that utilizes the extension mechanisms built into standard UML to enrich its expressive powers for use in real time and embedded systems. Using object oriented methodology in hardware design has come a long way and at Buskerud University College we are using System C as our object oriented language for hardware development.

Efficient tools are already available from a number of vendors that will ease the development of UML based models. Most current tools are also capable of generating code in a number of languages from the models and they are capable of reverse engineering of existing code to generate some of the modelling elements. It is expected that these capabilities will improve and be extended in the near future.

Programming using objects often brings us to a situation where we are faced with a problem we somehow feel we have encountered before. Recognizing and describing solutions to recurring problems is today referred to as patterns [19]. In the world of real time programming a number of useful patterns have been identified and described. Transforming our initial models using well-known patterns helps us develop efficient and robust architectures for our real time designs. Some modern tools support the use of patterns by offering built in pattern libraries.

Teaching the students to work at a higher abstraction level using object oriented models and UML is a challenge and takes time. At Buskerud University College both hardware and software undergraduates are introduced to objects and UML during the first two years. Students are encouraged to develop technology neutral models that will later be implemented in hardware and software. This increases their ability to understand each other and thus breaks down the traditional boundaries between hardware and software communities. This we feel is crucial for the students abilities to design tomorrow's complex real time and embedded systems. A similar approach is adopted in working with the students on the IMPACTS program, although they will already have developed expertise working at a higher abstraction level in their own undergraduate degrees and in following the core first semester.

In the last few years we have seen the emergence of multi core processors. This will allow extended use of parallelism in our designs. The transition from sequential programming to parallel programming is non-trivial and will require radical changes to curricula within this field of study. Thread programming, synchronization and administration of threads are but some of the challenges the next generation of engineers have to master.

IV. Reconfigurable Computing

Shrinking nanometric technologies enable single-chip implementation of high complexity systems that require unprecedented flexibility and reliability. Particularly in the case of mission-critical systems, where cost is not the main driving factor, the implementation technologies should support on-the-fly reconfiguration and fault tolerance features. These requirements can only be met by the latest generations of reconfigurable hardware, supporting partial and dynamic reconfiguration. Current reconfigurable hardware technologies also allow partial dynamic reconfiguration, enabling non-intrusive function swapping in real-time. Several applications may therefore share the same device floor space, being implemented and removed according to demand, without disturbing each other while the configuration memory is reprogrammed. The virtual hardware vision, where a finite number of physical resources enable the implementation of an unlimited number of applications, is nowadays reduced to the problem of finding an appropriate running sequence for the applications that share the same reconfigurable device. However, as integration density increases, every new generation of devices becomes more vulnerable to power fluctuations, electromagnetic interference and radiation. Typical problems such as single-event upsets, multi-bit upsets, single-event transients, etc. make such systems at risk and demand improved design methods in order to ensure reliable system operation.

The scenario presented above explains the rationale for including a Reconfigurable Computing area in the IMPACTS curricular structure. Being responsible for the curricular contents in this area, FEUP (Faculty of Engineering at University of Porto) delivers a set of course modules addressing Hardware Development Methods and Test, Signal Processing Architectures and Applications, Reconfigurable Computing Systems, Dynamic Reconfiguration and Resource Management, and Dependability and Fault Tolerance. The students are encouraged to pursue an exploratory model of learning, where work assignments associated to research projects are combined with standard lectures and e-learning contents.

V. Smart Systems

Smart Systems represents the convergence of a range of technologies developed in Computer Science, Electronic Engineering, Communications Engineering and Networking over the past twenty years. The development of micro and nano technologies, but most importantly the affordability of many of these technologies, offers the opportunity to move away from existing concepts of networked devices within traditional topologies, to much more flexible, heterogeneous and complex environments. The key feature of generic Smart Systems is the integration of technologies from network systems, Internet services, artificial intelligence, machine learning, robotics, human computer interaction, embedded systems, control systems, communications protocols, mobile and handheld devices, and many more. Smart systems also have considerable potential impacts on social systems and their organization. Computing and Engineering professionals involved in the creation of such systems have to master a highly diverse repertoire of basic professional techniques in order to cope with the complexity involved in developing heterogeneous system components that communicate and integrate, supporting diverse knowledge representations, blending hardware, software, sensors and other components with users, while taking into account the dynamic properties of such complex systems. Smart technologies are currently being developed widely in industry, to support mobile systems, eHealth, eCities, and many other areas. Two major initiatives seek to drive this development at a European level, EPoSS and NESSI: The European Technology Platform on Smart Systems Integration (EPOSS) [20] is an industry-driven European Research and Development consortium "seeking to bring together European private and public stakeholders in order to coordinate and to bundle efforts and to set-up sustainable structures for improving the competitiveness of European R&D on Smart Systems Technologies and their integration"; The Networked European Software and Services Initiative (NESSI) [21] seeks to provide a forum for the improved development of software engineering practice and service architectures, particularly in the area of web services, which will provide the software infrastructure, service architecture and application level for Smart Systems.

The University of Abertay Dundee (UAD) is the first University in Europe to offer undergraduate and postgraduate programs in Smart Systems, and students on the IMPACTS program will have the opportunity to follow a specialist semester at UAD in this area. Since such systems are necessarily highly distributed, linking together tools and components in a range of dynamic configurations and across widespread locations, the practical work undertaken by students involves considerable use of remote experimentation and virtual tools. UAD offers a complete local networking environment, incorporating a significant range of sensor and device technologies, embedded and control systems, but we also offer extended network capabilities across WAN and GRID technologies, and across virtual tools and devices. Students are expected to develop and deploy experimental services and system topologies, utilizing the facilities provided by UAD, and, where possible and appropriate, by the other partners as well.

VI. Use of Remote Experimentation and Virtualisation

Within the three programs offered by the partners, there are considerable high quality local resources to support teaching and learning, which require a location-based cohort to utilize. However, all three of the partners have also developed related online eLearning materials, virtual tools, and remote and distributed experimental facilities to support student learning. From the evidence of the research, both that carried out by the partners and the wider body of knowledge, there is a need to ensure that an appropriate mix or *blend* of location-specific teaching and learning resources and opportunities, and location-neutral online materials and facilities, is achieved. The model for the program has been set out to ensure that students can follow their specialist interest by studying locally at a location offering that specialism, but they do not require to follow their entire program there, and further work and study can be carried out utilizing the location-neutral facilities. This approach offers the opportunity for institutions to concentrate on their own areas of specialism, but still contribute to the wide-ranging and diverse programs of study necessary to produce next generation Engineers. By creating flexible consortia of Universities across Europe, and beyond, offering complementary specialisms within frameworks such as the IMPACTS program, we can offer high quality teaching and learning opportunities that offer all the benefits of actual, virtual, remote and distributed facilities to students in a variety of settings.

VII. Conclusion

Next generation engineers must be capable of working in mixed-reality environments, utilising tools and technologies that are real, virtual and remote in tandem and in concert. They must also be committed learners with the ability to utilise learning materials and experiences in whatever form they are presented to them. This paper presents a model for a distributed Masters program designed to support the development of such individuals, utilising a wide range of local, virtual and remote tools, techniques and technologies to support that development. The model is firmly founded in long-standing research and in the experience and research outcomes of the partners in a range of funded and reported projects. The model is already in operation and will seek to expand the number and range of partners in the immediate future.

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