Innovation as Part of Electrical Engineers Education

***Abstract*—Unprecedented dynamics of the development of electronics could be easily tracked by comparing market figures for electronics versus steel, chemical and automotive industries in US and across the world. The multifaceted nature of semiconductor technology is clearly visible. Spinoff of such products as solar cells, Micro Electronic Machines, where electric motors of 3 microns in diameter are produced on silicon chip, biological sensors capable to monitor about 26 parameters of human body and extremely intelligent robots, all of these are base of already existing and future subfields of electronics. We would like to underline that the major factor, which made success of semiconductor electronics possible is the human factor, i.e., existence and participation of highly qualified electronic engineers and scientists. We examine how our electrical engineering education programs teach creativity and innovation. We suggest the ways of how can an innovation theory and practice be integrated into a very full engineering curriculum, so the electronic engineers graduating today, continue to create and innovate. This article examines engineering education trends at University of Massachusetts that reflect a growing commitment to assuring 21st century engineers have the knowledge and skills required to develop innovative technologies and products.**

INTRODUCTION

Dynamics of electronic industry

IT would not be an exaggeration to point out that progress of human civilization, better to say, improvement of our life style, everything that surrounds us is provided largely through progress of electronic technology. Unprecedented dynamics of the development of electronics could be easily tracked by comparing market figures for electronics versus steel, chemical and automotive industries in US and across the world. Regardless where we will start the comparison, from 1948, when the first transistor was invented, or from 1964, when the first integrated Silicon circuit was produced, the incredible pace of development of electronic technology, especially semiconductors, clearly surpassed everyone' imagination. At the end of 1964 the total factory cells did consist of $10 billion with semiconductor technology to be at the level of $0.15 billion. Than 15 years later, in 1980, the electronic technology value was $150 billion and semiconductors at $20 billion level compared to automotive sales of $180 billion that year. The steel market that year was $140 billion.

In the year 2000 that the automotive and electronic sales reached parity of $11 trillion across the world [1-3]. And in the year 2010 the electronic sales across the world reached $15 trillion with automotive industry be at the $13 trillion level. Based on statistics published recently [1-3] we, authors of this paper, can securely forecast that in 2020 the electronic industry sales will be about $18 trillion, where automotive market sales across the world will be about $14.5 trillion. Most important, as we expect, the semiconductor components' sales will surpass automotive market reaching the level of $15 trillion.

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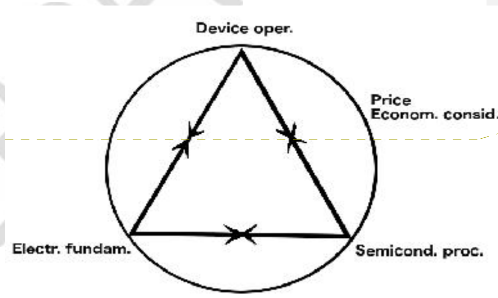
It is critical not to be dazzled by dollar figures mentioned above and address the real technical base of such unprecedented success of semiconductor technology. From the technical standpoint of view one should mention two major tendencies accelerating the development of electronic technology. Humans' need of processing steadily increasing flow of information delivered by our communication [4] and miniaturization trend of keeping our computers and telephones smaller in size and weight was realized thanks to ingenious work of semiconductor scientists and engineers [5-6]. There is no necessity to discuss basics of operation of semiconductor devices such as diodes, Field Effect Transistors (FETs), optoelectronic and/or quantum electronic components. It is sufficient to mention that semiconductor manufacturing handles the design, fabrication and testing of submicron features on a memory or a processor chips. One might want to compare the 1 micrometer size of bacteria or 0.5 micrometer size of biological virus with 0.1 micrometer dimension of the gate in field effect transistor. Ten billions of transistors on Intel chip is not the limit as we are moving too much smaller devices of nanoscale.

The multifaceted nature of semiconductor technology is clearly visible. Spinoff of such products as solar cells [7-8], Micro Electronic Machines (MEMs), where electric motors of 3 microns in diameter are produced on silicon chip [9], biological sensors capable to monitor about 26 parameters of human body and extremely intelligent robots, all of these are base of already existing and future subfields of electronics. We would like to underline that the major factor, which made success of semiconductor electronics possible is the human factor, i.e., Existence and participation of highly educated engineers and scientists.

Needed engineering know-how

A successful designer of electronics, especially semiconductor integrated electronics, faces multifold challenges. Figure 1 presents segments of knowledge, which are needed for the designer to be capable to create high-quality products and clear-cut vision of limits of semiconductor processing.

Fig. 1 Segments of knowledge a successful designer should have



One can imagine the symbolic position of a designer inside of the triangle, which is built of deep understanding of electromagnetic theories and basic principles of electronics combined with design principles of semiconductor devices. The symmetry of triangle symbolizes equal importance of mentioned segments of knowledge. The arrows on the sides of the triangle emphasize that moves between apexes of the figure are two-ways street, i.e., the know-how is inter-related. The outer circle emphasizes that at the end, the design and processing of integrated electronics should have well assessed production cost and market price. Finally, the critical ability of electronic engineer to be creative [10], i.e. innovative, requires discussion of special set

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of skills.

Where will this innovation skill set come from? Do our engineering education programs teach creativity and innovation? How can an innovation theory and practice be integrated into a very full engineering curriculum, so the electronic engineers graduating today, continue to create and innovate? This article examines engineering education trends in the United States that reflect a growing commitment to assuring 21st century engineers have the knowledge and skills required to develop innovative technologies and products.

Driving Innovation and Curriculum Changes

We live in an era of increasing technological sophistication. Smart phones, ubiquitous wireless connectivity, consumer-grade drones, and the Internet of Things reflect advances in technology only dreamed of twenty years ago. The timing of adoption cycles of these new technologies have also sped up, leading to rapid broad scale adoption of these devices among business and consumer cultures around the world [11]. These changes in technology adoption occur while we also witness dramatic changes in regional and national governments and economies as a result of globalization. Global challenges such as climate change, hunger, poverty, terrorism and cyber security require collaborative development of solutions that meet the needs of large numbers of people living and working in very different parts of the world. In short, the pace of innovation has increased in part due to technology as well to the demands and needs of our growing global society.

At the same time, the nature of work for engineers has changed in the U.S. While engineers were once guaranteed lifetime employment in major U.S. corporations; off-shoring, international mergers and changes in government funding priorities have reduced the number of professional engineering opportunities in large domestic companies and increased global competition for jobs [12-15]. Those engineers employed within large (and small) firms must now be more "entrepreneurial" within their organizations, bringing new ideas, technologies and products forward while competing in an environment with scarce resources [16]. Creed, Suuberg & Crawford (2002) [17] suggest that traditionally-educated engineering graduates are not adequately prepared for this new work environment, and urge the development of an "entrepreneurial engineer", one that is schooled in both science and technology education, but is also educated in team collaboration, communications, visionary leadership and opportunity-seeking [16]. In effect the characteristics of successful entrepreneurs.

There has been some movement on a national level toward the introduction of additional professional and business skills in the engineering curriculum. In the United States, organizations such as American Society for Engineering Education, National Research Council, National Science Board, and the National Science Foundation (NSF) called for changes to engineering education that would increase the experiential and professional nature of the programs [18]. Despite NSF funding efforts to encourage greater focus on professional and experiential experiences, we did not see initial adoption of these changes until the US accreditation agency ABET conducted a series of stakeholder workshops and published A Vision for Change (1995). ABET's efforts encouraged and catalyzed engineering programs to begin to shift from a focus on curricular requirements to student learning-outcomes. Concurrently, an increased emphasis on exposing students to

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the needs and culture of industry and the engineering profession began to take route. However the introduction of actual entrepreneurial thinking and entrepreneurship activities (e.g., pitch contests, competitions, entrepreneurship classes) did not really start to penetrate the engineering curriculum until the mid to late 2000's, after the Dot.com boom and bust gave rise to a new generation of technologies and technology entrepreneurs. Increasingly, the engineering alumni and industry partners (often the same people) began to ask for additional business and entrepreneurial skill sets in the engineering graduates they were recruiting.

This pressure from industry partners and alumni coincided with a growing acknowledgement at the federal level that innovation and entrepreneurship were critical to assist the US economy in recovering from the recession of 2008. The National Science Foundation launched their Innovation Corps (I-Corps) program which funds and trains NSF researchers and teams in the fundamentals of venture startup. Alexander Osterwalder [19] and Steve Blank [20] introduced popular visual and process oriented methods to venture development (Business Model Canvas and Lean Launch Pad) which shifted an entrepreneur's focus from the creation of a static 50-page business plan to a more visual "in-the-field" experiential approach to startup launch. Federal agencies like the Small Business Administration, the Economic Development Agency, National Science Foundation, as well as private foundations like the Kauffman Foundation and Lemelson Foundation provided multi-millions of dollars in funding to educational, community and economic development organizations to encourage the development of new approaches to encourage and support entrepreneurship. VentureWell (formerly the National Collegiate Inventor and Innovator's Alliance), a non-profit specifically focused on encouraging invention and entrepreneurship among higher education students partnered with Stanford University to launch an NSF-funded program specifically focused on increasing the number of engineering programs in the country that integrate entrepreneurship programs, spaces and experiences into their curriculum. The Pathways to Innovation program is a project conducted by the National Center for Engineering Pathways to Innovation (Epicenter) to support engineering programs across the country in integrating accessible and effective innovation and entrepreneurship courses into formal and informal undergraduate engineering curriculum. Epicenter's mission is "to unleash the entrepreneurial potential of undergraduate engineering students across the United States to create bold innovators with the knowledge, skills and attitudes to contribute to economic and societal prosperity" [21]. Over 50 colleges and universities from across the US have signed on to the Pathways program and are actively engaged in developing courses and activities that engage engineering students in learning about and "doing" entrepreneurship. The proverbial train has left the station in this regard.

Methods And Approaches

So how does an engineering program integrate engineering into a very comprehensive and crowded curriculum? Who should lead the charge and how do we engage faculty and students? Are we now developing business majors rather then engineers? All very reasonable questions.

We did find a way to answer these very realistic questions by practical changes in EE teaching programs. The major method of expanding creative thinking of our

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undergraduate and graduate students are questions which we put in front of class after discussion of every conventional textbook. An example of circuitry design or fabrication steps, namely, we expect our students to suggest an improvement of the design or modification of processing technology steps. We teach them not to think that the textbook chapter offers the most perfect circuitry cases and not to be fascinated by what is written in the textbook. The base for our approach counts that textbook writing and publishing takes 2- 5 years. During that time electronics technology has changed significantly. As obligation to be creative we during exams ask our students to come up with new concepts, not expecting detailed description of a concept.

In our graduate classes on solid-state electronics, MEMs, etc. we require that the final exam should be the design project. The most important aspect of design project is its novelty, i.e. it should not repeat already known developments in circuitry design or in semiconductor technology. We measure the success of this approach by the number of design projects which reach publishable results and appear in professional journal or professional conference.

The truth is that the rate of success of this approach is not 100%. Only 50 – 75% of these projects are submitted for publications [7-9].

It should be mentioned that the aspect of cost of novel products is central for innovative thinking. That is why our undergraduate and graduate students are required to take classes on economics. We often suggest our students take a double major, where in addition to their EE diploma they are asked to take classes in business.

The University of Massachusetts Lowell (UMass Lowell) offers an extra curricula program called Difference Maker in an effort to support student innovation. The Difference Maker program contributes to UMass Lowell's entrepreneurial ecosystem and supports growth of new businesses and industries by allowing students to apply their education through experiential learning [22]. The Difference Maker program was launched in June 2012, under the auspices of the Center for Innovation and Entrepreneurship at UMass Lowell. The goal of the program is to introduce students to creative problem solving, innovation, and entrepreneurship, as well as accelerate purpose in their education, connect them to experienced alumni, and encourage an ethos of social responsibility [23].

Difference Maker presents a range of extra-curricular and co-curricular activities that span disciplines to undergraduate and graduate students. These activities are meant to engage students in creative entrepreneurial action by developing sustainable solutions, products, services, organizations, and businesses to problems that affect our community, our region, and our world. The program helps students develop an understanding of how their UMass Lowell education will assist them in making a difference in the world [24].

Difference Maker is guided by a three-phase process: raise awareness, build skills and concepts, and then launch ventures. Freshman Orientation, Convocation Pitch Contest, the Difference Maker® Living Learning Community and countless classroom visits raise awareness among UMass Lowell students regarding both the potential for entrepreneurial thinking to assist in solving important problems, and also demonstrate the University's commitment to supporting our students in solving these problems through entrepreneurship.

The Idea Challenge workshops, college-based pitch events, rocket pitch coaching and mentoring are meant to provide students with the skills they need to develop an idea

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into a venture plan, including an understanding of markets, opportunities, customers, business models and business planning. Whether they propose a low-cost,

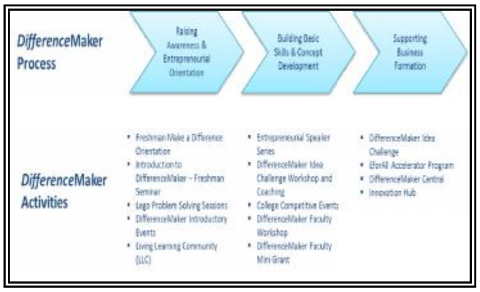

Fig. 2. Magnetization as a function of applied field. Note that “Fig.” is abbreviated. There is a period after the figure number, followed by two spaces. It is good practice to explain the significance of the figure in the caption.

adjustable prosthetic limb; a social service organization to address student hunger; or 3-D printed dentures – all teams are schooled in the basics of venture development.

CONCLUSIONS

While we entrust the primary responsibility for educating innovative engineering students to our faculty, our experience at UMass Lowell suggests that faculty efforts can be successfully complemented with extra and co-curricular programs like Difference Maker. This program extends learning beyond the classroom, physically and temporally. In doing this, it also provides for real-time application of knowledge in an experiential manner. If our earlier premise is accurate – that an increasing global demand for innovative technologies requires the education of entrepreneurial scientists and engineers - and we accept the fact that the engineering curriculum currently has limited space for additional coursework, extra and co-curricular programs that raise student awareness and skills around innovation and entrepreneurship offer one path to student success.

References

1. 2000 “Electronic Market Data Book”, Ind.Assoc., Washington, D.C. 2000

2. 2000 “Semiconductor Industry Report”, Ind.Techol. Res. Inst., Hsincho, Taiwan 2000

3. S. M. Sze, “Semiconductor Devices, Physics & Technology”, book,Wiley & Son, 2002

4. S. Milshtein and P. Ersland, “Progress of Quantum Electronics and Future of Wireless Technologies”, review paper, Microelectr. J.,Vol. 39, 669-673, (2008).

5. S. Thompson and S Parthasararhy, “Moores law: the future of Si microelectronics”, Mater. Today, pp20-25, 2006

6. M. Leong, V. Narayanan, D. Singh, A. Topol, V. Chan, and Z. Ren, “Transistor scaling with novel materials”, Mater. Today, pp26-31, 2006

7. S. Mil'shtein, J. Valenzuela (invited) "Modeling and Performance Expectations of Polymer Solar Cells", NASA,First Intern. Sympos,Nanotechn., Energy & Space, p.25 (2009)

8. S. Mil’shtein and J. Palma, “Improved Energy Harvesting by Cascaded Solar Cells” 3rd Internat. NASA Sympos. on Nanotechnology, Energy and Space, P47, 2013.

9. Jorge Valenzuela and Samson Mil’shtein “Applications of a Navigation Instrument Based on a Micro-Motor Driven by Photons” (invited), Sensors & Transducers

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Journal, Vol. 13, Special Issue, pp10-20, 2011

10. S. Mil'shtein, "Developing Student's Innovation Skills for Globalized Electronic Industry", Proceed. IEEE Intert.Confer. on Transforming Engineer. Education., pp 1-22, (2009)

11. Kurzweil R. 2001. The law of accelerating returns. Essay, March 7. Available online at www.kurzweilai.net/the-law- of-accelerating-returns.

12. Minniti, M., Bygrave, W., & Autio, E. (2006). Global Entrepreneurship Monitor: 2005 Executive Report. In G. E. R. Association (Ed.), (pp. 67). Babson Park, MA: Babson College.

13. Rover, D. T. (2005). New economy, new engineer. ASEE Journal of Engineering Education, 94(4), 427-428.

14. Wei, J. (2005). Engineering education for a post-industrial world. Technology in Society, 27(2), 123-132.

15. Yurtseven, H. (2002). How does the image of engineering affect student recruitment and retention? A perspective from the USA. Global Journal of Engineering Education, 6(1), 17-22.

16. Menzel, H. C., Aaltio, I., & Ulijn, J. M. (2007). On the way to creativity: Engineers as intrapreneurs in organizations. Technovation, 27(12), 732-743. doi: http://dx.doi.org/10.1016/j.technovation.2007.05.004

17. Creed C. J., Suuberg, E. M. & Crawford, G. P. (2002). Engineering Entrepreneurship: An Example of A Paradigm Shift in Engineering Education. Journal of Engineering Education, (91): 185–195. doi: 10.1002/j.2168-9830.2002.tb00691.x

18. Lattuca, L. R., Terenzini, P. T., Volkwein, J. F., & Peterson, George, D. (2006). The Changing Face of Engineering Education. The Bridge, 36, 5–13.

19. Osterwalder, A. and Pigneur, Y. (2010). Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers, Wiley.

20. Blank, S. and Dorf, B. (2012).The Startup Owner's Manual: The Step-by-Step Guide for Building a Great Company. K&S Ranch Publishing LLC.

21. Nilsen, E., Besterfield-Sacre, M. & Monroe-White, T. (2015). Landscape Analysis as a Tool in the Curricular Change Process. 2015 IEEE Frontiers in Education Conference, 110-116.

22. Catona, T., Tello, S., O'Toole, B. & Avdeev, I. (2016). Pathways Partners: Entrepreneurial Change Across Campus. Journal of Engineering Entrepreneurship, 7(1) 35-48.

[23] Catona, T., Tello, S., O'Toole, B. & Avdeev, I. Pathways Partners: Entrepreneurial Change Across Campus. Journal of Engineering Entrepreneurship, 7(1) 35-48, (2016).

[24] Tello S., Latham S. & Butler H. Learning by Doing: Student and Faculty Perspective on Experiential Learning, National Collegiate Inventor & Innovators Association Annual Conference, San Francisco, CA, March 22-24, (2012)..