# The TRP-Funded Integrated Manufacturing Laboratories at CCNY

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## Abstract

With the opportunity of funding from ARPA-NSF TRP (Technology Reinvestment Project), faculty and students at the City College of the City University of New York (CCNY) completely overhauled several teaching laboratories related to manufacturing education in the Department of Mechanical Engineering. This two-year effort started in early 1994 and more than $200,000 (along with countless personnel hours) has been invested into these laboratories, which are used in several required courses in our ME curriculum. Modern equipment procured for these laboratories is used for education in CNC machining, robotics, computer-integrated manufacturing, flexible manufacturing cells, and mechatronics using programmable logic controllers (PLC's) and microcontrollers for measurement and control.

Perhaps the most unique feature of our approach is the very extensive involvement of students (both graduate and undergraduate) in all phases of the project. From the very beginning students formed teams, each of which took charge of a major piece of equipment. They participated in the planning of manufacturing courses; got involved in the selection process of equipment purchase; learned to operate the equipment; developed laboratory projects suitable for the courses; communicated with vendors for technical support and the purchase of other accessories and supplies; negotiated among themselves to build consensus; tested their products; wrote users' manuals; served as course facilitators to implement their projects; conducted periodic reviews with other students using their projects; and finally, provided written reports to assess the projects and make suggestions for future improvement. In general, the full cycle of this "student-centered learning" process takes about six to eight months. During this process, faculty participants and senior graduate students served not in the traditional role of leaders and/or supervisors, but as coaches and consultants. Toward the end of these manufacturing projects, student participants usually had learned more about the equipment than the faculty participants. They knew about not only how to operate the equipment correctly, but also how to maintain and repair it properly. Such know-how, which usually is not described clearly enough in the owner's manual that came with the equipment, can certainly help our department to maintain these laboratories with a reasonable budget.

In a nutshell, the reversal of roles in the teaching-learning relation and our full-engagement approach to training in the operation and maintenance of manufacturing equipment enable us to gain complete knowledge about our manufacturing facilities. Such skills are rarely gained if a manufacturing laboratory is only equipped with "turn-key" equipment and the users (both faculty and students) can only follow "cook-book" type manuals to operate the equipment.

# I. Introduction

As a member of the NSF-funded ECSEL coalition, the Department of Mechanical Engineering at CCNY was awarded a two-year supplement grant (April 1, 1994-March 31, 1996) by ARPA-NSF TRP to renovate its program in manufacturing education with emphasis on student-centered learning, team work, and hands-on experience. The program includes four courses: ME 462 Manufacturing Processes and Materials, ME 546 Robotics and Automation, ME 311 Fundamentals of Mechatronics, and ME 511 Advanced Mechatronics. Course descriptions of these courses are listed in the Appendix. Both ME 311 and ME 462 are required while ME 511 and ME 546 are technical electives in the ME curriculum at CCNY.

The manufacturing sequence consisting of ME 462 (Manufacturing Processes and Materials) and ME 546 (Robotics and Automation) was developed to replace an outdated manufacturing course, in which traditional lectures and aged educational films were the main delivery methods for teaching. Hands-on experience was limited to tours of the machine shops. The mechatronics sequence consisting of ME 311 (Fundamentals of Mechatronics) and ME 511 (Advanced Mechatronics) was developed to expand an old instrumentation laboratory course so that modern control and measurement techniques with computer interfaces could be included.

# II. Description

During the planning phase of the program, the authors visited several manufacturing laboratories at universities within the metropolitan New York area. We were able to communicate freely with faculty and students involved in those laboratories. From their experiences we learned that (1) modern manufacturing equipment is usually very complex with extensive computer interfacing; (2) choice of equipment suitable for college education is very limited; and (3) more often than not, those instruments are made by relatively small companies who can provide customers with only limited (and sometimes unsatisfactory) technical support. Furthermore, the cost of setting up a decent manufacturing lab is not only very high (easily exceeding $200,000), but the required budget for maintenance may be even more prohibitive.

We were presented with an intriguing dilemma. On one hand we had the blessing of substantial one-time funding from NSF and ARPA; while on the other we needed to establish a modern manufacturing program in a relatively short period with minimal future funding for maintenance or support. We therefore decided to embark on an innovative pedagogical approach to complete our project. In a nutshell, it is a “student-centered, collaborative learning” process with emphasis on team work and hands-on experience (Ref. 1-3). Students (both graduate and undergraduate) participated fully in all phases of the program, including planning, implementation, and maintenance. During the planning phase (which usually spanned about three to five months prior to the first offering of a new course), students were recruited to form teams, each of which took the full responsibility of a major component of the project. They got involved in the process of equipment selection and procurement; learned to operate and even maintain the equipment; developed laboratory projects to be adopted in the course; communicated with vendors for technical support and the ordering of other accessories and supplies; built consensus among themselves that very often resulted in the best approach for their projects; tested their products; and finally wrote users’ manuals.

In the implementation phase (our experience indicates that it takes at least two semesters for a new course to mature), most of the students were retained to serve as course facilitators to implement their projects. They were invited as guest lecturers to give talks about their projects and to help other students learn about the equipment. Together with the course instructor, teaching assistant and lab technician, they held frequent reviews with students regarding their projects. At the end of the semester, they wrote reports to evaluate the projects and made suggestions for future improvement. In return, the student facilitators were rewarded with monetary compensation and/or 3 academic credits counted as a technical elective course in the ME curriculum. Many students felt that their experience as facilitators had helped them in less tangible ways. They saw themselves taking on the kinds of responsibilities that are rarely allowed in school, even though those responsibilities are expected in industry.

It should be pointed out that students who just completed the manufacturing and mechatronics courses were then recruited to become the facilitators for the following semester and the full cycle of this "student-centered teaching-learning" process would take place. During this process, faculty and senior graduate students didn't take the traditional role of "instructors"; instead, they served as coaches and consultants. Since this approach places learning in students' own hands, toward the end of the projects they usually had learned more about the equipment (and the project as well) than the "instructors". Because of their extensive involvement in the use of equipment, our students very often had also gained knowledge about the maintenance of that equipment during this learning process. Such know-how is extremely valuable to us. In general, detailed maintenance procedures are not described clearly in the owner's manual of the equipment. Knowing how to maintain and repair a piece of equipment properly can definitely help a department to contain its laboratory budget within an affordable limit.

As of today, we have applied this approach to the development and implementation of both ME 462 (Manufacturing Processes and Materials) and ME 311 (Fundamentals of Mechatronics). The development phases for ME 546 (Robotics and Automation) and ME 511 (Advanced Mechatronics) are on-going. Pilot sections of these two courses are expected to be offered within a year. Major pieces of equipment contained in the four laboratories (about 2,000 sq. ft.) dedicated to the manufacturing/mechatronics courses are: four CNC machines for milling and turning, four articulated-arm robots and a SCARA robot with guided vision, an AS/RS (automated storage/retrieval system), a CNC XYZ table for routing, a 3-station CIM line, a metal processing center capable of hot and cold working, an injection molding machine for plastics, an arc welding station, and several mechatronic stations using PLC's, microcontrollers, and modern electromechanical transducers with digital data acquisition for measurement and control. Photographs of our manufacturing facilities are shown in Figs 1 and 2.

## III. Conclusion

The development of integrated manufacturing laboratories for engineering education requires not only substantial funding but careful planning and implementation. This usually takes countless personnel hours. In our view, the best approach to overcome these inherent obstacles is to involve students extensively. In our study, their full engagement in planning and implementation has been proven to be an effective learning experience. During this student-centered learning process, complete knowledge about the equipment, including operation and maintenance, can also be acquired by the department.

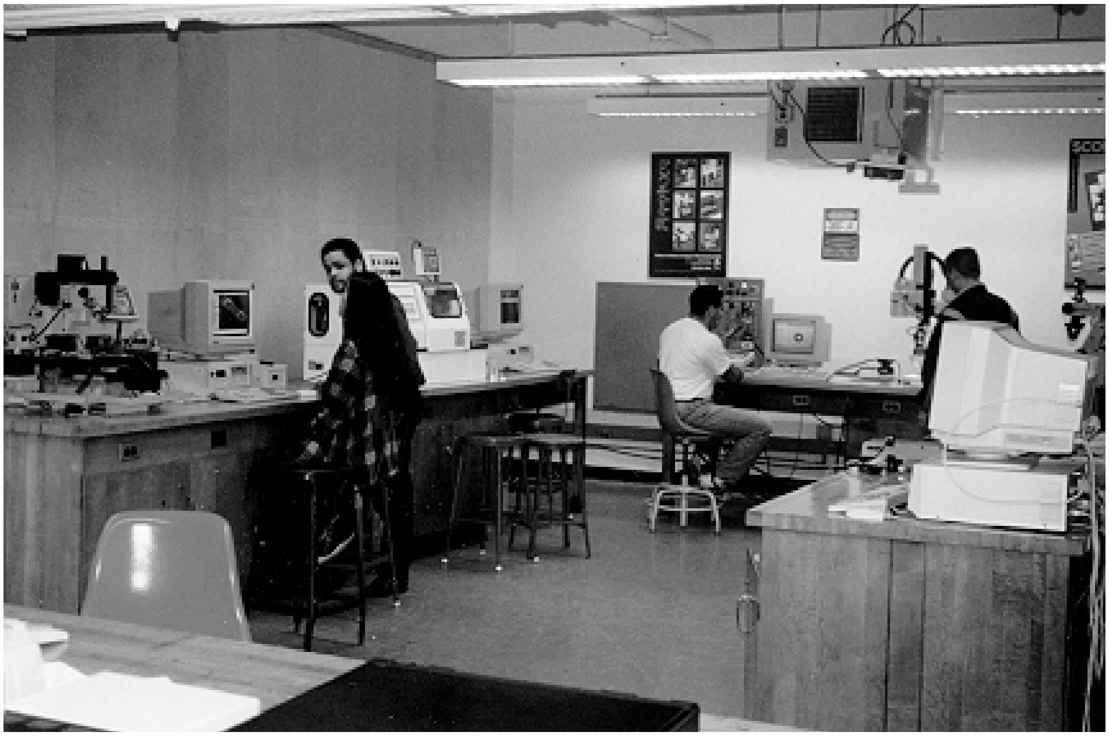

Figure 1. ECSEL Manufacturing Lab - CNC Machining & Robotics

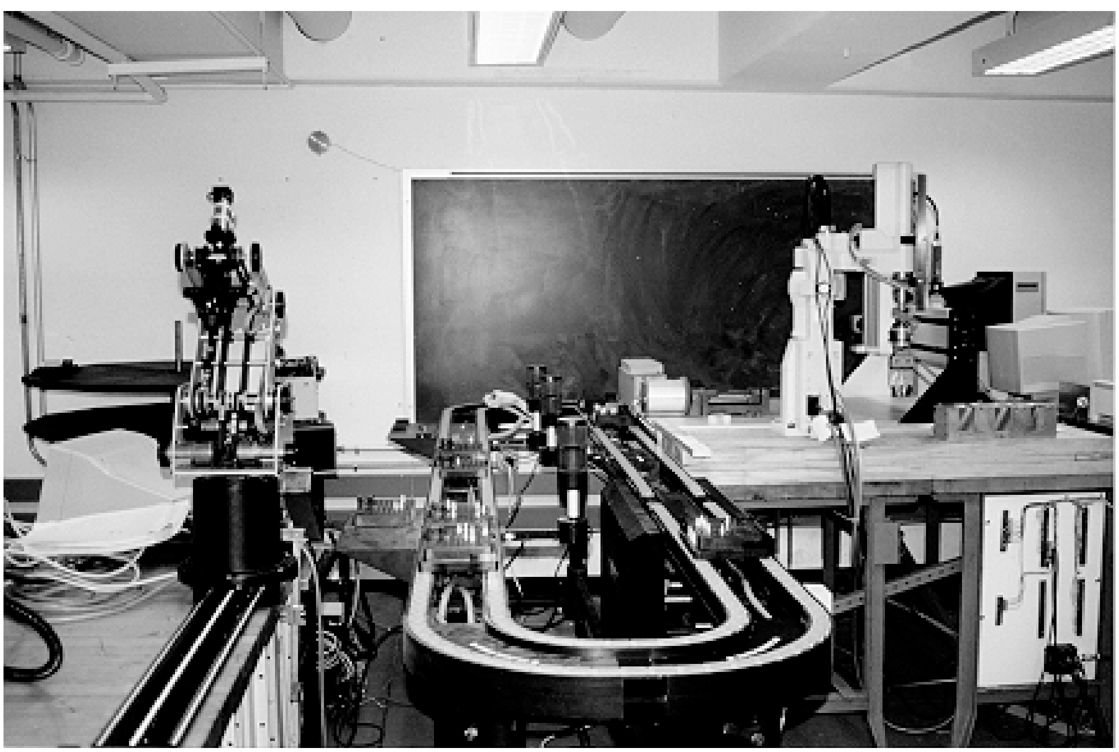

Figure 2.  ECSEL Manufacturing Lab - Computer-Integrated Manufacturing

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## Appendix

**ME 311: Fundamentals of Mechatronics** - Modern electric/electronic devices with applications in mechanical measurements are used as various sensors, such as strain gages, thermocouples, piezoelectric transducers, LVDT's, optoelectronic proximity sensors, etc. Static and dynamic characteristics of sensors and time and frequency responses of various measurement systems are studied. Concepts of filtering, amplification and signal condition are demonstrated through hands-on laboratory experiments. Engineering statistics and regression analysis are also introduced for analyzing measurement errors. Prereqs: Engr 204 and Math 291. *2 class, 2 lab hr/wk; 3 cr.*

**ME 462: Manufacturing Processes and Materials** - Relationship between product design and manufacturing influence of material properties. Capabilities and limitations of common methods of processing metallic and nonmetallic materials (casting, hot and cold working, joining, traditional and nontraditional machining). Introduction to computer-aided manufacturing, robotics and computer numerical control (CNC) machining. Prereqs: ME 145, ME 461. *2 class, 3 lab hr/wk; 3 cr.*

**ME 511: Advanced Mechatronics** - Digital principles are studied and their applications in A/D and D/A converters, microcontrollers and programmable logic controllers (PLC's) are demonstrated by controlling various electromechanical devices, such as relays, DC servos, and steeper motors. Principles of electric machines and selection of electric motors are also introduced. Hands-on laboratory experience, including team-design for measurement and control of various electromechanical devices, is particularly emphasized. Prereq: ME 311. *2 class, 2 lab hr/wk; 3 cr.*

**ME 546: Robotics and Automation** - Robotics and relative fields related to robot design and operation. Kinematic problems peculiar to robotic construction. Control consideration. Power sources. Sensory equipment and intelligence. Specifications used to evaluate robot performance. Economic considerations of robotized operations in various applications. Introduction to computer-integrated manufacturing (CIM), CNC programming languages, group technology, and flexible manufacturing systems. Prereqs: ME 247, ME 371, ME 462. *2 class, 3 lab hr/wk; 3 cr.*

## Biographical Sketches

**Benjamin Liaw** received his Ph.D. degree from the University of Washington in 1983. After a year of post-doctoral research study at University of Washington, he joined the faculty of CCNY in 1984, where he is now a Professor. His interests include (1) the design, analysis, manufacturing and testing of composites, and (2) improving engineering education through innovative research and teaching techniques, with emphasis on attracting underrepresented minorities and women. He published more than 50 refereed papers with funding support from NSF, U.S. Army TACOM, AFOSR, ARPA TRP, AT&T, DEC, Alliant Techsystems, NYS GRI, and PSC-CUNY. He also serves as the School PI of ECSEL at CCNY. The goal of the NSF-funded ECSEL is to improve engineering education through design for manufacturing across the curriculum.

**Gary Benenson** is an Associate Professor in the Mechanical Engineering Department at CCNY. He coordinates the CCNY ECSEL effort in manufacturing education and teacher's certificate programs. In addition, he was also the Project Director of City Science, an NSF teacher enhancement project. Its goal was to develop strategies for using everyday technology and the urban environment as the source of material for elementary science. Twenty schools from Harlem and the South Bronx participated. He has previously taught in the Technology Department at CCNY and the Electrical Engineering Technology Department at New York City Technical College. Prior to entering the field of education, he worked as a design engineer at the Pricker Corporation, Columbia University and Brookhaven National Labs. He is married and has two children.