Enabling Creative Thinking in Digital Design Education

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Abstract
Creative thinking in all areas of Engineering is a must in today's extremely competitive world, due to the high demand of highly skilled and innovative engineers. In a recent article in Harvard Business Review, referring to U.S.A., it is argued that the country's economic competitive edge and destiny to stay on top in the era of high-tech industry is tied directly "to its openness to new ideas, which has allowed it to mobilize and harness the creative energies of its people".
This paper presents the results of an on going experience enabling creativity in digital design education, at Rose Hulman Institute of Technology, U.S.A. Using advanced programmable logic devices and CAD tools the authors of this paper try to encourage the creative thinking and the spirit of innovation to electrical and computer undergraduate students, while teaching discipline's specific knowledge and skills. To assess students' creativity, different assessment methods were used: students' surveys, instructor's surveys. As an alternative method to teach discipline specific knowledge and skills, encouraging creativity and innovation, a Digital Design Competition was organized. Students entered the competition with their own designs, featuring the capabilities of powerful FPGA boards.

Keywords: digital design, creativity, FPGAs, functional verification, projects, competition

1. INTRODUCTION

Creative thinking in all areas of Engineering is a must in today's extremely competitive world, due to the high demand of highly skilled and innovative engineers. In a recent article in Harvard Business Review, referring to USA, it is argued that the country's economic competitive edge and destiny to stay on top in the era of high-tech industry "is tied directly to its openness to new ideas, which has allowed it to mobilize and harness the creative energies of its people…..As Stanford University economist Paul Romer has long argued, great advances have always come from ideas. Ideas do not fall from sky; they come from people"[1].

Creative thinking is the first step to innovation, which is a desirable feature of an engineering graduate. Creativity (or "creativeness") is a mental process involving the generation of new ideas or concepts, or new associations between existing ideas or concepts [2]. Innovation is the process of selecting/combining, refining and turning the best creative idea(s) into reality. Both are equally important for universities and companies to be competitive. Investing generously in education to tap into future professional's creative capacities is view as one of the top priority items for the higher education community [3].

In engineering education, creativity, according to [4] is classified as a Higher Order Thinking Skills. Encouraging this type of skills is a desirable teaching goal in every engineering design class [4]. Creativity is also considered as one of the 13 fundamental objectives of Engineering Instructional Laboratories, such as: proper use of instrumentation, ability to perform experiments and data analysis, team work, learning from failure, etc. Objective 7 states: "Creativity: Demonstrate appropriate levels of independent thought, creativity, and capability in real world problem solving" [5].

This paper presents the results of an on going experience fostering creativity in digital design education, at Rose Hulman Institute of Technology, USA, a prestigious school dedicated to undergraduate engineering education. Using advanced programmable logic devices and industrial CAD tools in an undergraduate class, the authors of this paper try to encourage creative thinking and foster the spirit of innovation to electrical and computer engineering students, while teaching discipline's specific knowledge and skills. To assess students' creativity, different assessment methods were used: students' surveys and instructor's surveys. As an alternative method to teach discipline specific knowledge and skills and to encourage creativity and innovation, a Digital Design Competition was also organized two consecutive academic years. Students entered the competition with their own designs, featuring the capabilities of powerful Field Programmable Gate Arrays (FPGA) boards. Students' projects were judged based on originality and creativity, by a panel of jury representing academia and industry.

2. DIGITAL DESIGN EDUCATION AT RHIT

Rose-Hulman Institute of Technology (RHIT) is one of the USA's top undergraduate engineering, science, and mathematics colleges. The Electrical and Computer Engineering (ECE) Department offers both BS and MS degrees in Electrical Engineering and a BS degree in Computer Engineering.

Logic Design sequence of courses consists of two courses, one at the freshman level, ECE 130-Introduction to Logic Design and one at the junior level, ECE 333-Digital Systems. The second one, Digital Systems is a required undergraduate level course for Electrical and Computer Engineering students. The ECE 130-Introduction to Logic Design course provides the students with basic knowledge necessary for designing and analyzing combinational circuits, sequential circuits and Register Transfer Level Systems. Important course objectives for ECE 333- Digital Systems course include: designing synthesizable Verilog HDL code fragments implementing basic combinational and sequential hardware and Finite State Machines; implementing Algorithmic State Machines with handshaking; understanding metastability of digital circuit; partitioning a system into the control unit and data path unit; understanding the importance of functional verification, implementing testing strategies using an HDL based test bench and interpreting the results; understanding the architectures of different Programmable Logic Devices. The present format of the ECE 333- Digital Systems course includes 3 lectures and 3 hours of laboratory per week, during 10 weeks, in a quarter formats. Detailed information about the course can be found in [6]. In this particular class, the creativity and spirit of innovations were encouraged using the techniques presented in the next paragraphs.

2.1 Extensive Use of Functional Verification to Teach Discipline Specific Knowledge and Skills

A different approach to teaching discipline specific knowledge and skills in digital systems design was used, starting the academic year 2005-2006. The proposed approach modifies the content of the lectures, placing more emphasis on functional verification of hardware designs as opposed to the established method of teaching HDL semantics and syntax. The educational research study conducted by The Office of Institutional Research, Planning and Assessment at Rose-Hulman Institute of Technology, suggests that the extensive coverage of functional verification improves the learning process and the achievement of concepts and skills in digital design. The results of this research can be found in references [7] and [8].

What is the relationship between functional verification and creativity? According to reference [9], debugging designs involves creativity. Functional verification of digital systems is an essential component of debugging at the level of digital design. Developing a good testing strategy, writing complete test benches, practically debugging the designs before the implementation involves creativity. Also designing easy to test/debug modules is an important concept covered in digital design education. Reference [9] argues: “Pragmatic approach to debugging shares the same principles with the critical thinking approach within a typical design process. The formulation of effective teaching method to communicate debugging techniques to students is also based on these principles. In essence, we find the relationship between creative thinking, creative problem solving, creativity in design and debugging to be intriguing and instrumental to our discussion….. Are creative designs easy to debug? Do the students who are creative in design also possess good debugging skills?” The same reference proves/argues that “We view design for debug concept as not only a technical design attribute but also a product of creativity…. Creative thinking can be a framework in developing useful debugging exercises", concepts that the authors of this paper agree with.

2.2 Hands-on-Experiences

Creativity, being an important lab objective is emphasized through hands-on experiences. In the Digital Systems course, after mastering all the essential concepts during the first five weeks of the quarter, the concepts are incorporated into a design project, which is an essential part of this course that covers three lab sessions (three weeks). The projects assigned over the past 3 years were: Controller for Two-Floors Elevator; Controller for Traffic Lights; Controller for a Pig Game. The degree of difficulty and the specific requirements for the projects were gradually increased over the past four years. Students were strongly encouraged to expand the original specifications, adding extra features. Every quarter several teams expanded the original specification of their projects, including extra features at their own expense (extra hours work), showing a lot of interest for these projects and a lot of creativity. They were rewarded with extra points for their hard work. Examples:

- Controllers for an Elevator: extend the specifications to four floors instead of two floors, add safety features, specific messages for different floors, etc.
- Traffic Light controller: add night lights which are blinking for extra safety, implement a pedestrian crossing, etc.
- PIG GAME: add music to the game, emulate the sound of the rolling dice, display different messages for the winner and looser of the game, a "cheating" button, extend the specifications to allow more than 2 players at the time, etc.

Projects are divided in three stages and the students, working in team of two, are supposed to submit detailed reports after each accomplished stage of the project. First stage involves the conceptual design, showing detailed documentation for the design. Second stage involves functional verification of their projects, using Cadence NC-Simulator. The students are required to develop a testing strategy to verify their design and based on that to write thorough Test Benches (creativity strongly emphasized-see previous paragraph). Third stage involves: hardware implementation of their design on the FPGA boards (Digilent boards-based on Xilinx Spartan 3 FPGA chip), performance verification and validation. This stage involves the implementation of extra features.

2.3 Extensive use of FPGA boards

This academic year, 2007-2008, as part of another educational research project, other avenues for creativity are opened. A new approach, where every student owns his or her own programmable hardware system and CAD tool suite, is now feasible due to decreased costs. Starting in the winter quarter of the 2007-2008 academic year, every student enrolled in the ECE 333-Digital Systems course at Rose Hulman Institute of Technology was given a Digilent board, based on Xilinx Spartan-3 FPGA chips. A study is attempting to measure the effect on student learning when students own their own programmable hardware system, and have unrestricted access to programmable technologies.

This approach is different that the traditional way of conducting labs in similar courses. The vast majority of undergraduate programs that use programmable logic technologies provide only limited access to these technologies in 2 or 3 hour weekly lab sessions. The limitation of this traditional approach is the fact that 2 or 3 hours of lab sessions prove insufficient to meet all the lab objectives. Consequently, students might not develop the right skills required by industry, including creativity. Having unlimited access to powerful boards and CAD tools during an entire quarter, 24 hours a day, students may extend the specifications of their laboratory assignments and projects and experiment new designs on their own.

2.4 Organizing a Design Competition

Trying to organize and to integrate in a very packed curriculum a Digital Design Project Competition open to Electrical and Computer Engineering students is another way to foster creativity and the spirit of innovation. The challenge is to attract and stimulate the students who are already extremely busy. The students enrolled in the contest receive free boards donated by Digilent Inc, the sponsor of the competition, and they can keep the boards if they finalize their projects regardless of the final prize or position in the competition. This experience counts also as professional development (2 credits).

This competition gives the students the opportunity to demonstrate their creativity and spirit of innovation, problem solving skills, motivation to work for a project outside class requirements and to learn how to mange their own time. Students, working in teams of maximum 2, compete with original projects. The projects are judged by a panel of jury representing academia (ECE RHIT professors and technical stuff) and industry (Digilent Inc.) based on creativity, originality, feasibility, degree of difficulty. In the first edition of the competition, over 30 students enrolled initially, but only 10 finished the projects. In the second edition, over 20 students enrolled individually or in teams of two enrolled and four teams competed in the final.

Selected examples of innovative projects from the first and second edition are: “Laser Harp with variable volume and tone”, “Low Cost Oscilloscope”, “Audio Signal Equalizer”, “Spectrum Analyzer with VGA Display”, “Reactive Light Machine”, “Remote Control Robot”, “Oregon Trail”, Drum-O-Scope”, etc. More details about the competition can be found in reference [6].

3. ASSESSMENT DATA

3.1 Students’ Surveys

In this academic year, part of the educational research project regarding the extensive use of FPGA boards in digital design education (see part 2.4 of this paper), students’ surveys were administered as pre- and post- course surveys. Fifteen students (83% of the total enrolment) enrolled in the Digital Systems course participated in the assessment during the Fall quarter and 24 students (52 % of the total enrolment) in the Winter quarter.

The survey was administered anonymously, meaning that no identifying information was collected with the survey. The *pre-course* survey serves as a baseline for the level of understanding each student came to the course with, while the *post-course* survey assess the level of understanding students left the course with. The post-course survey contained these same 12 items as well as items concerning the use of logic boards in the class and the impact on their learning. The complete results of these surveys are presented in reference [10]. In the *post-course survey*, students responded to open ended questions regarding the impact of extensive use of programmable boards on their learning and effort, acquiring discipline specific skills (hardware and software skills), **creativity, innovation,** intention to continue in the engineering program.

FPGA Board Impact	Number of Response Fall 2007-2008	Percentage of Responses Fall 2007-2008	Number of Response Winter 2007-2008	Percentage of Responses Winter 2007-2008
How often did you use the FPGA boards during the quarter?				
A few times per day	1	7%	0	0%
Once a day	0	0%	0	0%
A few times per week	**4**	**27%**	**13**	**54%**
Once a week	5	33%	5	21%

A few times per month	5	33%	5	21%
Once a month	0	0%	1	4%
Less than once a month	0	0%	0	0%
Which of the following attributes did the use of FPGA boards help you develop?				
Generate new ideas (creativity)	**10**	**67%**	**17**	**71%**
Make improvements by introducing something new (innovation)	**12**	**80%**	**19**	**80%**
Hardware skills	14	93%	21	88%
Software skills	12	80%	24	100%

TABLE 1. Post course Survey- fall and winter 2007-2008-impact of the use of FPGA boards

The results, investigating creativity and innovation, suggest that the extensive use of FPGA boards encourage creativity and the desire of innovations, students being confident about these skills. The educational research continues during the spring quarter 2007-2008 and next academic year**.**

3.2 Instructor's Surveys

The following survey was initiated by the instructor during the academic year 2007-2008, fall, winter and spring quarter. The number of teams that added extra features to their project (the PIG GAME), and the degree of difficulty of these extra features were counted every quarter and a comparison will be made to see if the extensive of FPGA boards helps the creative thinking and at what extent. Complete results of these surveys will be presented at the time of the conference. Due to the small size of classes at RHIT (about 25 students), more data is needed to validate the results.

4. CONCLUSIONS

This paper shows the on-going educational efforts of the authors to encourage creative thinking and the spirit of innovation in an undergraduate digital systems class, which is a small niche in engineering education. The on-going effort and educational research will continue the academic year 2008-2009.

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