European Perspectives on Teaching, Education and Training for Dependable Embedded and Cyber-physical Systems

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***Abstract* — The paper provides a short introduction to the European perspectives on the role of teaching, education and training in context of achieving a sustainable innovation eco-system as e.g. the European Technology Platform ARTEMIS is aiming at. Studies and examples from different European projects are discussed, including the ARTEMIS Strategic Research Agenda and Multi-annual Strategic Plan and the ARTEMIS Working Group on Education and Training, the ideas of three ARTEMIS projects (R3-COP, MBAT and SafeCer) to deliver supporting training material to promote more widespread use of the outcomes of the projects, the study (report) performed within the FP6 European Integrated Project DECOS, and experiences with the European Master in Embedded Computing Systems (EMECS) .** *(Abstract)*

Keywords – Dependability; Embedded Systems; Cyber-physical Systems; Teaching; Education; Training

I. INTRODUCTION

Embedded systems are everywhere – may they be visible or integrated into every day devices. Comfort, health, services, safety and security of people depend increasingly on them. In combination and close interaction with the (somehow unpredictable) real-world environment and humans, they become so-called "Cyber-physical Systems", acting independently, co-operative or as "systems-of-systems" (including legacy systems). The impact on society as a whole is tremendous - thus dependability (safety, reliability, availability, security, maintainability etc.) in a holistic manner becomes an important issue, including resilience, robustness, sustainability and so forth, despite emergent behaviors and interdependencies.

Demanding challenges have to be met by research, engineering and education. Smart (embedded) systems are regarded as the most important business driver for European industry. They are a targeted research area for European Research Programmes in Framework 7, in the ARTEMIS Joint Undertaking, European Technology Platforms (ARTEMIS, EPoSS) or the future JTI ECSEL (Electronic Components and Systems for European Leadership) in Horizon 2020. Their application is not only in the traditional areas of aerospace, railways, automotive, or process industry and manufacturing, but also in robotics and services of all kind, home appliances (smart homes, ambient assisted living) and health care. ARTEMIS has founded an E&T Working Group to establish a Strategic Agenda for E&T, taking into account the needs of European industry. This activities were partly triggered by previous work in so-called NoEs (Networks of Excellence) like ARTIST and their follow-ups in the EU framework programmes, and studies on this subject in the FP6 Integrated Project DECOS (Dependable Embedded Components and Systems) [5]. As a consequence, several ARTEMIS [4] projects aim at providing E&T material (R3-COP [8], MBAT [7], SafeCer [6]) to contribute to a sustainable innovation eco-system in the long term by supporting E&T on tools and achievements of the projects.

There is tremendous investment in research and innovation – but is this complemented comparably in education and training as well? Obviously there are gaps. An important question is therefore "How do we educate and train our current and future engineers and researchers?"

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II. DECOS – DEPENDABLE EMBEDDED COMPONENTS AND SYSTEMS

A. Introduction to DECOS (general description)

DECOS (Dependable Embedded Components and Systems) was an Integrated Project of EU-Call FP6-2003-IST-2 and started July 1st, 2004 (ended Dec. 31st, 2007) under contract n° 511764 [4]. To tackle the enormous increase in system complexity, it addressed particularly *component-based design* by providing pre-validated hardware and software components and an appropriate integration methodology for the design of *next generation* dependable embedded real-time systems. The major objective of DECOS was to perform research in and to develop a set of generic hardware and software components within the framework of the Time-Triggered Architecture.

DECOS developed a basic enabling technology to move from a *federated distributed architecture* to an *integrated distributed architecture* in order to reduce development,

production and maintenance cost and increase the dependability of embedded applications in many application domains. DECOS developed *technology invariant software interfaces* and *encapsulated virtual networks* with predictable temporal properties such that application software can be transferred to a new hardware and communication base with minimal effort (legacy re-use). The DECOS methodology and the tools were evaluated by building three applications in the automotive, aerospace and control domain, respectively. DECOS built on the substantial results of previous European research projects (NextTTA, FIT, TTA, SETTA, RISE, X-By-Wire, PDCS, DEVA, DSOS). The components and tools developed within DECOS covered: cluster design, middleware and code generators, validation and certification as well as systems-on-a-chip (SoCs) for high dependability applications. DECOS was rather successful in providing a basis for many further industrial as well as research activities, particularly in FP7 and the ARTEMIS JU. Just as one example, the certification approaches and the DECOS Test-Bench are basic technologies used and further developed in the ARTEMIS projects referred to in section II and the abstract.

B. Education and Training as significant part of the DECOS activitie, co-operation with ARTIST-2 NoE

DECOS had, due to its relevance, a dedicated work package within the subproject "Dissemination, Exploitation and Standardization" on "Education and Training".

According to requirements set by the EC office at this time, separate tasks had to be included on "Gender issues", with focus on supporting events specifically to raise interest or make aware females for taking up technical or engineering studies. As consequence, DECOS partners organized or took part in so called "girls' days" (starting from school age, according to results of several workshops about this topic that starting with grown-ups is starting too late) or "girls' trial studies", but also by co-operating with e.g. "Ditact-women's IT summer studies" and WIT (women for IT) in Austria and Germany. A public DECOS Deliverable "DECOS Gender Booklet"-report is still available on request (2008). Unfortunately, this type of activities was dropped as mandatory requirement for IPs (Integrated Projects) in the following calls.

DECOS started 2004/05 with a report on "Training Needs and Challenges", triggered by co-operation with the ARTIST networks (ARTIST, ARTIST-2 at this time) and as results from previous joint workshops, where considerable gaps had been identified, partially still valid until today with respect to embedded systems engineering and cyber-physical systems:

- Lack of qualified engineers to be able to develop Embedded Systems (traditional engineers learn on-the-job, application domain specific)
- Broad system perspective required
- Knowledge of dependability issues not disseminated properly
- Designers of Embedded systems do often not systematically consider interdependencies between critical and non-critical (sub-)systems (air conditioning corrupts vehicle network, toilet control influences critical general bus corrupting critical functions)
- Need for standardization and knowledge/proper understanding of standards
- Experience on incidents not properly exchanged and documented (confidentiality prohibits learning from incidents)

Skills required because of the multi-disciplinary nature of design in embedded/cyber-physical systems have been identified:

- Both hardware & software skills
- Understanding of engineering beyond digital logic
- Ability to take a project from specification through production
- Communication & teamwork skills
- Work with other disciplines, manufacturing, marketing
- Work with customers to understand the real problem being solved
- Make a good presentation; even better -- write "trade rag" articles

And, by the way, technical skills too…

- Low level: Microcontrollers, FPGA/ASIC, assembly language, A/D, D/A
- High level: Object-oriented Design, C/C++, Real Time Operating Systems
- Dependable Middleware Knowledge (e.g. TTP/TTA, FlexRay)
- Control- and signal processing
- Meta level: Creative solutions to highly constrained problems
- Dependability assessment and Evaluation, Risk/Hazard Analysis, Safety Case Analysis
- Understanding requirements – requirements capture
- Understanding non-functional properties typical for embedded systems: low power, size, weight, dependability, performance, etc.
- Formal methods application

Besides the "Gender Program" mentioned before, DECOS collected examples from the following areas:

- (1) University education and training,

- (2) Professional education and training (by universities, offering masters degrees by "blended education"),
- (3) Summer schools addressing both, academic as well as professionals trying to qualify themselves (e.g. done by DECOS as well).

C. Education and Training examples studied by DECOS, co-operation with EWICS TC7

Examples studied for University curricula were:

- **European Master in Informatics (EuMI), Embedded Systems Informatics:** a very interesting approach cross-Europe and holistic in a manifold manner (the student works in two different environments and can achieve far more (a broader view) than just from attending one university), which is very beneficial in such a diverse field as embedded systems.
- **Vienna University of Technology: Specialisation in Real-Time and Embedded Systems:** At the moment, there is no dedicated "Embedded Systems Master Course" available. However, in the course of the Master Studies "Technische Informatik" a specialization in embedded systems is possible.
- **ALaRI – University of Lugano: Master in Advanced Studies in Embedded Systems Design**. There are two tracks available, one research oriented, the other business oriented, seminars for additional knowledge and skills (legal, IP, (human) communication, management) are available.
- **Nanyang Technological University (Singapur): Degree of Master of Science (Embedded Systems).** The core subjects focus already on embedded systems design rather than generic computer science. The elective subjects include special topics such as secure embedded systems, advanced computer architecture, embedded operating systems, advanced real-time systems and wireless communications, just to name a few.
- **National University of Singapur: Master of Technological Design in Embedded Systems**. Core modules include already very specific embedded systems topics, including DSP algorithms, embedded systems in silicon and specification of complex HW/SW systems. Specialization is possible selecting 2 or 3 out of several topics (wireless systems, multimedia systems, storage system, and a set of "Enrichment topics", e.g. VLSI design, multiprocessor systems, digital signal processing etc. The "project module" is an industrial project.
- **Budapest University of Technology and Economics: Master in Embedded Systems Engineering.** This course is based on the general informatics study and takes from the 6.-9. semester normally, specializing in embedded systems design, logic design, digital signal processing software technology, analysis of computer system and micro-processor based system lab.

Examples studied from Electrotechnical Engineering Institutes who wanted to adapt for critical embedded systems desgin were:

- **Fairfield University: Master of Science in Electrical and Computer Engineering:** There are 4 required courses (SW: JAVA; Engineering lectures in Electrical, Computer Engineering and Numerical Methods) and core courses respectively electives from 9 domains, one of which is specializing in embedded systems (networked embedded systems).
- **EWICS TC7/Proposal** Z. Zurakowski (Polish Institute for Power Systems Automation): The proposals contains general computing lectures as well as relevant lectures and labs for embedded systems, real-time systems, dependability issues (safety case, fault tolerance, system complxity, RAMSS, standards for safety (IEC 61508) and security (ISO/IEC 17799), and network topics/standards, just to highlight a few relevant topics).
- **Eindhoven University of Technology: Master's Degree Program in Embedded Systems.** This program has a compulsory part of subjects from computer science and electrical engineering and one course on societal impact of embedded systems. Elective courses lead students to one or the other direction to deepen their knowledge, the "crowning achievement" is the final (industrial) project.

Particularly targeted at industrial needs were the programs DECOS had studied at

- **Arizona State University (distance education): Master of Science in Engineering Science, Executive Embedded Systems Program**
  "The program targets engineering professionals working full-time in industry with at least a BS degree in electrical or computer engineering. In general, students are mid-level engineering managers in industry and are aspiring for engineering leadership and/or executive management positions. No degree required for admission."
- **Hogeschool/mbo-college Rens&Rens in Hilversum – Master of Embedded Systems**

The professional master course in embedded systems addresses professionals who want to develop their professional skills, most of the modules of the course can be followed separately.

There was, particularly after DECOS, intensive co-operation with EWICS TC7, European Workshop of Industrial Computer Systems (TC7 - Reliability, Safety and Security) who created similar proposals in the Curricula WG as explained in III., EMECS.

One of the results of DECOS E&T activities was the support of the creation of a new master course in Embedded Systems at University of Applied Sciences FH Technikum in Vienna, the first master course of this type in Austria. **DECOS members from Austria considerably influenced the program and were included in the set-up process from the very beginning.** The start will be fall 2006. The program includes hardware and software issues, system-on-chip, system architectures, real-time systems and system dependability, software designed for embedded systems etc., but also training of social competences and management capabilities. This covers almost all of the requirements stated in AMSD and ARTIST documents for embedded systems engineers. One of the goals of this university is the possibility of studying by "blended learning", especially suited for active professionals.

The report on DECOS E&T activities in Chamber B (Research members) of ARTEMIS-IA (ARTEMIS Industrial Association) was one of the reasons why E. Schoitsch, one of the authors of this article, became chairperson of the E&T Working group of ARTEMIS.

III. E&T IN ARTEMIS, THE EUROPEAN TECHNOLOGY PLATFORM ON ADVANCED RESEARCH AND TECHNOLOGY FOR EMBEDDED INTELLIGENCE AND SYSTEMS

A. The role of E&T in the ARTEMIS Sustainable Innovation Ecosystem

ARTEMIS [4] is a European Technology Platform on Advanced Research and Technology for Embedded Intelligence and Systems. It is an industry-driven initiative, which successfully resulted in a Joint Technology Initiative, which is a PPP (Public Private Partnership) between the EC, national public authorities of 23 member states and the industrial and research partners of ARTEMIS-IA, the ARTEMIS Industrial Association, with a separate Annual Work Program and annual calls for proposals. The research projects are managed by the ARTEMIS JU (Joint Undertaking), an independent office organization partly paid by the EC and ARTEMIS-IA.

ARTEMIS aims at not being "just another funding program", it aims at clustering of projects (e.g. the "High-Rel<iability> Cluster of projects like CESAR, MBAT, SafeCer, iFEST, RECOMP etc.) building an ARTEMIS RTP (Reference Technology Platform and Interoperability Specification), and in the medium/long term a sustainable innovation eco-system around the achievements of these project. The ARTEMIS SRA (Strategic Research Agenda [4]) respectively MASP (Multi-Annual Strategic Plan and Research Agenda) describes seven pillars of the intended ARTEMIS Sustainable Ecosystems visualized in the following graphics (Figure 1).

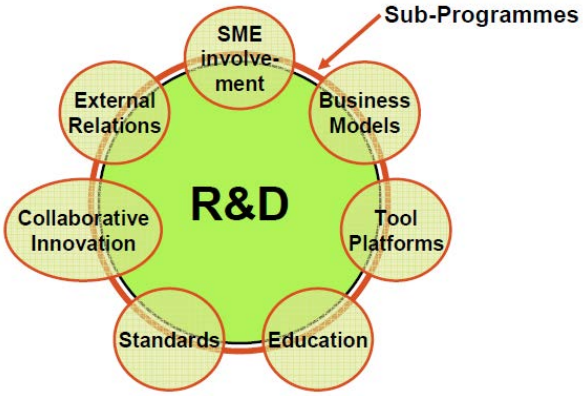

Figure 1: Conceptual model of an ARTEMIS eco-system for (open) innovation

Education & Training is one of these pillars. To put results of ARTEMIS projects into practice can be achieved in the long term by including them in teaching, education and training programs at universities, universities of applied sciences and professional education in industrial and technology transfer organizations. The latter is a means not to address only students but also industrial professionals. This is additionally a very effective means of dissemination with medium to long-term impact since persons trained in courses on the use of a certain methodology or tools during their studies tend to apply their knowledge later on during their professional career.

B. The E&T Working group of ARTEMIS: Motivation and programme

Education and Training (E&T) is a crucial factor in maintaining leadership and competitiveness in such a dynamically evolving domain as Embedded Systems. The European landscape of universities and research institutes specialised in the field of Embedded Systems is still highly fragmented with national champions, sometimes several, in each member state. But E&T is not only an issue of students in universities and research institutes: it includes training of professionals as well, since a large community of engineering staff active in industry since many years or even decades needs focussed E&T as well to cope with the emerging and new challenges. Large industries can provide their own training programmes, but SMEs do need support.

With the ARTEMIS aim of creating an innovation eco-system, in part through a community and shared scientific vision, the mission of the WG E&T is to enable the long-term sustainability of these innovation eco-systems by:

- Building an infrastructure for E&T that facilitates the introduction of new content and curricula.
- Strengthening links between industry and academia,
- Building on and integrating the results of recent and on-going European activities, networks and projects
- Raising business awareness and facilitating short-term exchange and training in both directions (industry and academia), complementary to long-term basic research.

Cooperation with other initiatives and groups working on E&T related topics (EWICS TC7, ARTIST 2 and ARTIST Design, ReSIST, COSINE2 and others) resulted in a recommendation to include an E&T section in each ARTEMIS project proposal as a mandatory requirement.

The importance of the WG E&T to the ARTEMIS strategy is clear in the statement of intent in the SRA 2011 to "facilitate the productive engagement of industry and academia to match the pace of evolution of educational systems and curricula to the rapid evolution in technologies." Not only will ARTEMIS break down the present distinctions between system architects, hardware and software engineers, and promote a more holistic approach to system design, covering all levels of industrial groups (OEMs, suppliers, end-users) but it will also use **EIT ICT Labs** of the European Institute of Innovation and Technology (EIT) to get ARTEMIS results quickly to the curricula of students, to the knowledge of SMEs and to the products of European industry.

The primary question discussed at the ARTEMIS E&T WG is "What can the ARTEMIS E&T Working Group contribute to better match the innovation needs in this fast evolving technological world?" This was broken down into several subtopics, the results of the discussions are summarized under each bullet point [10]:

- **Ideas & priorities for future activities of the WG:**
  - Although E&T plans are now addressed in the ARTEMIS Work Programme, the evaluation criteria should include concrete E&T target values.
  - A new approach was discussed at length and included as target for next year's activities: The whole chain for professionals has to be addressed in the field, not only academic and professionals, but also at school level (e.g. project courses 15-18years, e.g. in manufacturing environment, and specific training for teachers in E.S. area)! There is a shortage in engineering staff on all levels, which has become a problem for industry, and it is too late in curricula to start at academic level.
  - Complementary funding to explore innovation etc. is unfortunately not possible in current ARTEMIS projects: Target for "Next Generation Joint Undertaking"? NOTE: In the evolving JTI ECSEL, such support actions (CSA) will be possible as bi-partite projects (only EC funding and partners).
- **Co-operation with other initiatives or programmes:**
  - Co-operation with EIT-ICT Labs will be fruitful for both sides
  - The E&T WG will follow the firm request for co-operation with Prof. Hannu Tenhunen (hannu@kth.se), who is in charge of EIT ICT Lab's Embedded Systems M.Sc. Program (besides some other contacts)
  - Co-operation with KET has to be looked into (high-level group)
- **Link with and tap into projects and their innovation activities?**
  - Examples from recent ARTEMIS projects explained: in R3-COP, pSafeCer and the nSafeCer proposal as well as in MBAT Dissemination E&T activities (development of training material, workshops) are planned.
  - Contribution to future MASP: strengthen E&T as Work Program requirement.
  - Pupils/girls days (like in the FP6 IP DECOS project) (companies, research organizations)
  - Short internships for students and schools: Can we *train* companies to take this into account as part of ARTEMIS projects? (ARTEMIS challenge and possibility for ARTEMIS companies!)
- **"Make it happen" chapter of the new SRA 2011- Implications for the WG:**
  - SRA: "Sustaining the Artemis innovation environment"– E&T has an important role! (p. 16, p. 95/96)
  - ARTEMIS organizers: Invite local students, their teachers and local industrial community to ARTEMIS/ITEA2 Co-Summit exhibition etc.: (potential partners: EIT ICT Labs)
  - ARTEMIS Centres of Innovation Excellence (CoIE): E&T should be an important criterion (EICOSE, Process-IT). The discussion revealed that at the moment E&T is not an issue – to be changed!!

Since ARTEMIS E&T WG should differentiate from similar groups: the involvement of industry is a key requirement (chambers A and C, SMEs and large industries).

C. E&T use cases in selected ARTEMIS projects

As a trial of the idea to include Education & Training more explicit in ARTEMIS projects with the objective to create a long term impact towards a sustainable innovation eco-system, three projects have definitely defined specific actions towards an E&T use case/demonstrator. These projects are R3-COP [8], SafeCer [6] and MBAT [7].

1) R3-COP (Resilient Reasoning Robotic Co-operative Systems):

The Technical Annex of R3-COP foresees that the technical work packages provide in the end, coordinated by the dissemination manager, besides the usual E&T activities of academic and industrial partners,

- training material for potential users of the R3-COP platform and tools (user manuals and training material to be done within technical WPs),
- to (co-) organize a workshop with E&T relevance

The task of the dissemination/E&T work package is to facilitate the generation of appropriate training material for tool and platform users and motivate the partners to include R3-COP results and ideas in their teaching, education and training activities (lectures, lab exercises, industrial seminars, workshops). The various demonstrators in the different application areas (aircraft, ground, under water and manufacturing) are part of this activity. The TA explicitly refers to the ARTEMIS SRA, MASP and E&T Working Group.

2) MBAT (Combined Model-based Analysis and Testing of Embedded Systems):

MBAT refers to the ARTEMIS "sustainable innovation eco-systems" and the E&T Working Group, stating:

"The objectives of education & training activities are:

- *To achieve long term impact towards a self-sustaining innovation ecosystem (ARTEMIS MASP and SRA, requirement of Work Program 2010)*
- *To support especially the second and third dissemination objective (close relation to dissemination)*
- *Monitoring the provision of training material and an <u>educational subset of the Technology Platform</u> (AIT holding the chair of the E&T WG of ARTEMIS)."*

The task Education & Training is defined as:

- Education and Training Material Promotion: Monitoring of and Facilitation of production of dissemination and training material as outcome of the respective technical work packages (for future users/trainees of the tool platform)
- NEW IDEA: "Experience package" describing the use cases and other outcomes of the project.
- Specific focus on E&T requirements of industry and especially of SMEs !
- Inclusion of MBAT goals and achievements in lectures, lab exercises and seminars (universities, universities of applied sciences, technology transfer centers and organizations, and the like), PhD and Diploma Thesis. (Example: AIT e.g. took part with a tutorial in the "Safety Day" of the University of Applied Sciences FH Campus in Vienna, VISSE Vienna Institute of Safety and Systems Engineering, and provides contributions to lectures and lab exercises in Model-Based Testing, Test Case Generation and Formal Methods).

3) SafeCer (Safety Certification of Software-intensive Systems with Reusable Components):

SafeCer is building on two overlapping projects p[ilot]SafeCer and n[ext]SafeCer with a total duration of 4 years. The reason was that the first project started with insufficient funding available in a shorter pilot-version and a successful follow-up proposal nSafeCer enabled to continue the work in the originally planned extent.

SafeCer has established a complete "education & training" use case in a formally similar manner as any other use case, with deliverables comparable (and integrated) into the regular deliverable series as one of the so-called "cross-domain" use cases. This is the only project where this is planned with in-depth consequences as a trial for future exploration and exploitation. The reason is that particularly certification issues are rather neglected in E&T during regular courses.

The E&T use case aims at promoting the outcomes of SafeCer (pSafeCer and nSafeCer) in the Embedded Systems Community. A detailed example performed by the University of Mondragon is presented at this workshop session of Euromicro-SEAA 2013 in Santander [11]. Since the "E&T Use Case" is not considered to fit just one particular domain or application. It should rather provide general ideas and guidelines, together with simplified examples, to transfer knowledge concerning the methodology and approach of SafeCer to the next generation of engineers. An equally important goal is to train skills of professionals in the field (domain independent) to be able to apply the SafeCer methodology, particularly covering the "re-use" aspect of arguments and safety contracts of components. Therefore it is included in the cross-domain/other domain work package.

The outcome may be either:

- a guideline set to explain and train how to apply the SafeCer methodology and approach with a few simple examples as a paper-based or interactive training material, or a
- SafeCer Training suite for university or industrial training, e.g. in technology transfer centres, if some agreement between the partners holding different IPRs can be achieved to provide a subset of tools.

Particularly the second approach would facilitate wide spread exploitation and usage of the SafeCer methodology and tools, thus contributing to the sustainable innovation eco-system as anticipated by the ARTEMIS SRA.

The SafeCer Poster produced for the ARTEMIS/ ITEA2 Co-Summit 2012 in Paris shows very well the contents and objectives of the SafeCer Technology and Processes which have to be trained in the Trainee example and E&T training material (Figure 2).

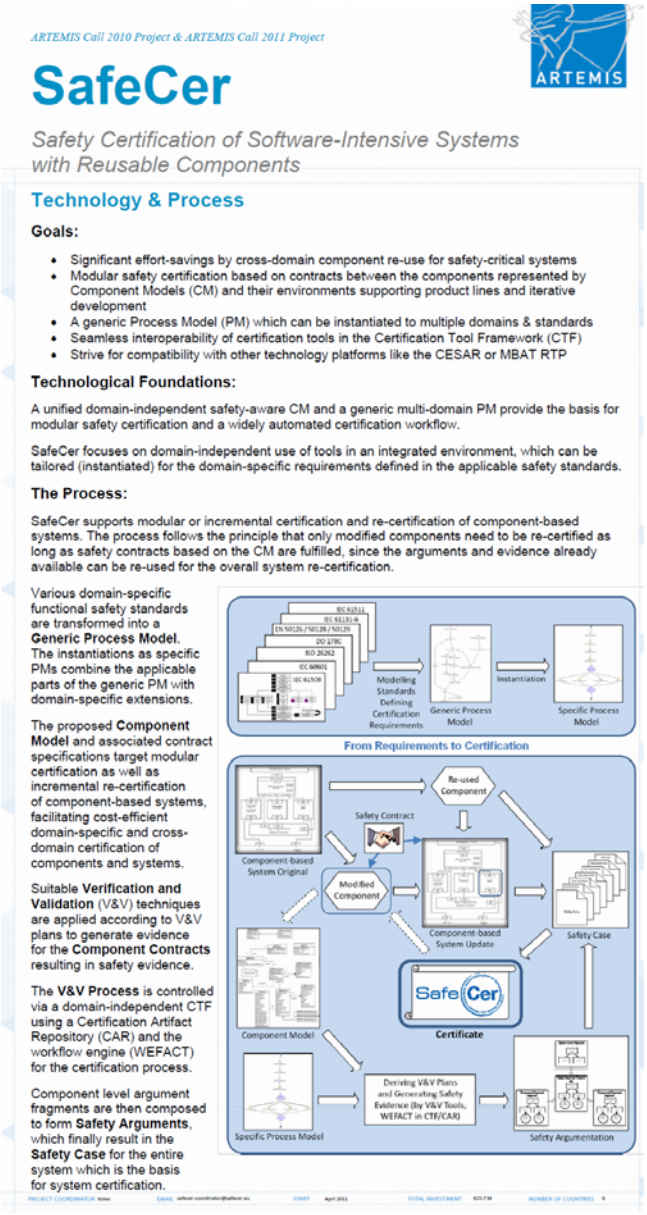

Figure 2: SafeCer Technology and Processes – what should be trained

In pSafeCer only basic principles and ideas have been planned to describe, since a sufficient maturity of the inputs from the development work packages has to be achieved before training material can be prepared. It should be noted that the E&T material has to be provided by the development work packages on modeling, processes and tools. Therefore the E&T work package and the E&T use case have to be based on these inputs and on the willingness of partners to provide E&T versions for an E&T suite. The E&T Use case was designed to motivate and direct activities in this direction. In the mean time it was clarified that the important parts of the necessary tools will be open source and therefore publicly available for educational purposes.

IV. Experiences with the European Master in Embedded Computing Systems, EMECS.

Within EU there is a perhaps not-so-well-known two-year European master's program in embedded computing systems, EMECS.

A. *Erasmus Mundus*

Erasmus Mundus II (2009-2013) is a program for co-operation and mobility in higher education [1]. As stated in [1], it aims amongst others at promoting structured cooperation between higher education institutions and enhancing quality. In addition it is a stated goal to increase the mobility for the most talented students and academics in certain third-world countries towards the European Union (and vice versa.) There is a large number of, limited to 150, Master programs in Erasmus, EMMCs.

In the Erasmus Mundus programme guide [2] it is described that the EMMCs must:

- have a duration of one to two years (60 to 120 ECTS credits);
- be implemented by a consortium of European and, where relevant, third-country HEIs;
- provide high-quality education to European and third country students and reserve a number of places for Erasmus Mundus scholarship holders;
- include a mandatory period of study for students in at least two of the European countries;
- include mandatory scholar mobility between the consortium HEIs;
- lead to the award of recognised joint, double or multiple degrees (covering the entire study programme) to successful students.

B. *A description of EMECS*

One of the EMMCs is the EMECS – European Master in Embedded Computer Systems. This is an "excellency" program. Amongst others, this means that only the very best students from all over the wold are admitted. This program is organized by the University of Kaiserlautern,

where the University of Southampton, United Kingdom, and the Norwegian University of Science and Technology, NTNU are partners. For the Tuition, for a 2-years period, the institutions receive €8000 for European students, and €16000 for Non-European students. The prospective EMECS students can apply for scholarships. For non-EU students this is the amounts:

- Travel etc.: €4000 per year
- Tuition: €4000 per semester (full coverage)
- Monthly allowance: €1000

For the EU students the following numbers are valid:

- Tuition: €2000 per semester (full coverage)
- Monthly allowance: €500

From the mastersportal.eu for EMECS [3] the description of this program is as follows (directly cited):

EMECS is a two-year master's program. A total of 120 ECTS (European Credit Transfer and Accumulations System) credit points must be acquired. The curriculum consists of a core program, an elective program and a Master's Thesis. The core program covers the fundamentals of Embedded Computing Systems and offers an equivalent education in all three institutions. The elective program reflects the specific profiles of the participating partner universities and their associated research institutes.

Core Program (45 ECTS)

The core program consists of three study areas:

- Embedded System Hardware Architectures
- System Software
- System-on-Chip (SoC) Design Methodology

The three partner universities have agreed on the contents of these core study areas. All teaching modules of the core program are mandatory to all students and need to be finished within the first year of study at one of the partner universities. The core program guarantees that all students can achieve an equivalent educational level regarding the basic principles of embedded system design and architecture. After completion of the core program, no matter at which partner institution, students will be able to take full profit of the elective program and project activities offered throughout the consortium.

Elective Program (45 ECTS)

The elective program consists of four study areas:

- Advanced Topics in Embedded Systems
- Communication & Signal Processing
- Automation & Control
- Microsys-tems

These areas are offered by all partner universities. Each partner university contributes a number of teaching modules to each elective study area. The teaching modules within an elective study area are varying between universities and reflect specific local strengths, special application areas, design methodologies and architectures of embedded systems.

There are no mandatory teaching modules in the elective program. Every student is assigned a supervisor at each of the two partner universities that he or she attends. Based on the elective program an individual study plan is elaborated and mutually agreed on between the student and the supervisors.

Master's Thesis (30 ECTS)

The last part of the curriculum during the second year of study is dedicated to a Master thesis. The Master thesis is typically embedded into larger research projects conducted by the local research centres or together with industry. The topic of the Master's thesis is determined during the second year of studies.

C. Experiences at NTNU

Three different departments at NTNU were involved in order to provide the necessary classes:

- Computer and Information Science
- Electronics and Telecommunications
- Engineering Cybernetics

No tuition fee is received by NTNU, since there are no tuition fees at Norwegian universities.

The number of students admitted every year has been quite similar for all three institutions. At NTNU the numbers so far was, as seen in TABLE I. , 4 in 2010, 12 in 2011 and 11 in 2012. The first year we only admitted students for the first year, then in accordance with how this is supposed to work, we received students in both first and second year of their master, that is, they had been at one of the other partner universities the first year, then studying the final year at NTNU. (And Vice versa.)

The courses offered for EMECS students at NTNU initially, referred to as the Core program, were the following (contents listed below each):

- Embedded Systems
- Computer Architecture
- Real-time Systems
- Real-time Programming
- Design of Integrated Circuits
- Modelling and Analysis of Digital Systems

The grants given are sufficient for students, even with such high costs of living as in Norway. Every year we have also had 2-3 students admitted without scholarships, which is feasible since universities in Norway are not charging any tuition fee, no matter nationality of the student. However, here it must be noted that for non-EU citizens there are quite strict requirements for proving that the student can afford living in Norway.

It required a substantial effort especially to ensure that all teaching materials for all offered classes were available and taught in a satisfactorily English. And one must say, for a quite small number of students, as seen in TABLE I.

We have observed that grades of Excellency given in different countries in earlier courses do not necessarily mean the same level of achievements or visible academic

talent. More importantly, the background in basic courses differs widely, even if the names of classes taken seem quite similar. With 21 Nationalities represented over just 3 years and 35 students this is to be expected.

An interesting observation was the praise many of the lecturers at NTNU have got from the students for using practical laboratory exercises extensively. Many of the students tell that they have experienced mainly theoretical lectures and exercises for many, or even all courses in their earlier studies.

There have been many debates on campus on the use of English or not in classes. It is clearly necessary in order to host students from such a variety of nations. And the literature used is often in English anyway. However: Lecturers have to use their second language, and the majority of students are usually Norwegian, and although trained in English since the age of 6, often a bit shy, and less likely to participate actively in a class using their second language.

In general our experience is that the EMECS students are very motivated, hard-working and talented. Just as the local students admitted for the same or similar studies are, one dear say.

It is easy to see the differences in earlier education as well as the different cultures. At NTNU the EMECS students have been given a large common room for study, which has been good for creating a sense of a companion-ship for this group. The contact with the local students might, on the other hand, have suffered from this. Therefore we have also tried to have extra laboratory places mixed with the local students for the 2-year students doing their master.

Without the funding for re-location, it is not so likely that we would get some of the students we have had from certain third-world countries, no matter their abilities and academic talent.

TABLE I. EMECS STUDENTS AT NTNU

Nationality	**Year**		
	2010	***2011***	***2012***
Azerbaijan			1
Belgium	1		
Brazil			1
Egypt			1
Ethiopia	1		
Finland		1	
India			1
Indonesia			1
Iran		1	
Lithuania		1	
Mexico		1	
Moldova			1
Nepal			1
Pakistan	1	2	1
Romania		1	2
Russia		1	
Spain			1
Turkey		1	
Germany		1	
Uganda		1	
Vietnam	1	1	
SUM	4	12	11

a. Source: Norsk samfunnsvitenskapelig datatjeneste AS (NSD).

Even if the EMECS program might not continue after 2014/2015, the Erasmus Mundus programs having endedj at this time, the participating departments at NTNU are now cooperating better internally regarding relevant courses for embedded systems, and will make use of this, possibly for offering an international master in embedded computing systems by ourselves when the EMECS funding ends.

V. CONCLUSIONS

Several projects within EU are targeting teaching, education and training for embedded and cyber-physical systems. In order for the industry in the EU-region to succeed in these important areas one must strive to increase such efforts.

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