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Professional Education for the 21st Century Workforce

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Abstract*—This paper offers a brief history of the development of professional 'engineering' curricula across the last six decades. The affects occasioned by Sputnik, Japanese quality triumphs, the growth of microelectronics, and how subsequent skills deficiencies were addressed by IBM and the professional society community are discussed. Future curriculum or educational problems need cross- or inter-disciplinary solutions. The adoption of project-based learning regimes, emphasizing collaboration, students learning together to solve ambiguous problems, and acquiring modules of theory as necessitated by the problem being dealt with is recommended**. **In short -*"learning by making and creating rather than from the simple consumption of content."

***Index Terms*—Education, Engineering Curricula, Future Workforce, Project-Based Learning.**

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I. INTRODUCTION

It is acknowledged by many 'experts' that the World is changing; it has been changing for many centuries. However many of our cultural and social arrangements do not necessarily keep pace with these changes. There are many dichotomies, and to some social change is perceived as being fast, almost impossible to handle, while organizational or administrative change possesses a different impedance and time scale.

The scale, scope and pace of technological change has grown exponentially while beliefs, cultures, customs, habits and traditions remained almost unchanged and surround us like ghosts from prior centuries. This paper endeavors to trace engineering curriculum developmental trends and their context across the last six decades. Examples of adjustments and curricula augmentations will be discussed. Alternative pedagogical schemes for generating stimulating and practical learning experiences for the present and future workforce are discussed and suggested.

II. FAST FORWARD

Just over 56 years ago, in October of 1957, the Russians launched Sputnik successfully and surprised a world audience. This historic achievement had a disruptive influence on science, technology, engineering and mathematics (STEM) education in the US. As a result the sciences received greater emphasis and focus, meanwhile practical skills and manufacturing 'arts' became de-emphasized as being unsuited for baccalaureate programs [1]. This adjustment was to have far reaching impacts that may still haunt current practice. Our American academic 'models' have gradually matured and now with modified formats are having some pervasive effects in other nations. Today US research universities are held in high esteem; our research and funding continues to garner respect today. Nevertheless 'technical' programs are still regarded with some slight disdain.

III. 1970'S AND 1980'S

Commercial competition from Japan increased through the late seventies and then eighties; there were balance of payment issues, and every major US industry had task forces studying Japanese methods. Total Quality Management, and Quality Circles became a powerful mantra and various professional groups, together with the National Science Foundation (NSF) and the National Academy of Engineering (NAE) spawned endless reports and studies [2]. Overall these called for broadening of the traditional engineering curricula to very definitively embrace the newer manufacturing processes and technologies, together with an awareness of business factors, communication, information technology (IT), project planning and management. The value of adapting IT for the management and planning required by these advanced technology products was highlighted. Computer Aided Design (CAD) and Numerically Controlled (NC) machine tools were much sought after. The Society of Manufacturing Engineers spun off a special section entitled 'Computer Automated Systems Association or CASA. The perceived and even real threat from Asia became a reprise of the 'Sputnik' panic of the late fifties and the content of then current engineering curricula was challenged.

IV. 1990'S TO 2002

Leading academic and industry personnel formed Task Groups actively examining deficiencies in engineering curricula. SME, the Society of Manufacturing Engineers, published a 1988 study entitled "Profile 21" dealing with the ideal content for the education of a successful manufacturing engineer [3]. Manufacturing and production systems courses and laboratories regained some prominence. A division of SME was responsible for a series of conferences that generated heavy volumes of papers with Volume I being published in 1995 [4]. In 1999 the National Academy Press published the NSF-NAE findings as *"Visionary Manufacturing Challenges for 2020* [5]." International groups also joined the fray in 2001 and the Intelligent Manufacturing Systems (IMS) Steering Council accepted a proposal submitted by Asbjørn Rolstadås in 2002, "*GEM - Global Education in Manufacturing* [6]." 2002 also saw a paper presented to the International Council for Production Research (CIRP) on *"Education for Future Manufacturing* [7]." It was notable that the general focus and tenor among the academic and professional communities at this time became very similar to the attitudes towards Sputnik and the threats posed by Japan in earlier decades.

V. MICROELECTRONICS SKILLS SHORTAGES – PLUS A SOLUTION

In the late sixties and early seventies transistors and integrated circuits were making headlines. The design and manufacture of these devices came to the fore requiring different workforce skills, technologies and disciplined clean rooms. The response of the academic world seemed lethargic. IBM was committed to the new technologies and ran internal programs to transform the workforce from what had been primarily electromechanical assembly tasks to semiconductor manufacturing. Computer Assisted Instruction (CAI) pairing keyboards and printers provided a means for independent studies; graphics and a mouse were yet to be developed. Flip charts, easels and 2x2 slide sets were more prevalent, eventually to be succeeded by overhead projectors with sequences of foils with access amplified by making video recordings – again advanced technology for that era. IBM also funded the development of a Master's Program at the University of Vermont in 1973; this was designated as the Large Scale Integration or LSI program. Employees from worldwide sites were relocated to Burlington, Vermont, for one year to participate in this program and develop an appreciation and understanding of semiconductor design, manufacturing processes and associated manufacturing systems philosophies. In parallel the major professional societies, primarily ASME, IEEE, and SME developed appropriate Section structures and provided conferences, publications and supporting events.

VI. IBM MANUFACTURING TECHNOLOGY INSTITUTE (MTI)

In the late seventies an IBM Task Force was charged with reviewing manufacturing capabilities and performance. The Task Force concluded that technical leaders throughout the Corporation needed opportunities for revitalization and to acquire an appreciation for trends affecting future manufacturing. The establishment of a Manufacturing Technology Institute within the Corporate Technical Institutes group was recommended. The Institute was charged to improve the business, communication, logistics, management and teamwork abilities and advanced technological awareness of graduate engineers that were already experienced in the IBM workplace and to not forget the rising importance of information technology. Classes commenced in summer of 1981. The first 45 students, senior IBM employees from worldwide locations were welcomed for a ten week program in Manhattan that fall [8]. The program received good ratings and was in heavy demand. A parallel program was launched in Belgium. The hypothesis that formed the basis of the MTI curriculum was that a manufacturing system needed to be understood and managed as a totally integrated operation from the initial product concept out to delivery to the revenue customer and eventual product end-of-life. This was a relatively novel construct when it was first enunciated. The earlier and immediate success of this internal cross disciplinary curriculum reinforced the thesis that most baccalaureate engineering programs were not developing the 'soft' and somewhat intangible skills required of future leaders in high technology industries. The next step lead by IBM was a Request for Proposals (RFP) for Masters programs to complement the education of baccalaureate engineers. After some 115 proposals had been reviewed over $10M together with equipment grants were awarded to Georgia Tech., Lehigh, RPI, Stanford and Wisconsin-Madison to set up Manufacturing Systems Engineering programs. The cross disciplinary Lehigh MS in MSE Program opened for business in the Spring semester of 1984, and by fall 2013 boasts of graduating 396 alumni [9].

VII. MS IN MSE PROGRAM GROWTH AT LEHIGH

The response to an RFP from the AT&T Foundation in 1991 produced funding that allowed establishment of a parallel part-time offering running Thursday evenings and all day Friday, sharing plant tours and some classes with the full-time residential students. Companies were enthusiastic in adopting this graduate education opportunity for their 'tagged' high performance engineers, and even transferred employees (and families) from Asia to take advantage of the part-time or partial release component of the Lehigh program. The next major development came in the form of a grant from GM to develop a course embodying the principles of the 'Agility Forum,' a group headquartered at Lehigh [10] [11]. The course *"Agile Organizations and Manufacturing Systems"* was team taught to combine content, opinions and experiences from a variety of business and engineering faculty together with visiting industry practitioners. Initially, in 1997, this course was captured on VHS tapes and distributed overnight for asynchronous viewing by students at GM sites in Canada, Mexico and the US. Up to seventy GM employees registered in other MS programs at Kettering, Michigan and Purdue were enrolled every fall semester. As technologies progressed this course went via satellite, and ultimately defaulting to the rapidly improving web in 2002. An elective course on *'International Supply Chains'* was introduced at the behest of an Industrial Advisory board in 1998, followed by a course on Sustainability in 2003 – these are now offered alternate years, as is the *"Agility…"* course. A majority of students take classes spread over 3-4 years, with occasional on-campus students taking 3 or 4 semesters. A web site displays the 30 credit curriculum [12]. Today all MSE-numbered and cross-listed courses are wholly available via web both as 'Lehigh Live' or asynchronously. The participation and classroom inputs of the full-time employed Distance students contributes immeasurably to the learning experiences of the on-campus students in other Lehigh programs that are able to share these classes. Additionally students in many MSE courses are required to collaborate and work in teams on specific class projects. Teams are assembled with managed combinations of employees from different companies and with diverse degrees, experience and backgrounds. Asynchronous students, students with different shifts and/or time zones are assigned so as to create diverse groups and amplify overall collaborative learning experiences.

VIII. INTERNATIONAL FACTORS

In the early years of the first decade of the twenty-first century cross- and interdisciplinary academic collaborations became more acceptable and customary. "Globalization," "Innovation," "Integration," "Logistics," "Supply Chains," and "Teamwork" entered the vocabulary in business, engineering and management curricula. Relationships developed through contacts, meetings and negotiations during the 'Global Education for Manufacturing' project have resulted in useful contributions to Lehigh classrooms and discussion from Norway Technological University (NTU), Nottingham University and Tokyo Metropolitan University (6). However, it has not been found possible to share curricula, exchange courses or maintain 'open' virtual classrooms across diverse campuses as a regular feature. In fact, given access to the web it is technically fairly straightforward to run classes in parallel multiplexed across separate institutions. Ideally this is possible, and provided contributions from all collaborating parties were approximately at parity there is no seeming need for tortuous financial arrangements. Each campus could administer, manage, grade and certify the performance of their students to suit their needs. Such procedures would strengthen the offerings for all participants, but for now this remains a 'pipe dream.' Currently it has been possible to arrange occasional virtual visiting lectures, and sometimes Lehigh registered students join discussions or presentations while based in Asia or Europe – but more thorough web globalization, exchanges and implementation are yet to be realized. Future IMS assemblies could ponder this concept (6).

IX. MISSING SKILLS

It is the author's hypothesis and practice that students learn by doing, collaborating and working in teams, and by becoming capable of appreciating the context of the problems that their profession requires them to solve. There is inevitably a requirement to understand the needs and be capable of communicating with accountants, planners, and a phalanx of non-technical associates, not forgetting cultural and global considerations and factors. Context here involves many ideas – as Adam Davidson suggests in an article from the New York Times, "*Skills Don't Pay the Bills*" and he quotes an anonymous worker – *"Running these machines requires a basic understanding of metallurgy, physics, chemistry, pneumatics, electrical wiring and computer code. It also requires a worker with the ability to figure out what's going on when the machine isn't working properly* [13]*."* Our idealized curriculum must encourage and promote the development of broad ranging curiosity in students, and particularly reward innovation, and outside-the-box thinking patterns. The employees or students must be empowered and imbued with sufficient curiosity to be self-learners, capable and conscious to collaborate well in a variety of team situations. Lawrence H. Summers suggested in the New York Times [14] that learning how to acquire and process information is of greater importance than imparting and measuring it. The ongoing changes in communication are giving different and pervasive access to new discoveries, knowledge, and of the urgent needs of present and future societies. These issues must be addressed collaboratively with the thoroughgoing cooperation of the affected administrations, and potential customers. Any related and necessary coursework must be integrated to reflect the societal context, the importance and significance for all engaged and likely to be affected. The increasing use of social media together with improved search engines should enable rising generations to access information with ease and solve problems that may have been previously considered intractable. There is a potent quote and some valid projections from a recent article in the Chronicle of Higher Education [15] that our academic programs must shift toward *"learning by making and creating rather than from the simple consumption of content."* Hunter Rawlings [16] has expressed similar thoughts *"In brief, students learn by solving problems, not just by listening to someone else, not by positively absorbing concepts; they learn best in groups of peers working things out together."* A recent '*Commission: Ideas for a New American Century'* engaged former Governors Haley Barbour (Mississippi) and Evan Bayh (Indiana); they have suggested inverting the baccalaureate process and securing agreements with industry to open up apprenticeships immediately following high school. Students would secure 'in factory' practical job experience and then go to college, probably part-time to acquire more traditional coursework leading to associate degrees [17]. As Sir

Kenneth Robinson [18] has pointed out in numerous talks on innovation, encouraging creativity is of paramount importance. In fact, it would seem that accreditation processes are an anomaly. Our custom of having hard working dedicated teams of experts critiquing the work of experts who are their peers has a suffocating effect on important and novel curricula developments. Creativity, innovation, out-of-the-box thinking skills are not enhanced within a highly structured prescriptive academic environment. There is a need for more levels of chaos, inspiration, self-organization, communication, collaboration, imagination and teamwork among the whole academic community. Laszlo Bock, senior vice-president of people operations for Google deserves the final word in this debate [19]. Google focuses on cognitive or learning ability, a knack of bringing together many, possibly ‘off the wall,’ information sources. These assets must be melded with leadership characteristics, knowing when to step back, and humility in accepting other ideas. The need for strong technical abilities for the specific task on the horizon goes without saying together with curiosity and habits of life-long learning.

X. A 21ST CENTURY CURRICULUM

When we step back and view aging academic catalogs it can be perceived that course titles and descriptions may have been tweaked, adjusted, new ‘buzz’ words or current clichés added here and there, and one or two excitingly brand new high tech. and bio- or nanotechnological topics inserted. Notwithstanding the awesome and comprehensive changes in technology since the eras of log tables and slide rules there has been less change in testing, grading and pedagogy. The academic workplace is very different and disparate from the industrial workplace environment. Our present pedagogical systems have barely changed in a structural and format sense; ‘Yes,’ there are additions, and extras inserted into an overloaded curricula but creative and dramatic changes are left to adventurous outliers. We do mix students from different disciplines and colleges together in many classes. They all benefit from rubbing shoulders, sharing concerns, working in teams, and from learning to communicate and understand each other but generally they remain tied to the specific content and inelasticity imposed by an accredited curriculum. Cross-disciplinary content has to be suitably structured for students with initial degrees or interests in many different disciplines. Also it is important to make elective courses available to allow students to specialize or become familiar with particular foci that may interest them, or prepare them for making contributions by understanding the research and vocabularies in specific industries. As this century advances it will become increasingly important to empower students to develop sufficient curiosity to become self-learners and our academic structures should adapt to accommodate these aims. An important factor should include student studies in collaboration with research, development and manufacturing sectors by way of internships, co-op programs and part-time assignments. Programs that students seem to find attractive, and that are often oversubscribed, are not the single discipline traditional offerings. These are ‘mongrel’ curricula that borrow courses from different colleges and overcrowd the labs with strangely configured art and other perhaps more practical projects. The notions of Barbour and Bayh are not too crazy [17]. What if academic and practical credits could be accumulated in a similar way to merit badges in scouting? The distinction between vocational coursework and academic studies needs to be eliminated – engineering education should be all about learning and developing abilities to solve ambiguous problems, understand and appreciate the context of these problems, the costs and ramifications, their possible solutions and impact on society, and the environment. Coursework needs to be available as called for by the needs of the scope of problems being considered. A library of on-demand modules using technology, Distance Education archives, YouTube and TED etc. could impart the necessary theoretical information as and when it was required. Testing and measurement would then commence to simulate operations in a ‘real world’ environment; multiple choice assignments and quizzes would become irrelevant.

XI. SUMMARY

Large scale adoption of the notions expressed above would require de-emphasizing disciplines and possibly pursuing single credit modular structures grounded in collaborating self-selected study projects with individualized learning contracts. Doing and making would be emphasized, but also with a concomitant focus on explanations, descriptions and well-structured laboratory notes to be created by the student. This would incorporate ‘Project-Based Learning’ (PBL) or ‘Learning by Doing.’ This ‘Experiential Learning’ defines a pedagogic method going back to the time of Confucius around 450 B.C. [20]. The manufacturing system treated generically and holistically is the epitome of a cross- and inter-disciplinary system. Going back to the quote on the skills and knowledge needed to fix a recalcitrant machine; these types of skills are not transferred or developed very successfully using chalk-on-board, pens on paper, reading words in heavy texts, and quizzes. Time spent watching YouTube may assist in solving the problem. Or alternately, and better still, searching for others with similar problems using Facebook, Twitter or other social media, technology etc. Finally genuine and memorable learning can occur when metaphorical 'finger nails get dirty and broken!' Once students are encouraged to challenge uncertainty and ignorance then doing this the next time becomes easier. It is hard to deny the reported facts that almost two-thirds of employers say that job seekers are deficient in *"communication and interpersonal skills, can't think critically and creatively, solve problems or write well."*[21] The output of our academic systems is far from ideal. Good students can manage to succeed in the workplace but, in many cases, they could be better prepared. Recent articles express customer dissatisfaction with much current practice at all levels from K-12 through fossilized curricula often administered in 'silo' fashion by competing departments and colleges [22]. A key notion must be that every commercial, industrial or manufacturing system extends for many layers beyond actual factory physical output or the point of final assembly and subsequent distribution and service. An engineer that wishes to solve problems, generate revenue, and assist an operation to satisfy and even delight customers by establishing relationships and providing service must be aware and conscious of the integration of all the activities from initial concept out to the final end of the product/service life cycle with eventual reclamation, recycling, or re-use. This whole system is required to be 'sustainable' and thus as 'trauma-free' and thermodynamically efficient as can be achieved. These attributes called forth by the enduring needs of our planet are difficult to incorporate in a world that comprises diverse populations, business and economic conditions, not to forget stringent political factors and a sensitive environment. Finally, the tools are available to curious and motivated students that can secure adequate mentoring. There are many truly excellent 'craft' and 'vocational' avenues available, but they deserve emphasis and more secure funding support. At the undergraduate levels cross-disciplinary project-based approaches are desirable, 'silos' need to be broken down. Course modules must take greater advantage of video technologies, with practical 'real-world' examples to create smaller more flexible modules. Distance Education has a role to play, as do 'Webinars.' Sharing and collaboration should be encouraged both among departments, but also among institutions and companies. In fact, certifying attainment levels and skills could be achieved with appropriate administration, leadership and modifications to the schemes adopted by the bodies that oversee Professional Engineering registration. Finally responding to expressed needs of the customers, the future employers, rather than obeying the dictates of accreditation could improve the appetites of our students for attacking more difficult and ambiguous problems. A degree does not need to consist of 120+ credit hours of mind numbing calculations when actual real-world practical and often spectacular problems could be being addressed.

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