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Worldwide Digital Design Contest: A Decade of Development and Success Developing Students' Hardware and Software Skills

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I. Introduction

With the publication of *The Engineer of 2020: Visions of engineering in the New Century*, The National Academy of Engineering (NAE) Committee on Engineering Education (CEE) aimed to identify the opportunities and challenges for the 21th century, anticipating and shaping the future practice of engineering, the characteristics of the engineering workforce and their education[1]. To enhance the nation's economic productivity and improve the quality of life worldwide, engineering education in the U.S. must anticipate and adapt to the dramatic changes of engineering practice. Engineering schools must attract the best and brightest students and be open to new teaching and training approaches.

As we enter the new millennium, some of the most important trends that will redefine the boundaries of engineering and the composition of engineering forces are: globalization of industry and engineering practice; an accelerated pace of technological advances, including the increasing importance of information technology, communication science, and biological materials and processes in engineering; the growing complexity, uncertainty, and interdisciplinary foundations of engineering systems; increasing opportunities for incorporating technology into the education and work life of engineer [1, 2]. College graduates should expect to work in culturally diverse workplaces, work across national borders and understand global challenges.

According to published reports [1,2,3], looking at particular skills and successful attributes of the Engineer of 2020, top priorities are: strong analytical skills; exhibit practical ingenuity and possess creativity; good communication skills; business and management skills; lifelong learners; ability to frame problems and put them in a socio-technical and operational contest. Creativity (invention, innovation, "thinking outside the box") is an indispensable quality for engineers, and given the growing scope of the challenges ahead and the complexity and the diversity of the technologies of the 21th century, creativity will grow in importance. It is an essential tool required to flourish within the ever changing contemporary world, so educators have a responsibility to develop students' creativity capacities.[4]

II. Digital Design Education and Design Contest

Digital Design represents an integral part of any electrical, electronic and computer engineering education program. In the areas of digital design and systems, universities must update their curricula to cope with the increased demands of research and development required by the global industry. Continual advances in technology necessitate on-going updates and modifications to existing digital design teaching methods and associated computer-based-tools, in order to reinforce students' technical and practical knowledge. In digital design areas, the design tools, and technologies used in industry to design digital hardware evolve quickly and continuously, with revolutionary tool changes occurring every 5 to 10 years[5].

Novel and more "hands-on" educational approaches are possible due to the continued revolution in electronic miniaturization which makes possible portable, low-cost, robust digital platforms (based on Field Programmable Gate Arrays and/or Microcontrollers) that allows for valuable hands-on experiences for students anywhere and anytime[5]. The programmable platforms can be integrated with lectures in the classroom or online, home projects, or when students want to try out their own ideas, explore creative projects and ideas, using their *own computers and associated free computer-based-tools.* Enriching students educational experiences, by providing opportunities inside and especially outside the traditional classroom and laboratory setting, enhance learning[6]. It is well supported by educational research that people retain 10% of what they hear but retain as much as 90% of what they "learn by doing"[6]. The inexpensive programmable hardware platforms enable students to quickly and easily experiment with advanced technologies and build and test real-world, functional designs anytime and anywhere students prefer to work[7].

Trying to address the above mentioned issues and taking advantage of the proliferation of free computer-based-design tools and low cost hardware platforms, motivated enthusiastic professors at different universities in Europe, USA and Asia. Gradually, they joined forces, organizing local , regional, national and Worldwide (global) Digital Design Contests, open to students enrolled in different majors such as: Electrical and Computer Engineering, Electronics and Telecommunications, Mechatronics, Computer Science, Engineering Technology etc. Competitions at local universities located in different countries and on different continents have been sponsored mainly by Digilent[7] and Xilinx [8] companies. The mission of Diligent is to make electrical engineering and design technologies understandable and accessible to all, by providing educators and students with low cost-fundamental tools and curriculum. Through the Xilinx University Program (XUP), professors and students all over the world have access to the latest technologies and tools for academic teaching and research.

This paper presents the results of a decade of Digital Design Contests, reviewing topics such as the successes and challenges developing and organizing a novel worldwide contest, trying to enhance students hardware and software skills, preparing the engineering workforce for the next decade, and measuring the results. The rest of the paper is organized as follows: Section III presents the student design contest as an educational vehicle; Section IV presents the evolution of the contest in Europe, USA and Asia, culminating with the worldwide editions; Section V presents the assessment of the contest and Section V concludes the paper.

III. Student Design Contest

According to Gregson and Little[9], a good design experience offers opportunities for learning to identify and remedy procedural and factual knowledge deficits and to exercise judgment. A design contest is a good vehicle to offer students a consistent design experience outside of the classroom. Trying to organize competitive design contests, organizers mainly focus on the following attributes of a good competition [4]:

a) incorporates significant course material from more than one discipline;
b) provides success commensurate with care in design;
c) requires increasing factual and procedural knowledge;
d) requires exercising engineering judgment;
e) does not require significant infrastructure;
f) offers a spectacle;

Academia and industry join forces to organize various design contests, from the course level[4], to the international levels, giving students opportunities to grow professionally and to connect with their peers and potential employers. In the area of electrical and computer engineering and related majors, very popular contests are the contests sponsored by IEEE[10]. IEEE offers a variety of competitions, locally, regionally, and globally to IEEE student members and graduate student members. Many competitions provide a way for student members to connect to the global IEEE community and impact humanity through *the creative application of technology and engineering.* The motto of these competitions is: *"Get involved, have fun, and take the challenge. You might just win some prizes and recognition from your peers around the world"*[10]. Very popular IEEE contests are the Humanitarian Technology Challenge, IEEE International Future Energy Challenge, IEEEXtreme 24-Hour Programming Competition, etc. Similar contests with the one presented in this paper are organized by the Xilinx University Program for the Europe region: "University Contest on Embedded Systems Design" in UK and the "Open Hardware Design" open to all European Universities[11, 12].

For the Digital Design Contest presented in this paper, students design and implement original and creative projects, following the contest's rules established by representatives from industry and academia, and presented on the Digilent company web page[7]. Students work at their own pace, using free hardware and have 24 hours a day access to their hardware platforms and computer-based-tools. The objectives of this experiment (Design Contest), which started ten years ago at the Technical University of Cluj-Napoca, Romania, are to:

a) help students to develop the engineering skills of the 21th century;
b) provide an avenue to a large number of students to express their creativity and innovative sprit outside the traditional laboratory and class environment;
c) give a forum to students from different countries to interact and challenge each other;
d) encourage the feedforward effect: the published projects inspire new generations of students to design novel products, using their own computers and associated computer-based-tools.

The organizers of the contest(s) presented in this paper, try to make it more rigorous every year, by studying similar competitions[10-12], receiving feedback from participants (students, advisers, audience, jury members) and applying "lessons learned" from previous editions. The following set of criteria was used to judge the projects for the past five years[13, 14].

a) the complexity of the project relative to the author's level of knowledge;
b) the hardware is used to its capacity, in an ingenious and effective manner;
c) the software is mainly original and fully functional;
d) the core underlying idea is understandable, creative, feasible, path-breaking;
e) the project solves a problem, the idea is feasible or could be commercialized
f) the written report is thorough, clear, compelling, logical, elegant, and professional;

g) the presenters are professional, confident, comfortable and enthusiastic in presenting;
h) the presentation is thorough, well structured, informative, and professionally delivered;

The feedback from the community is an important factor. Students are encouraged to post their work on public websites, social network websites, in order to receive feedback from the viewers.

IV. Evolution of the Design Contest

The contest is mainly dedicated to undergraduate students but it is also open to graduate students. The openings are in November or December with an enrollment period of one month. Students projects are pre-evaluated a month before the finals in order to verify the status and the timetable set by each team. Contest rules were the same for all the regions, starting in 2011. Each region's participants received the hardware platforms free of charge and kept it after the final presentation in his/her region. Winners of the four regional contests were invited to participate in the finals held in a different country and continent: 2011-Germany, 2012-USA, and 2014-China. All the details of the Contest are posted on the web page of Digilent. Figure 1 presents a summary of the contest logistics and Figure 2 presents the flyer for the worldwide contest (2014).

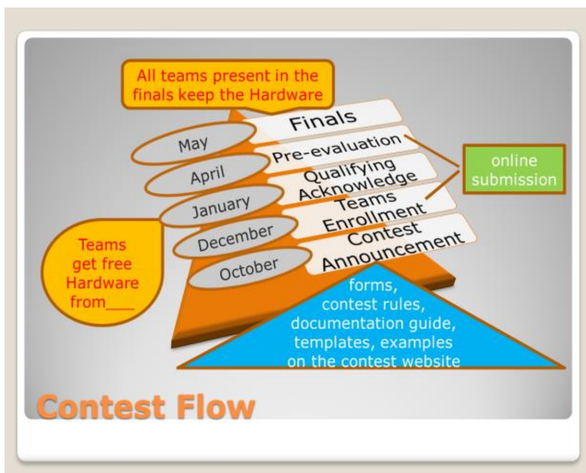

Figure 1. Contest Logistic

Figure 2. Worldwide Finals in China

All the projects (open source) are posted on the Digilent web page. They represent an excellent source of information for college instructors interested to incorporate project-based-learning in their digital design courses and students interested to design using programmable platforms.

For each edition of the contest. Digilent provided the latest and most advanced technology platforms. In the last three years, the most popular platforms chosen by the students were:

- **Nexys4** board: a complete, ready-to-use digital circuit development platform based on the latest Artix-7™ FPGA from Xilinx. With its large, high-capacity FPGA generous external memories, and collection of USB, Ethernet, and other ports, the Nexys 4 can host designs ranging from introductory combinational circuits to powerful embedded processors. Several built-in peripherals, including an accelerometer, temperature sensor, MEMs digital microphone, speaker amplifier and lots of I/O devices allow the Nexys4 to be used for a wide range of designs without needing any other components.

- **ZYBO** (Zynq Board): an entry-level embedded software and digital circuit development platform built around the smallest member of the Xilinx Zynq-7000 family, the Z-7010. The Z-7010 is based on the Xilinx All Programmable System-on-Chip (AP SoC) architecture, which tightly integrates a dual-core ARM Cortex-A9 processor with Xilinx 7- FPGA logic.

- **chipKIT™** development boards: 32-bit-microcontroller-based platforms compatible with many existing Arduino™ code examples, reference materials and other resources. They feature pin-out compatibility with many existing Arduino™ shields that can operate at 3.3V, lower price-point at four times the performance than existing solutions, advanced capabilities including integrated USB (Device/Host, OTG) and integrated Ethernet.

Europe Region

The first contest was organized at the Technical University of Cluj-Napoca, Romania in the academic year 2004-2005, for the students enrolled in that university. Due to the huge popularity and interest, students from different technical universities in Romania were invited starting in the academic year 2006-2007. In 2009, students and instructors from all over Europe were invited and it became international. The contests held at the Technical University of Cluj-Napoca, Romania became a tradition, the **2014 edition being the 10th edition**. The number of enrolled teams in the past three editions has also increased, due to the appreciation coming from universities and advertising. As expected, the complexity of the projects increased over the years.

The First Prize in the 2014 edition was awarded to the group of students who design an *"Auto Scaling Impedance Meter''* used to measure the impedance parameters for elementary or complex unknown impedances. Figure 3 presents the winning project. This project uses a chipKIT™ PRO MX4 system board, several peripheral modules Pmods and a custom designed adapter board. It measures the R and *X* parameters of the unknown impedance, calculate the impedance modulus and phase, as well as others parameters (*C or L, Q*) and plot the values on the LCD display.

Figure 3. Winning Project Europe Region - 2014

USA Region

The first Digital Design Competition was organized at Rose Hulman Institute of Technology, In, USA, starting in the academic year 2006-2007. The contest was very popular among students, an average of 10-15 students participating every year, despite a very busy schedule. Students who presented their final projects received professional development credits. Starting in 2012, the contest became national and the last three editions were organized as follows: Indianapolis, in conjunction with the IEEE EIT International Conference (2012); Baltimore, by Morgan State University (2013); New York, by New York City College of Technology (2014). In 2014, ten teams from all over country qualified and presented their design projects showcasing FPGA, microcontroller, and robotics-based platforms. Figure 4 presents the winning project, *"**T.O.B.I.A.S- Tele Operated Bi Manual Augmented System**"***,** a humanoid robot that can be intuitively operated remotely via Bluetooth Interface. It was developed by a team of students from New York City College of Technology. It includes a humanoid robot equipped with servo motors and a Tele-Operation Control Station which senses all movements of a human operator and relays them to the robot. A pair of smart phones and wireless video/audio transmission allows the user to see through the eyes of the robot in real time and thereby effortlessly manipulate the robots extremities as if though they were one's own.

Figure 4. Winning Project 2014 - USA Region

ASIA Region

Starting in 2011, the first editions were held in India (Sir Padampat Singhania University Udaipur) and China (Tsing Hua University in Beijing). The two universities that hosted the finals cooperated with Diligent organizers very well and the feedback from the instructors was extremely positive. The first Japan contest was organized in 2014, at Tokyo Electron Device. Six teams from five universities enrolled. Figure 5 presents the winning project, *"Sensory mounted Robotic ARM Rover"* (China, 2014), a chipKIT-based Wi-Fi Rover that can run and provide feedback in a rugged and rough environment. It was designed by students from Huazhong University of Science and Technology, China.

Figure 5. Winning Project China (2014)

Worldwide Finals (Germany, USA, China)

The first edition of the Worldwide Finals (global) was in 2011, in Munich Germany, in conjunction with FPGA World Conference. As a reward and recognition of their hard work, the winners from each region were invited to present their projects at the Worldwide Finals, in Munich, September 2011. The projects were also exhibited at the *FPGA World* Conference, which was chosen as a strategic place to host the contest. The members of the jury invited to evaluate the projects were selected from industry: Analog Devices - Germany, Trenz Electronic - Germany, ESG Elektroniksystem und Logistik - Germany, Mirifica - Italy and Computer Measurement Laboratory – USA, etc. First Prize was awarded to the team of two students from Switzerland who designed a "*BitHound*" - a 32-channel logic analyzer implemented on an Atlys Spartan-6 board and with a custom interface board. The analyzer is able to sample 32 channels with 200MHz or 16 channels with 400MHz. The data is transferred via 100MBit/s Ethernet from the 128MB DRAM to the PC client for displaying in the GUI custom software. The analyzer is a versatile tool that can be used to debug digital circuits. The project is presented in figure 6.

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Figure 6. Winning Project   First Worldwide   Finals   (Munich, Germany 2011)

The second edition of the Worldwide Finals was hosted in Pullman, USA, in September 2012. Eight teams from Romania, US and China competed for honor and generous cash prizes. The contest was co-sponsored by Diligent and Washington State University. A "*Three-Arm Optical Tracking System*" a "*WebScope"*, and a "*FPGA Based M2M Heterogeneous Virtualization System*", *a Xilinx® FPGA-based cloud computing system* (first prize) were the winners of the 2012 Worldwide Finals. The student engineering contest was a showdown between projects that won top honors in the 2012 Design Contests in Europe, China and United States. Figure 7 presents the winning project.

Figure 7. Winning Project - Second Worldwide Finals (Pullman, USA, 2012)

The third edition of the Worldwide Finals took place in Shanghai, China August 2014. Winners of the regional editions in China, Europe and Asia were invited to compete. Teams from US, Hungary, Romania, Japan and China competed for the best project. Xilinx and Diligent representatives along with local industry and University representatives chose the best projects. The winning project was the *"Tele Operated BiManual Augmented System"*. See figure 4.
Students had the opportunity to visit China's most known attractions and enjoy the culture and food in the days following the contest, as part of their global learning experience. Figure 8 present participants visiting the Great Wall of China and enjoying the local cuisine. They had similar experiences in Germany, during the previous edition, as seen in figure 9. During the

Worldwide final in USA, students had a chance to visit prestigious companies (Xilinx, Intel, Cypress Semiconductor, Digilent) and universities (University of California at Berkeley, Stanford University, Washington State University).

Figure 8. Cultural and Culinary Experiences in China (2014)

Figure 9. Cultural and Culinary Experiences in Germany (2011)

IV. Contest Evaluation

Students' Participation

The European regional contest, organized in Romania, at the Technical University of Cluj Napoca, Romania, gained prestige over the years, with the largest number of participants over a decade, followed closely by the contests organized in the United States and China. The following two graphs present a synthesis of the European contests in terms of students' participation (number of students enrolled compared to the number of finalists) and affiliation (university, country). The graphs show expansion of the competition as well as its international recognition.

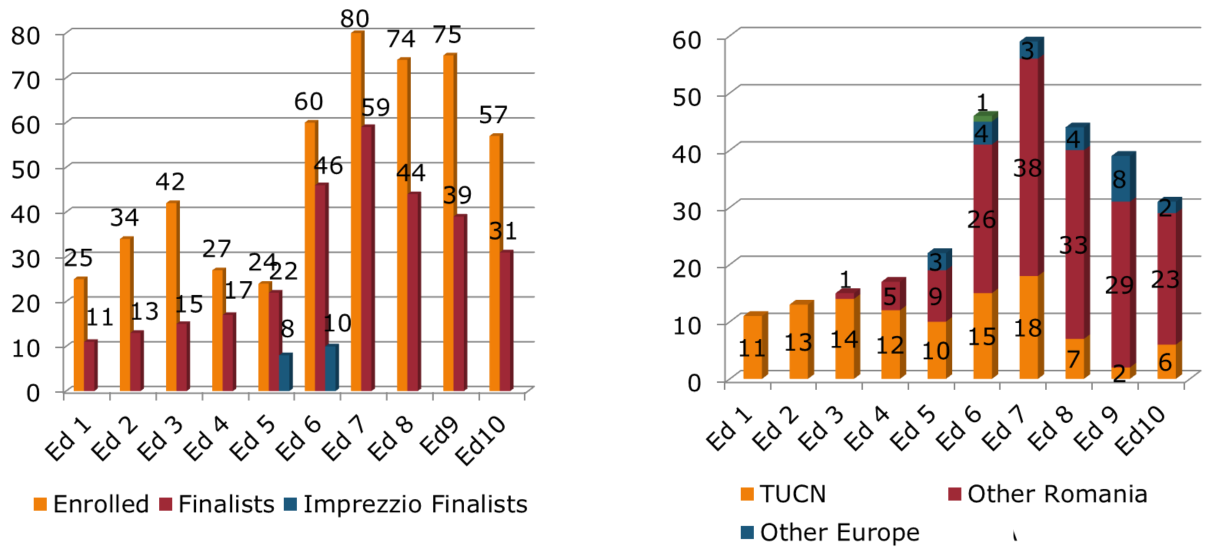

Figure 10. (a) Students Enrollment; (b) Students Affiliation

Student's Choice of Platforms and Projects

The graph presented in figure 11 show student's choice of platforms (FPGA versus microcontroller) in Europe. The percentage of FPGA platforms used by the students was higher in the first editions, but starting with the 6th edition, the number of projects using microcontroller boards and combined platforms increased, reaching about 40 % in the latest edition.

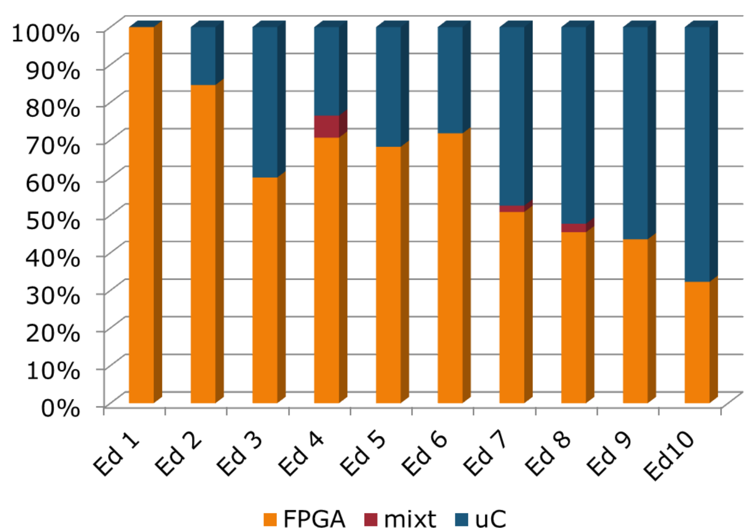

Figure 11. Europe hardware platform student's choice evolution

The retention rate is lower for FPGA and ARM based projects, as shown in Figure 12. A possible explanation for the trends presented in figure 12, is the fact that students consider HDL languages and FPGA more difficult and/or courses covering these topics are offered later in the curriculum at various universities worldwide.

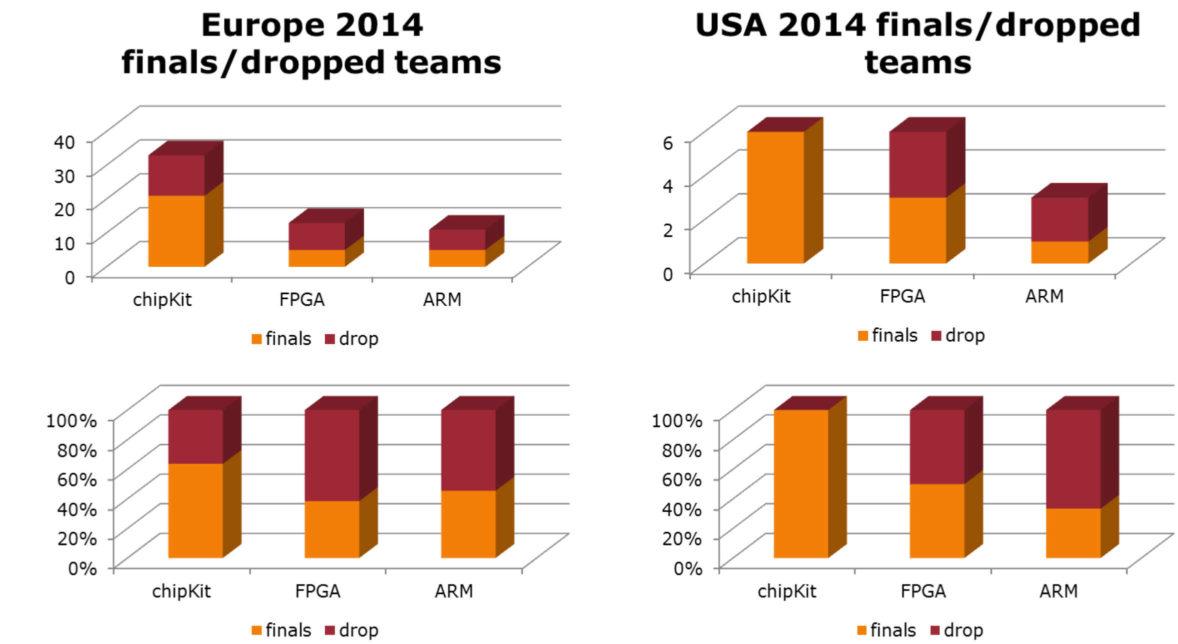

Figure 12. Student's Choice of Hardware Platform: finalist/dropped teams in 2014. Europe and USA

Robotic based projects gained in popularity over the years, extremely complex projects being presented in the last three editions. Student's interest for a different platform or type of project can be related to the student's major, job opportunities in the region, social media, etc. Popular categories in the 2014 edition were automotive, medical assistance and environment control, as shown in Figure 13.

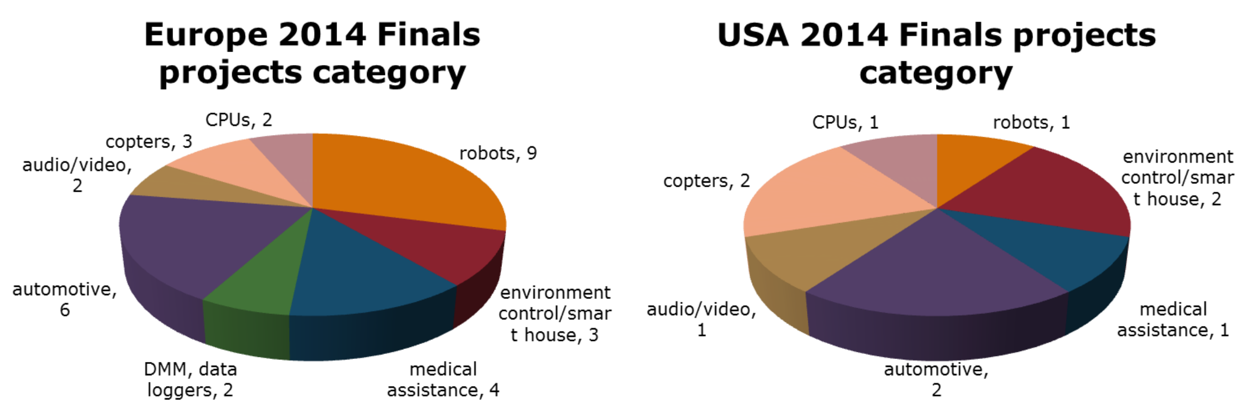

Figure 13. Finals project categories in Europe and USA (2014)

For the ASIA regions, the number of editions, participants and countries were smaller compared with Europe and USA, but similar trends were observed.

Student's Surveys - Student's Perception as a Learning Experience

The surveys that followed the majority of the competitions were designed to evaluate the entire event from the perspective of students' learning experience outside the traditional classroom and laboratory environment. Over one hundred students' surveys were carefully analyzed, mainly from the Europe and USA contest regions and worldwide events, over the last five years.

The first question of the survey investigates how beneficial is the competition for the students' professional development and future career as engineer. The majority of the students' comments reflect their positive perceptions of learning new computer-based-tools, new technologies, and presenting their projects in front of a professional audience.

"I learned a lot while developing the project itself. It required getting used to a lot of new tools and features. I now have a much deeper understanding of Xilinx FPGAs then before."
"I learned a lot about putting the software and hardware together. It was beyond theory".
"It was a nice experience to present an alternative to an industry solution with better features."
"I have learned a great deal of things from the contest: technical, mathematical, and the experience of the contest itself, the presentation of our work in front of such an exclusive audience".
"I learned a lot about complex system's planning and verification".

Several students' comments refer to the job offers or scholarships that they received after participating in this competition and meeting industry representatives:

"It helped me get a job in the embedded design".
"*For me, the 4th edition of the Diligent Design Contest was a career-changer... literally... At the end of my 3rd year at TUCN, I was looking for a job... and I found it thanks to the Design Contest".*
"The fact that I won a prestigious European contest contributed very much to the added value of my applications for the DAAD scholarship and the Master at the Technical University of Munich".

The second question of the survey investigated in which area the students think that they improved their knowledge and specific hardware and software skills in digital design: hardware-digital, hardware-analog, HDL languages and/or programming languages (Verilog HDL, VHDL, C++, C, Assembly language, etc.) or others. These topics are covered in digital design and embedded courses worldwide, and they are related to student's learning objectives for specific courses. Students were asked to use a scale from 1 to 10, 10 being the highest to rate these skills and to write comments explaining their rating. Hardware-digital, HDL and programming languages received the highest scores from the students participating in the contest. Over 75 % of the students who answered the surveys gave scores of 9 and 10 to these categories, being confident with their skills. Connecting different modules for the project and dealing with mechanical and electronic parts was a skill that students mentioned also, as others.

The third question investigates which engineering skills the students thought that they improved working on the projects for the contest. The skills mentioned were: problem solving, creativity and innovation, time management, team work. Students were asked to use a scale from 1 to 10, 10 being the highest to rate these categories. As expected, the highest scores received problem solving and creativity and innovation. Over 60 % of the students who answered the surveys gave scores of 8, 9 and 10 to these categories. Time management scored the lowest, this being one of the biggest issue for all the students enrolled in the contest, and the main reason that so many students drop the contest. Helping students to manage their time, to stay motivated and to finish the project, (without the pressure of getting a "course grade", is an important "lesson learned" by the all students, but also instructors and organizers.

The 4th question was related to student's motivation to enroll in this competition. Answers like making their own tools, putting in practice ideas and "dreams", challenge themselves, competing with other students were frequent. Suggestive students' comments include:

"*I wanted to share research experiences with the other student teams and receive feedback and advices from other engineers".*
"Meet new people, show others my ideas."
"I wanted to experience how a serious engineer works and feels".
"*To experience the emotions of a contest at a higher level".*

Additional questions in the surveys gave useful feedback to the sponsors and organizers of the competition related to the quality of their products, support materials, evaluation criteria, web page features, tutorials for various platforms and associated computer-based-tools, and how to organize better competitions.

Instructor's Surveys

Another survey was sent to the instructors (project advisers), with different questions.
One of the questions was asking how they encourage their students to participate in this contest or similar ones. Typical answers were: "*the students are also self-motivated*"; "*we find students [willing] to participate every year*". Free hardware coming from the organizers was greatly appreciated and considered a good starting point for developing competitive projects.

Reasons to encourage the students to participate every year were:
"*For the experience of meeting other contestants. It is a great chance for the cultural exchange".*
"It familiarizes students with how a complete project should be solved, starting with planning, implementing, managing errors, and time constraints such as deadlines".

V. **Conclusions**

Based on the results of a decade of design contest and feedback received from students, instructors and industry representatives, the authors of this paper have reasons to believe that the design contest brings great benefits to all the parties involved, despite various challenges and considerable financial and human resources allocated by the sponsors of the contests and host universities.

The students have a great opportunity to demonstrate their creativity, problem solving skills working for a project outside the class; learn how to write technical documentation and provide a good presentation of their work; implement a project from scratch and manage their time; better job and/or scholarship opportunities.
The instructors (advisers) gain experience in coordinating individuals or teams to create complex applications and keep the students motivated; have the opportunity to meet people with similar positions and share their teaching experiences; learn new technologies.
The universities gain prestige by hosting design contests and/or having student teams participating and winning national and international awards.
Industry representatives have the opportunity to evaluate the participants looking for potential employees; learn about the educational level of the future graduates.
The sponsors of the contest receive valuable feedback about their products and original projects showcasing their products that are posted on the company web page. They will continue to sponsor the contest in the future years with the support of local universities and highly motivated and enthusiastic instructors.

The interaction between people representing different parts of the world, with different cultures is a great accomplishment. Gathering representatives from different parts of the world to present their innovative projects and level of knowledge was a welcomed and innovative idea for design contests.

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