ISE Industrial and Systems Engineering

# Discovery, Learning and Research in a Classroom Factory

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Abstract

Procedures in undergraduate and graduate engineering courses that place heavy emphasis on student empowerment and learning by doing are described. Students are introduced to the concept that the classroom can be used as an analog of the industrial workplace. Individual and team assignments and projects are structured with the required output as the product. To be successful in the process of product realization students must engage in project planning and management individually and in teams as may be appropriate. Output, or products, may range from brief 'executive' analyses or reports relevant to course objectives to comprehensive 'publication ready' technical papers or reviews prepared in response to initial requests for proposals (RFP). Research topics reported range from organizational planning and control, manufacturing management, micromanufacturing and leading edge advanced technology trends and also deal with energy issues, alternative fuels, and surveys of food chain supply matters. Students make presentations that are peer-graded and there is an emphasis on development of interpersonal communication skills. Assessment and grading are discussed.

## Introduction

As a consequence of lifelong exposure to a wide variety of pedagogic experiences both as a pupil and as an instructor the author has successfully adopted techniques of industry in various undergraduate and graduate courses. The concept of empowering students and encouraging them to be responsible for their own learning was first reported at an ASEE Mid-Atlantic Region Conference at Temple University in 1996[1] and was subsequently expanded in 2001[2] at Rowan University. A third paper followed at the ASEE Annual Meeting at Montreal in 2002.[3]

The author has been blessed with many good students that become enthusiastic to undertake new challenges without routine tests and examinations. The empowerment analogy can be traced back to the ideas of Deming. He campaigned for the abolition of fear and the encouragement of the full and participative engagement of employees in the industrial workplace. Ray and Yates[4] at a Frontiers in Education Conference in 1995 proposed two 'philosophies' for the classroom: "*The first philosophy is that to graduate without a strong knowledge base and the ability to continually ``self-teach" is of no advantage to the student. The second philosophy is to convince the student that the faculty is an ally in the true goal of gaining knowledge, rather than an adversary standing in the way of graduation.*"

These philosophies are consistent with 'empowerment' and collaborative (and also 'experiential') learning. Now there has been more than a decade working with the concept of empowering students at all levels in classroom environments that are likened to an industrial factory or workplace. Two products are emphasized as objectives but there are many complementary results. The primary objective is to engender an adequate learning experience to satisfy the catalog description for the course. A secondary target is to have individual students, or teams depending upon their level, either produce a physical product or undertake research and develop a 'publication ready' term paper as their final 'product.' In this way they demonstrate the acquisition of knowledge and gain valuable experience.

In the 'classroom factory' the instructor must wear many hats; there is a formal instructional role, a mentoring role, and that of factory manager monitoring output, providing regulation, quality control, schedules and any necessary logistical support. This 'management' duty also occasions the selection of teams and following up to ensure sound project planning and some minimum team functionality.

**The Courses**

The application of these techniques has been reported most extensively for an elective fall course offered by the department of Industrial and Systems Engineering.[1,2,3] IE334, Organizational Planning and Control, or 'OPC,' has the catalog description: "*Design of organization and procedures for managing functions of industrial engineering. Analysis and design of resources planning and control, including introduction of change in man-machine systems; manpower management and wage administration (3 cr.).*"

In order to convince undergraduates that they are capable of evaluating and accomplishing 'frontiers of knowledge' output the first team assignment in IE334 is to review and suggest enhancements to papers selected from prior graduate classes. In this way graduate work feeds the studies of the undergraduates giving them critiquing experience and exposure to what 'publication-ready' implies.

Table 1 shows a list of topic areas dealt with in the final team presentations and accompanying reports. In order to realize this output the teams are briefed on interpersonal communication issues and must make spontaneous progress reports to the whole class at intervals through the semester. Formal team presentations are graded by students, and there are two confidential reports required. In these individual assessments, each student describes their own contribution and that of each of their colleagues and must explain and justify recommendations for the allocation of a shared bonus totaling a virtual $10,000 among team members. This task aims to develop consciousness and sensitivity to interpersonal and also ethnic and cultural differences. Teams are structured after submission of vita and a very brief "Working Together Teams" personality test.[5]

Grading of these 'products' or term papers is not unlike reviewing as an editor or associate editor for professional journals, however, this is not the sole source of student performance data. There are also opportunities for minor individual research assignments in some courses, and separate grades are assigned to the confidential reports, the bonuses recommended after aggregation and averaging, and formal presentations both individually and in teams. More recently the use of the Blackboard System™ Discussion Board features, and blogs provide additional sources for stimulating learning activities, communication experiences and grades.

Current publications or topical problems (referenced in Table 1 below) that likely afford a variety of interesting and challenging organizational issues are used to structure a Request For Proposals (RFP) which is issued to the student teams. The RFP is deliberately open-ended and ambiguous to leave scope for creativity and imagination by the teams. Team responses (topics) have included: "Impact of GM Foods," "Grim Reality of the Fast Food Industry," "OPC of Government Agencies with respect to SUV's," "Optimal SUV Business Strategies," and "Franchise vs. Corner Store." By 2005 there was a greater focus on energy concerns with teams examining fuel cells, hydropower, nuclear, solar, wind and environmental OPC matters. In 2006 topics studied included ethanol, dairy products, geothermal, hydrogen, oil options, waste and wind. Now for 2007 reports being awaited with interest include: "Alternative Fuels (auto), Hybrids, Efficiency & the Environment," "Infinite and Renewable Energy Sources – Solar, Tidal, & Wind," "Hydropower," "Individual Energy Use, Carbon Footprint &

Pollution," "Biomass Gasification," Fertilizer, Pesticides & Steroids in Food Production," "GE and the Food Supply, EU & US," and "Impact of GM/GE: Family Farms to Multinationals & Viability."

Table 1

| IE334 – Organizational Planning & Control (OPC) (Junior/Senior elective)<br>A selection of topics used for the origination of team research projects |
|---|
| 1. Logistics for an ascent of Mt. Everest (focused on 1996 when there were many different teams and 15 deaths). Described in many texts but initially by Krakauer in "Into Thin Air."[6] |
| 2. The water and manufacturing problems at Woburn, MA portrayed in the movie "A Civil Action," and text by Harr.[7] |
| 3. The tobacco industry using primary source "Ashes to Ashes: America's Hundred-Year Cigarette War, the Public Health, and the Unabashed Triumph of Philip Morris," by Kluger.[8] |
| 4. Organizational, planning aspects for the Olympic Games using information from multiple sources but with initial reliance on Jennings, "The Great Olympic Swindle: When the World Wanted Its Games Back;"[9] Lenskyi, "Inside the Olympic Industry: Power, Politics and Activism,"[10] and Senn, "Power, Politics and the Olympic Games."[11] |
| 5. Expedition and trek planning and analysis using materials based on Shackleton in Antarctica.[12] |
| 6. Organization and planning of the whole supply chain of the fast food industry.[13] |
| 7. The construction of Brunelleschi's dome in Florence.[14] |
| 8. The topic of the safety, roll-over tendencies and fuel efficiency of Sport Utility Vehicles (SUV's) was used with reliance on items then current in the media. |
| 9. Energy issues using source texts from Heinberg,[15] Kunstler[16] and Tertzakian[17] complemented by ample and debatable resources on the web and in the media. These topics are inevitably interleaved with environmental concerns and specifically global warming. |
| 10. Current local and international issues relating to genetic engineered (GE) or modified (GM) materials in the food supply chain starting with agriculture and animal husbandry and examining organic ideas, labeling issues etc.[18] |

**Graduate Courses**

In graduate classes it is appreciably easier to explain and implement the empowerment concept. A majority of graduate students in the courses to be described here are studying part-time with tuition reimbursement from their employers. There are many using 'Distance' technologies. They are already mature professionals with ample experience of the industrial workplace, and in many cases they are actively doing 'research' to solve problems 'on the job.' The idea of doing research as an assignment for the class with some degree of selection of topic and title is more stimulating than grinding through formulaic exercises or fossilized case studies from obsolescent texts. Today, especially, by the time materials are embedded in a text, unless they are remarkably well-structured and generic there is danger of rapid obsolescence. IE415 entitled "Manufacturing Management" (recently renumbered IE442) has the following catalog description: *"Study of factors affecting the development of manufacturing management philosophy; decision-making process in areas of organization, planning, and control of manufacturing. The principles and techniques of TQM, Deming and others; metrics, costs, benchmarking, quality circles, and continuous improvement. Influence of the social, technical, and economic environment upon manufacturing management decisions. Case studies."*

Also in the course outline information: *"Students are expected to undertake research, develop and deliver presentations, contribute to discussions on the course Blackboard System, submit examples from their own experience, and write a thoroughly referenced technical paper appropriate to the topic area."*

In the most recent offering of this course the students were 'empowered' and challenged to collaboratively develop a system of grading. Discussion was based on materials about the attitude of W. Edwards Deming to grading and measurement of educational accomplishment or learning.[4] It would be ideal if grading were not to be required and all class participants possessed equivalent levels of curiosity and enthusiasm, but this an unrealizable dream! In this case there were several disadvantages in the scoring system adopted in that points were available for numbers of posts on a Discussion Board without note of the substantive quality of the posted comments. This created floods of posts of little consequence. Additionally, in the final analysis the key individual term papers were left with less than one third of the total score. As result of this experience the topic of appraisals, measurements and rewards is discussed, but the freedom of the student classroom 'employees' to select their own metrics is now much more tightly constrained. Papers generated in these classes have been published in the proceedings of the Lehigh University, Center for Manufacturing Systems Engineering Conference with Industry Series and elsewhere. Table 2 shows a sampling of titles of final research projects.

Table 2

| IE415/IE442 – Manufacturing Management (Graduate)<br>Sampling of titles of research papers produced: |
|---|
| 1. "A Study of Temporary Workers and the Impact on the Industries."<br>2. "Decline in Manufacturing - Contributing Factors of Illegal Immigrants & Outsourcing."<br>3. "Eliminating The Waste."<br>4. "Ethanol Production from Sugar Cane: Manufacturing and Business Overview."<br>5. "Lean Six Sigma."<br>6. "Managing Manufacturing While Promoting Work-Life Balance."<br>7. ""On-the-job" training, review of training programs and their impact on productivity."<br>8. "Organized Labor in 21st Century Economy – Are Unions a Failing Institution?"<br>9. "RFID and EPC Applied in Supply Chain."<br>10. "Sustaining Organization Change Drivers in Successful Manufacturing Environments."<br>11. "The Challenges of Managing Just In Time Manufacturing in a Global Economy."<br>12. "The Lean Manufacturing Journey: A Trail Blazed With Quality Initiatives."<br>13. "The Toyota Way - 14 Management Principles."<br>14. "The True Costs of Off-shore Outsourcing."<br>15. "Up and Coming eBay Technology - New Shipping, Communication, and Mobile Bidding Methods Contribute to their Supply Chain Efficiency."<br>16. "Using Metrics to Guide Organizational Performance." |

**Advanced Technology**

The author spent fourteen years with IBM closely involved with semiconductor memory manufacturing from the first 64 bit bipolar chip of the late sixties up to the megabit products of the eighties. As a part of his IBM duties in the early seventies he served as part-time adjunct faculty at the University of Vermont offering a graduate course entitled "Micromanufacturing." This was also offered during an assignment as IBM faculty loan professor at Southern University and a course developed from these foundations has been in the catalog at Lehigh since the late eighties. The catalog entry is pending up-dating to cover the newer micro- and nano-scale and opto- technologies.

*MSE496 - Manufacturing engineering in electronics manufacture: crystal growth, doping, thin film deposition technologies and tooling, pattern generation techniques, contamination control, clean room practices, microelectronics assembly and packaging. Examination of systems design and operation issues. [This course also explores manufacturing processes associated with nanotechnology, optoelectronics and related newer advanced manufacturing technologies – a catalog revision is in process.]*

This course attracted enrollment of employees from nearby A.T. & T. (formerly Western Electric) and subsequently Lucent (now Agere/LSI) and from a Ford/Visteon plant that was just in the planning stages in 1987. In the mid-nineties the semiconductor industry was in the throes of debates about wafer sizes (forecasts going to 300mm.) and the projected high costs of building new s-c fabrications plants (fabs). It was decided to assign students in MSE496 with the task of developing a product/process forecast as the basis for making an estimate of the costs and potential output for a 300mm. wafer fab projected to be operational in 2001. There were sufficient numbers of students to assign teams with responsibility for each process sector; diffusion, ion implant, lithography, insulators, metals, interconnections etc. Their forecasts and the eventual derived paper was well received at an IEEE conference and was used by financial consultants in Silicon Valley as a useful 'first pass.' Cost and output figures were excusably low due to some flawed assumptions, but the process technology forecasts did happen and approximately 'on schedule.' Subsequent classes have placed great reliance on similar levels of research investigations using the Worldwide Web, roadmaps and e-newsletters from equipment manufacturers.

Table 3

| |
|---|
| MSE496 – Microelectronics Manufacturing Systems & Technologies (Graduate),<br>Occasionally run concurrently with experimental course IE397, same class for undergraduates.<br>Representative sample of research papers produced: |
| 1. Alicandú-Thurman, M. G., "Anti-reflecting (thin film) Materials & Nanotechnology"<br>2. Almeida, T. A., "The Cleaning of *In Situ* LPCVD Polysilicon and Silicon Nitride Tubes Using High Purity Nitrogen Trifluoride."<br>3. Berquist, S., and Pritom, R. (u-g's), "Electronic Entertainment Technology, Systems and Manufacturing."<br>4. Brooks, J., "Lithium Ion Batteries and Ultra Capacitors."<br>5. Carre, K., "Organic Light Emitting Diodes (OLEDs): Technical Challenges and Limitations - Advantages/Disadvantages."<br>6. Gomez, J. R., "Investigation and Deposition of Low Stress Silicon Nitride Thin Films."<br>7. Hughes, R. "Silver Nanotechnology (Nano-Silver) - A Medical Approach."<br>8. Lenio, T., "In Situ Cleaning Applications of Halogenated Gasses."<br>9. Light, M., "Nano Drug Delivery."<br>10. Marschhauser, K. N., and DiPisa, J. R.(u-g's), "Nanorobotics."<br>11. Stover, J., "MOEMS: Basic Components and Integration." [*Micro- Opto- Electro- Mechanical Systems*]<br>12. Szabo, S., "Dip Pen Nanolithography: From Discovery to the Next Evolution." |
| A notable paper developed as result of collaborative effort by this whole class was: "Projection for a 300mm. Wafer Fab. in 2001," Proc. 19th IEEE/CPMT Int. Elec. Mfg. Tech. Symp., 1996, pp.141-151. |

## Sustainability

An experimental course entitled "Aspects of Sustainable Systems Design (MSE495)" has been offered twice successfully and is now moving forward for formal approval and addition to the catalog. This is a very topical area that certainly excites Distance students working in industry and there has been a surprising variety of research output.

The catalog description runs as follows: *"Factors affecting design of sustainable systems for manufacturing that fulfill human needs and generate wealth. Examination of demographic, ecological, economic, environmental, ergonomic, health and global or local socio-political impacts on design and operation of future systems. Conservation of resources in the design, manufacture and use of products, processes, and implementation systems; life cycle engineering, reclamation, recycling, remanufacture. Research-based term paper required."* Titles of a sampling of papers are shown in Table 4.

Table 4

| MSE495 – Aspects of Sustainable Systems Design (Graduate)<br>Titles of a sample of research papers produced: |
|---|
| 1. Alicandú-Thurman, M. G., "Sustainable Living: Eco-Homes."<br>2. Brooks, J., "Alternative Fuels and the Need for a Renewable Fuel Source."<br>3. Centanni, M., "Toxic Air Emissions- Policy & Controls."<br>4. Dodge, T., "A Sustainably Designed Tax Structure."<br>5. Duffy Krywicki, R. H., "Aspects of Sustainable Packaging in the Beverage Industry."<br>6. Gomatam, R. R., "Role of Nanotechnology for Sustainability of Natural Resources."<br>7. Halmen, J., "Massachusetts Water Sustainability."<br>8. Hinojosa, M., "Geographical Information Systems, Seawater Desalination and Reforestation Integration Aid and Sustain our Existence."<br>9. Lenza, M., "UPS Making an Effort for Brown to be the Next Green."<br>10. Lindsay, K. R., "Green Chemistry: Applications for the Pharmaceutical Industry."<br>11. Paulic, F., "Simple and Sustainable System Designs for Water Conservation in the Southwest United States."<br>12. Raley, J., "Sustainability of Mass-Transportation."<br>13. Ulinitz, M., "Wind Power - Renewable Energy For The Future."<br>14. Wolf, J., "Sustainability of Global and Domestic Growth in the Ethanol Industry." |

**First Year Students**

A mandatory course for first year engineering students is now in the fifth year of offering.[19] Engineering 5, Introduction to Engineering Practice, involves weekly 50 minute lectures and laboratory project experiences in two different departments of the seven at Lehigh. These project experiences are variously structured, or left open to inspire student creativity within specific departmental equipment and laboratory constraints. The catalog states: *First year practical engineering experience; introduction to concepts, methods and principles of engineering practice. Problem solving, design, project planning, communication, teamwork, ethics and professionalism; innovative solution development and implementation. Introduction to various engineering disciplines and degree programs.* Table 5 lists some of projects successfully completed by first year engineers.

Table 5

| Engr5 – Introduction to Engineering Practice (First year, mandatory)<br>Sampling of projects undertaken: |
|---|
| 1. Solution to problem of transferring many boxes of stored library books from temporary storage on an upper floor to the ground floor for return to the stacks.<br>2. Design and build inexpensive street luge.<br>3. Portable cage to protect spectators from flying objects at an annual Celtic Festival.<br>4. Inexpensive heated pallet and thermal sensor for monitoring and controlling body temperature for small animals under anesthetic.<br>5. Implementation and programming of robots and sensors to enable coordinated activity between two robots (e.g. dancing).<br>6. Development of inexpensive alloy for golf club head that to give greater range.<br>7. Construction of a golf ball with limited distance capability for use on pitch and put courses.<br>8. Manufacture of unique Lehigh University bottle openers. |

**Summary**

Students can successfully undertake general research into issues affecting manufacturing management, the organizational planning and control of anything associated with our daily lives, and more specific engineering assignments in specialized areas such as advanced manufacturing technologies. These investigations, the presentations and reports provide excellent experience for the students that essay them. Their peers also gain benefits and are able to offer collaborative input. This supplementary student input enables the range of topics covered by each class to be broader, and it is readily possible to move beyond the most recent texts. The best papers are also available for publication at appropriate local, regional and even national/international conferences. Future students are able to build on the output of their predecessors and further expand each field.

**Acknowledgements**

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Biographical information

Gardiner joined Lehigh in 1987 and is director of the Center for Manufacturing Systems Engineering and professor in Industrial and Systems Engineering. 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. He serves on the advisory board for the 7-8th grade Future City Competition with other affiliations including ASEE, ASME, Sigma Xi and the Engineers Club of the Lehigh Valley. He was North American Editor for the Journal of Electronics Manufacturing, and is currently an Associate Editor for the Journals of Manufacturing Systems, and Manufacturing Processes.
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