ISE

Industrial and
Systems Engineering

The Future City Competition - A Successful STEM Experience for Middle School Students

Keith M. Gardiner
Lehigh University

Report: 09T-010

The Future City Competition - A Successful STEM Experience for Middle School Students

Keith M. Gardiner, Lehigh University

K-12 Education (Engineering Curriculum Integration)

The Future City Competition for 7-8th grade students completed the fifteenth year of offering during Engineers Week in February, 2007; it continues to build on success. The program is described showing how principles of science, technology, engineering and mathematics (STEM) are wedded to communication and teamwork to provide an invaluable experience for increasingly diverse groups of middle school students and their classmates. The primary aim of the program is to nurture and enhance interests in engineering and science by affording students practical opportunities and engagement in productive and competitive team-based activities that are fun. Now some 30,000 students become engaged in the competition every fall. The history, program logistics and statistics are covered briefly. The author is a member of the FCC Advisory Board.
Key Words: K-12 Education, STEM, Middle School Engineering

Introduction

Last February, when Engineers Week 2007 concluded over 30,000 7th and 8th grade pupils had enjoyed a valuable Future City **s**cience, **t**echnology, **e**ngineering and **m**athematics (STEM) experience. In all, over 1,000 schools spread nationally across 39 regions entered the required 3 students in the 2006-2007 version of the competition [1]. Ultimately, following a busy fall semester of creative engineering activities, largely outside school hours, 35 regional winning teams qualified to attend the National Finals in Washington D. C. The masters of ceremonies at all these types of events are adept at assuring us that all the competitors are winners; it is not only quite difficult, but even invidious, to differentiate, score and award prizes. However, competition affords powerful incentives that drive the students, their teachers and engineering mentors to impressive achievements. The Future City Competition is fun; the output, contributions and presentations of the participants are measured rigorously, debated, discussed, and scored by engineers. The thoroughgoing implementation of the competition is all about engineering, communication and working in teams. It is not just a computer game, architecture, city design and some model construction.

It was 1992 and a different age and decade when the Institute of Electrical and Electronic Engineers (IEEE) developed the idea of utilizing the popular SimCity™ software as the basis for a competition for middle school pupils under the aegis of National Engineers Week [2,3,4]. Since the first Washington finals in February of 1993 the competition has grown and prospered under an umbrella afforded by the E'week Joint Planning (or Steering) Committee hosted by the National Society of Professional Engineers (NSPE) (Figure 1). NSPE were the initial instigators of E'week back in 1951 [5]. More recently the FCC has developed its own Board, and substantial funding comes through the National Engineers Week Foundation (a 501(c)(3) entity). None of

the growth which has occurred over the fifteen years of the program would have been possible without armies of enthusiastic volunteers in the regions, the regional coordinators and a remarkably accomplished and dedicated National Director, Ms. Carol D. Rieg [6].

Engineers' Week is a celebration of engineering and engineers recognized nationally, every February, around Washington's Birthday. General Washington, with the approval of the Continental Congress appointed the first Chief Engineer, this lead eventually to the formation of a Corps of Engineers and, under Jefferson in 1802, the Military Academy at West Point directed to develop US military engineering skills [7]. Since 1951 the leading US engineering professional societies have collaborated in funding, encouraging, initiating, organizing, and sponsoring events nationally and regionally aimed at improving public awareness of the contributions of engineers and engineering. Events and promotions by local chapters and engineering schools are also encouraged. A most significant objective is to encourage rising generations (K-12) to focus on Science, Technology, Engineering and Mathematics or "STEM" topics and to consider engineering as a future career. A major aspect is a focus on enhancing the technological literacy of the whole community.

The context

For the last half-century, and even since the beginning of the industrial revolution, there have been serious concerns not unlike those in the time of George Washington about education in engineering, sciences and technology. For example, the development of tanks and the obsolescence of cavalry in the later stages of the first World War showed the relationships of advanced technology to warfare. The Spanish Civil War (Guernica) and then World War II demonstrated the effects of aerial bombardment followed subsequently by the development of nuclear weapons that further emphasized the importance of technology to national defense.

American concerns for STEM education were awakened by the Cold War and the launch of Sputnik by the USSR in 1951 [8]. A renewed national focus on science education and research followed. Eventually the initial impetus eased and declined as result of alternative budget pressures and a comfortable perception of technological supremacy following the 1969 Moon landings. US engineering education was revered worldwide and universities were inundated with offshore applications throughout the later decades of the last century.

Even so in the late seventies and early eighties it was noted that US engineering graduates were, to a large extent, deficient in broad ranging skills relating to business, communication, management and ability to collaborate and work well in teams. These deficiencies were recognized belatedly by American industry and the engineering professional societies. Foreign competition with imports from Europe and the 'Asian Tigers' began to threaten the vaunted US manufacturing base. Individual companies responded with internal transformations and by adopting the teachings of W. Edwards Deming and his fellow 'Quality' aficionados using "Quality Circles" and similar procedures [9]. IBM, and other companies, created their own internal "finishing schools" to develop and enhance the cross-disciplinary skills of their technical engineering and manufacturing workforce. Continuing life long education was seen as essential for engineering employees. In summer of 1981 IBM established a Manufacturing Technology Institute (MTI) on 42nd Street in Manhattan (NY) [10].

The main MTI Program lasted ten weeks for each class of 45 employees from IBM manufacturing locations worldwide. There were three of these classes every year. Classes covered a complete range of topics relating to business, corporate strategy, manufacturing systems and global aspects of their creation, implementation and operation embracing manufacturing as a whole, or holistic cycle, from a product concept out to realization of final customer satisfaction and even retirement and recycling at end-of-life in the marketplace. This initiative caused IBM to become more aware of the now pressing deficiencies of undergraduate engineering education and in 1983 funding was offered for the creation of cross-disciplinary masters programs in Manufacturing Systems Engineering (MSE) [11]. The MS in MSE Program proposal from Lehigh was accepted for funding among several others. The first students were welcomed in January 1984 and the program won an award from the Society of Manufacturing Engineers (SME) in 1985 (the program now operates using distance technologies and claims over 360 alumni). By the late eighties parallel efforts to broaden (or truly "liberalize") engineering education had percolated into undergraduate curricula. Communication skills, working in teams and the importance of some appreciation of business and management became pervasive in discussions on engineering education and institutional accreditation [12].

Similar curricula broadening trends were mirrored in the better school systems with emphasis on communication, presentation (show and tell) and teamwork. However, by the early nineties there were significant concerns with respect to STEM education for the world performance rankings of US K-12 students. These disturbing indicators were accompanied by declining engineering enrollments and what was viewed as a poor overall image of engineering ("They drive trains don't they?")[13]. Societal knowledge of engineering and engineers usually conveyed by the media tends to focus on the type of disasters, failures, and industry lay-offs that do not merit enumerating here. Engineers are perceived as "nerds with pocket protectors," and as ineffective in explaining what they do for society or of conveying the excitement of solving problems and making contributions. The representative professional groups also confuse matters by promoting their separate and distinct disciplines and not emulating the importance of the cross-disciplinary integration which is essential in most industry environments. In the workplace engineers are mostly problem solvers and integrators with only slim ties to the specific disciplines and/or knowledge bases that may be represented by their initial degrees.

As aforementioned, leading US-based professional societies collaborate to fund National Engineers Week and national events sponsored through a Steering Committee. There is a planned rotation with a change of lead society each year. The lead society chairs the Steering Committee and has the opportunity to propose (and assist with the funding of) special activities, events (nationally and/or regionally), publications, and more recently web sites, radio spots and other ventures* [4]. A lead industry sponsor is also invited to play a major role, and representatives of various interested agencies attend organizational meetings. The Society of Manufacturing Engineers was the lead for 2007, with Tyco in the industry role. Back in 1992 it was the turn of IEEE to take the role of lead society for National Engineers Week 1993. Technologies were developing and changing fast with IEEE in the forefront. The ground was fertile for the establishment of a competition for middle school students that would bring together the burgeoning interest in computer games and industry perceptions of the skills needs of the future workforce.

* The Steering Committee together with FCC Regional Coordinators have assisted PBS station WGBH in the development and promotion of kids programs "ZOOM" and "Design Squad."

The Future City Competition

There are many science or mathematics based contests for high school students but relatively few at the middle school level. Many are focused on specific sciences, or the use of kits to address formulaic problems [14]. A team format was preferred for the FCC so as to be less intimidating and also to encourage the development of collaborative interpersonal skills. Each year the competition materials are made available to schools and interested individuals at the start of the fall semester. Registration is by school, and in some regions it is acceptable to register two teams from a single school. A few schools run internal elimination trials. Once the fairly trivial fee is paid ($25) each registrant receives a disk with the SimCity™ software courtesy of Electronic Arts Inc. [3] Seventh and eighth graders then work on their computers, sometimes in class periods and sometimes at home depending upon the degree of incorporation of the FCC features into the local curricula. The task is to design a possible city a century and a half or so in the future. The city may be of any size, and can be located anywhere on the Earth or in the Universe. The design must satisfy rigorous requirements and is evaluated based on factors such as:
City layout *- convenience of shopping and workplace to residential areas, position of subways, magnetic rails and similar facilities, location of power plants etc.*
Energy Efficiency *– public transportation systems, number, type and generating capacity of power plants.*
Livability *– parks, trees, scenery around residential areas, ease of transportation, hospitals, fire, police and safety arrangements, recreation.*
The Computer City Design must illustrate the different zoning sections and be submitted for judging on a CD-ROM [1].

A further and very significant component are two written pieces. An abstract of 3-500 words giving an overview of the future city, some of the advantages, attributes and services: *"Why would anyone want to live there?"* The second is a 5-700 word essay on a specific topic relating to the design, for 2007 the question was *"Develop an energy strategy to include fuel cell systems to power a city of the future."* The registration package includes details, hints and references relating to city size, power consumption, fuel cell characteristics and resource information.

Finally, each team must build a scale model that represents some section of their city using recycled materials and with a total cost of less than $100. Dimensions are strictly controlled, and must not exceed 25" wide, 50" long and 20" in height; there must be at least one moving part in the model. Judges are asked to evaluate creativity (*futuristic concepts, materials used*), quality of workmanship, accuracy to scale, innovative transportation ideas, the moving component, and imaginative use of recycled materials. The team also must accompany this with a 5-7 minute presentation supported by limited media where they explain and "market" their city and the model before a panel of judges. Easel charts, posters or pamphlets are permitted, but active computer use or Power Point presentations are not allowed. The team must answer both spontaneous and prepared questions and be ready to discuss their city with numerous volunteer judges. Interactions among team members are also critiqued.

Approaches vary by school, school systems and regions. Regions are responsible for developing their own budgets, awards etc., administrative and organizational resources and booking a suitable site for their Regional Finals in January. The first prize for winners of 'qualified'

regional contests is an all-expense paid trip to the National Finals in Washington for three pupils, the teacher and engineer-mentor. A region must register a minimum of twenty-five schools to be 'qualified.' Some more established regions where school boards recognize the competition are able to register as many as sixty teams, most regions manage approximately thirty. The national winners receive a week at US Space Camp in Huntsville, Alabama, sponsored by Bentley Systems, Inc. (also hosts for the finals). There are over thirty additional awards, prizes and plaques for other placings and special categories provided by sponsoring industries, groups and societies. The special categories represent every imaginable discipline of engineering.

Teams of home schoolers are often present at the national finals. At the 2007 finals one school team explained that their city was created by separate groups comprising sixth, seventh and eighth graders. One group looked after the essay, others the abstract, the computer portion and then the model. All crucial strategic and design decisions were discussed and voted upon by all participants; finally the three presenters were elected by ballot. Other school entries comprised the output of a whole class with again the election or appointment of the presenters, back-ups could also be appointed. In other schools the activities are supplementary and completed after school by three or more, self-selected students. When a school chooses to register and competes at the regional level many more students hear about and are affected by the 'zone of influence' of the competition. Parents, grandparents, neighbors and the community at large are also afforded a view of a fascinating engineering activity. This complements engineering image and outreach objectives.

The administrative and mentoring structure forms an important part of the competition. There are also some constraints that usefully inhibit partially committed or frivolous entrants. Registration must be from a suitably accredited group or recognized home school consortium. There must be a teacher sign-off, and there must be a mentor with engineering skills and background to counsel the participants. These engineering mentors are frequently found from the local chapters of professional societies supporting E'week, or from sponsoring companies. A special "Teacher & Engineer-Mentors Handbook" is available with many suggestions [1]. It is important for the continuity of the competition that it is not 'parent driven' although parental engagement and support are certainly encouraged. The Regional Coordinators are key gatekeepers; their backgrounds vary as much the geographic locations. Some are unpaid volunteers with employers that support community outreach activities. Others have job assignments or responsibilities that additionally cover FCC coordination. There were fifty-six coordinators, or co-coordinators listed in 2007 FCC literature [1]:

Professional society affiliation in address	25 (including IEEE 6, ASCE 8)
State Agency, University or Education affiliation	16 (including some above)
Company or apparent professional work address	28 (including some above)

Impact and importance

Thirty-nine regions were listed in the Judge's Manual for 2007 [1]. If we assume the average of thirty schools per region then we have around 1200 schools engaged. There is a wide range of students affected per school. The minimum being the three elected, appointed or self-selected presenters (front people) plus their friends and the maximum uncertain; one school in the '07 finals claimed ninety – all their students in grades six, seven and eight (quite a feat of

coordination and class scheduling!). Securing sufficient accommodations for the 4-5 day stay in Washington for the finals for teams, teachers, engineer-mentors, parents and often almost whole classes that wish to travel is a challenge. It is estimated that as the result of participation in the competition at least thirty students per school are exposed to the excitement of engineering problem solving – this suggests an affected middle school population of some 36,000. Regional winners and their achievements receive extensive media coverage on local news channels, and there is appreciable follow-up so the engineering messages are well disseminated .

Another worthwhile attribute of the competition is the success in attracting diverse participation from a range of schools. Admittedly traditional minorities may not often reach the national finals in representative proportions, but they appear and place at regional contests. The fifteen winning schools since 1993 comprised 7 municipal middle schools, 6 parochial schools, and 2 junior high/central schools. The gender balance of the 35 2007 finalist teams was 55 girls and 50 boys. Notably, girls comprised the majority of the participants of the winning teams since 2000 [6].

Students and teachers surveyed in 2004 regarded FCC as an '*enjoyable learning experience;*' half the responding students said that they would like to study engineering in high school and college [15]. Other limited follow-ups of FCC alumni reveal a high proportion of participants maintain an interest in STEM subjects, although a few enjoy the communication and presentation aspects so intensely that they may adopt careers in those fields. Record keeping and tracing alumni is difficult due to personal confidentiality concerns regarding minors. In any event affected individuals, and their families undoubtedly gain appreciation and understanding of the contributions of engineering to society.

Craig Barrett, the chairman of Intel, highlighted the importance of a technically proficient population well in a 2005 article in Electronics Design News [16]. This opens with a quote "*The harsh fact is that the US need for the highest quality human capital in science, mathematics, and engineering is not being met.*"[17] Subsequently Barrett defines the problem – "*We are facing a new and even more serious challenge. The unhappy fact is that, as a nation, we are producing fewer of the people we need to ensure the health of our economy and our national security. Although the demand for skilled engineers is growing at a rate five times that of other occupations, the supply is not keeping pace. We're experiencing a graduation gap among the growing number of mathematically and scientifically literate people we need. Fewer US graduates have the training and skills to do the high-end jobs we used to think of as our birthright. Although many US citizens still believe that foreign workers are no match for US workers in knowledge, skills, and creativity, evidence to the contrary exists.*" These are cruel words but they demand attention. There is an urgent need for an increase in the numbers of well-trained imaginative and innovative engineers to maintain the Nation's prosperity. Thus, contests like FCC are an important, even vital, component of attracting K-12 students into STEM fields.

Summary

The Future City Competition is successful in bringing skills of cross-disciplinary engineering problem solving to middle school students. Participants acquire computer-related design and writing skills while also learning to communicate effectively interpersonally in their team and before panels of judges. The winners present capably before huge audiences in large auditoriums

and while being interviewed by the media. All participants learn to think on their feet and respond to spontaneous questions from judges, and they gain appreciable confidence. These 7-8th grade leaders are an inspiration to judge and to be associated with. In fact, one realizes that their competence tells us that we must develop more demanding, exacting and ambiguous practice-oriented assignments and curricula for their further education. The academic paradigms and disciplinary structures that have served adequately in the past are no longer relevant to satisfy the likely needs of future students [18].

As preparations commence for the sixteenth competition there is growing interest internationally. Already there are pilot programs in Egypt, Japan and Sweden with a major government funded program in place in India. Both stimulating, maintaining and handling this growth presents exciting problems. Funding becomes a major priority if the levels of prizes and travel budgets are to be maintained. Accommodation and scheduling are on the horizon as difficulties. The trip to Washington for regional winners is a most powerful and educational incentive, but D.C. hotel options, accommodation for the numbers engaged, model display etc. are difficult factors. It is a future vision to engage more students, schools and to gradually increase the numbers of regions, but there are many challenges along the way. One idea is to create zones with adjacent regions combining for semi-finals with a final cut going on to the National event. However, such remedies would stretch out the schedule, and require the availability of greater numbers of volunteers for more extended duties.

A further expansion difficulty arises from the bottom up. It is a challenge to persuade new schools or teachers to adopt the FCC, this is more difficult when there is not already an established and accessible regional organization with the accompanying publicity. Schools must travel many miles to regional finals in the less populous parts of the US, overnight stays and extra expense is incurred. Finding the volunteer regional coordinators, engineering-mentors, judges etc. becomes another difficulty. However, these problems are all solvable when school systems, states and/or major companies are convinced of the value of the program and to provide endorsements together with resources.

Acknowledgements

This competition would not exist and have grown (Figure 1) without the phenomenal efforts and leadership of Ms. Carol D. Rieg, National Director since 1992. FCC is also indebted to Electronic Arts for the donation of SimCity™ software, Bentley Systems, Inc., and particularly CEO Greg Bentley for unfailing support as well as sponsorship of the National Finals. We are indebted to other companies, organizations and volunteers too numerous to mention. This paper could not have been assembled without significant contributions from Donald Lehr, Media Relations Consultant for the National Engineers Week Future City Competition and the support of advisory board colleagues Michael Andrews (Phoenix, AZ, Regional Coordinator) and John E. Kampmeyer, PE (Philadelphia, PA, Regional Coordinator).

References

1. Future City Competition Program materials available through National Engineers Week Headquarters, 1420 King Street, Alexandria, VA 22314. www.futurecity.org

2. The IEEE web site can be found at http://www.ieee.org/
3. A brief history of SimCity™ software is available at http://en.wikipedia.org/wiki/SimCity it is a product of Electronic Arts Inc. http://simcity.ea.com/
4. The National Engineers Week web site is at www.eweek.org there is also a brief description on Wikipedia at http://en.wikipedia.org/wiki/National_Engineers_Week_%28U.S.%29 and a comprehensive account of possible E'week activities with links is at the California Society of Professional Engineers site http://www.cspe.com/FunctionalAreas/ImageMkt/eweekideas.htm
5. National Engineers Week was established by an initiative of the National Society of Professional Engineers in 1951 http://www.nspe.org/
6. Rieg, C., Private Communication, "*Across the country, 7500 volunteers contribute total of 225,000 service hours each year to this program. Over the past 15 years, more than 250,000 students, teachers and engineer mentors have participated in the competition.*"
7. The Papers of George Washington, University of Virginia; http://gwpapers.virginia.edu/index.html and specifically http://gwpapers.virginia.edu/maps/ace/index.html
8. Many references including: Frelindich, N., "From Sputnik to TIMSS: Reforms in Science Education Make Headway Despite Setbacks," Harvard Education Letter, September/October 1998 - Volume 14. Also DeBoer, G. E., "What we have learned and where we are headed: Lessons from the Sputnik Era," National Academy of Science, 1997 at http://www.nas.edu/sputnik/index.htm
9. See texts on Quality Management, for example: Evans, J. R. and Lindsay, W. M., "The Management and Control of Quality," Third Edition, West Publishing Company, 1996.
10. Gardiner, K. M., and Korin, S. B., "Furthering the Integration of Manufacturing," 3rd Conf. Improving the Productivity of Technical Resources, IIT Res. Inst., Chicago, Nov., 1982.
11. Gardiner, K. M., "Technology Transfer – A Future Imperative," Proc. Seventh IEEE/CHMT International Electronics Manufacturing Tech. Symposium, 1989, pp. 176-181.
12. "Manufacturing Education Plan: 1999 Critical Competency Gaps, Industry Updates Competency Gaps Among Newly Hired Engineering Graduates," SME, 1999.
13. Baranowski, M. and Delorey, J., "Because Dreams Need Doing: New Messages for Enhancing Public Understanding of Engineering," research for a portion of an NSF project carried out by a committee of NAE, Final Report, February 2007, bring this up to date.
14. There are many national and state programs with parallel objectives to FCC including Science Olympiad, Exploravision, Mathcounts, Odyssey of the Mind, ThinkQuest, plus robotics competitions based on variations of Lego Mindstorms, and Science Fairs; these vary in scale, scope and costs of participation. A Google search readily brings up details.
15. "Building Careers & Shaping Public Policy," IEEE-USA, February 2005, at www.ieeeusa.org/communications/releases/2005/022505pr.asp
16. Barrett, C., "Sputnik, races and the state of US education," Electronic Design News, November 10, 2005. www.edn.com/article/CA6280033.html?spacedesc=opinions
17. Hart-Rudman, "U.S. Commission on National Security/21st Century," at www.au.af.mil/au/awc/awcgate/nssg/
18. Gardiner, K. M., "Education for Future Manufacturing," Proceedings CIRP International Manufacturing Education Conference; CIMEC-2002, University of Twente, Enschede, The Netherlands, April 3-5, 2002, ISBN 90-365-17346, pp. 359-366.

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Regions	5	7	7	7	9	12	17	19	25	30	31	36	37	33	39
Teams	5	7	7	7	9	12	13	19	21	27	30	33	32	31	35

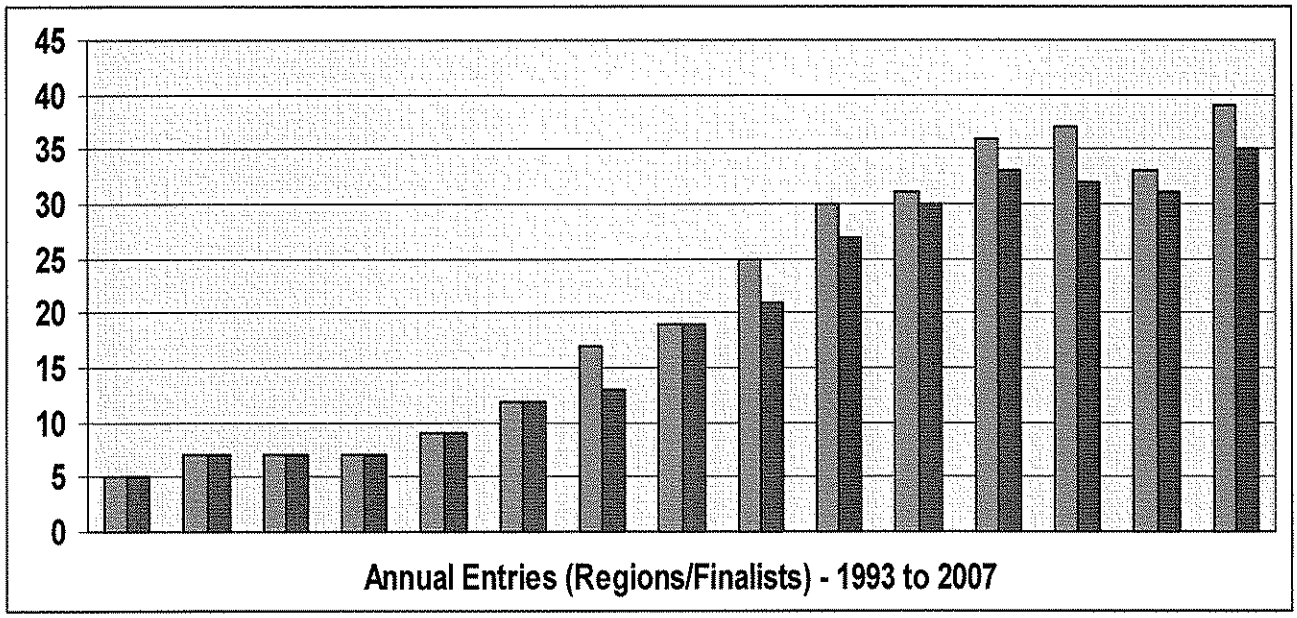

Figure 1 - Number of Regional Competitions and Teams at FCC National Finals

Author biography

Gardiner is director of the Center for Manufacturing Systems Engineering and professor in the department of Industrial and Systems Engineering at Lehigh University, Bethlehem, PA. He spent 21 years with IBM in semiconductor manufacturing and with the Corporate Manufacturing Technology Institute. Prior to this he worked on manufacturing methods for gas turbines with Rolls-Royce, and on the development of nuclear fuel elements with English Electric. He has degrees in metallurgy from the University of Manchester in England, and is a registered Professional Engineer (CA). He is a member of the College of Fellows of the Society of Manufacturing Engineers, past member of the SME board of directors, he was secretary-treasurer in 2000, and received the Joseph A. Siegel Service Award in 2003. He has a lengthy history of serving on curriculum development, certification and review committees, and he was US coordinator for the recently completed Intelligent Manufacturing Systems Global Education for Manufacturing initiative (IMS-GEM). Currently he is on the Advisory Board for the Future City Competition. His affiliations include ASEE, ASME, Sigma Xi and the Engineers Club of the Lehigh Valley. E-mail: Keith.Gardiner@Lehigh.edu
http://www.lehigh.edu/~inmse/content_html/kg03.html

Address: Lehigh University, Center for Manufacturing Systems Engineering,
200 West Packer Avenue, Bethlehem, PA 18015 Telephone: 610-758-5070