STRATEGIC PLAN FOR AN NSF ENGINEERING RESEARCH CENTER EDUCATION PROGRAM – THE ERC FOR RECONFIGURABLE MANUFACTURING SYSTEMS

ELIJAH KANNATEY-ASIBU, JR.
Yoram Koren
Lenea Howe

Engineering Research Center for Reconfigurable Manufacturing Systems
University of Michigan
Ann Arbor, Michigan 48109

Abstract

The Strategic Plan of the Engineering Research Center for Reconfigurable Manufacturing Systems (ERC/RMS) at the University of Michigan was established to streamline the Center’s educational activities thus enabling manufacturing engineers from industry to work with manufacturing faculty and students in both education and research. The Center has successfully developed an organization that can be responsive to both academic needs for process and to corporate needs for agility. The Education Strategic Plan integrates curriculum, culture and outreach. This paper provides an overview of each of the elements of this comprehensive effort.

Introduction

The vision for the Education Strategic Plan of the Engineering Research Center for Reconfigurable Manufacturing Systems (ERC/RMS) was driven by the desire to give the UM manufacturing curriculum and outreach activities an identity which would capitalize on the uniqueness of the ERC/RMS research challenge. Typical courses on manufacturing strategies and processes, as well as typical courses on industrial control and machining design, analyze known situations and consider given design goals. By contrast, RMS methodologies are based on design for a future change and a future re-use of components. With the RMS, the essence of decision making involves a consideration of the future. The future is inherently unknown, and the forces conspiring to produce the future often lie well outside the conventional designer and manager purview. The essential question was how does one make engineering decisions in this context? The new decisions would depend on the following facts:

- The forces shaping the future of a particular industry are not understood.
- The rate at which these facts are emerging are not known.
The opportunity that RMS design brought in teaching a systems approach to engineering was another important driver to our education plan. Due to the highly specialized and focused relationship between students and their individual faculty advisors, students typically have little opportunity to develop the systems perspective in engineering. They have limited experience in working with experts from diverse fields on a team to solve complex problems. By contrast, the design of RMS is composed of many individual projects, all driven by a systems perspective. It provides an excellent example to demonstrate how a system-level perspective drives the individual research projects, and, in turn, how projects are integrated to form a system. This is an integrative approach that combines the depth in a particular discipline with breadth due to interaction with students and researchers from other disciplines.

A driver of a different type for our education plan was the lack of valuable skills that would allow young engineering professionals to function more effectively in industry. Engineers in industry must be effective participants and leaders of teams, yet the traditional university environment was not well structured to support that methodology. Students were not familiar with the needs and goals of industry in which new products are developed in anticipation of a market demand. They had been educated about theories, working to grasp and understand concepts, without having the opportunity to see the challenges encountered when attempting to apply those concepts and theories in the real world.

By striving to meet the following initial goals we continue to work to attain that vision:

- Develop curriculum through course materials derived from ERC research.
- Impact the culture of research by involving undergraduates and graduate students in cross-disciplinary research teams with industry and systems-level activities.
- Develop outreach activities to other universities and pre-college students.

We will focus on these three areas beginning with the development and modifications made in the curriculum.

**Developing Curriculum**

Now in the 8th year of our 11 year NSF grant, our ERC has had a significant impact on both the undergraduate and graduate curricula, and has contributed to new dimensions in teaching the engineering workforce. We elaborate below on curriculum changes at both the undergraduate and graduate levels. Before discussing these curriculum changes, it is necessary to understand that any change to the Engineering Curriculum is dependent upon approval at a number of levels within the College. Although infusion of RMS modules does not require approval, cross-listing of courses, modification of courses, and the introduction of new courses requires approval by appropriate committees within departments and the College. The ERC worked diligently with those committees to implement the appropriate curriculum changes.

The new ERC courses and the modified ERC courses have utilized the concept of education modules, reflecting a just-in-time approach that is recognized in industry as the key to life-long learning (that is, “exactly the education needed, exactly when needed.”).
Undergraduate Curriculum

The ERC has made great strides in strengthening its undergraduate curricular component.

Undergraduate Manufacturing Systems Concentration (MSC). The Manufacturing Systems Concentration is a cross-disciplinary specialty option open to undergraduates pursuing degrees in the Mechanical Engineering and Industrial and Operations Engineering departments. The concentration focuses on (i) a systems-approach to manufacturing and (ii) design for future requirements. It consists of at least 13 credit hours, including eight credit hours of required core courses:

- ME450 Capstone Cross-Disciplinary Project course (4 credit hours)
- ME483 Manufacturing Systems Design course (2 credit hours)
- IOE425 Manufacturing Strategies course (2 credit hours)

Other requirements are as follows:
- Students must take one technical elective.
- Students must take two electives, one from each of a recommended list of existing manufacturing-related (Process and Systems) courses. This is required for the concentration.

Process-Related Courses
ME381 Manufacturing Processes
ME482 Machining Processes
ME487 Welding
EECS423 Solid-State Device Laboratory
EECS425 Integrated Circuits Laboratory
EECS567 Robotics
IOE449 Material Handling Systems

Systems Related Courses
ME401 Engineering Statistics for Manufacturing Systems
ME452 Design for Manufacturability
ME454 Computer Aided Mechanical Design
ME583(599) Science Base for Reconfigurable Manufacturing Systems
ME 584 Control of Manufacturing Systems
ME587 Reconfigurable, Agile Manufacturing
EECS481 Software Engineering
IOE201 Economic Decision Making
IOE 441 Production and Inventory Control
IOE447 Facility Planning
IOE452 Capital Budgeting
IOE466 Statistical Quality Control

The undergraduate student advisors in the ME and IOE departments assist the ERC with recruitment into the program and monitoring student progress. The ERC tracks the
participation of students in the program and upon completion, awards them a certificate. It is evident from student surveys that traditional ME and IOE students have sufficient background in manufacturing systems to do well in the concentration because of the breadth of academic experience prescribed by the Accreditation Board of Engineering and Technology (ABET). At the end of the program, the designation of Manufacturing Systems Concentration is posted on the student’s final transcript. To date, thirty students have graduated with the concentration in manufacturing systems. There are sixteen students currently enrolled. The MSC designation enables industry to identify those students who have gone through this unique manufacturing education. Our industry members tell us that before this concentration was developed it was very difficult to find students with a complete set of manufacturing systems skills. Now they actively recruit our students with this certificate.

Textbooks. The ME584 course “Control of Manufacturing Systems” was reworked to provide undergraduates with an introduction to manufacturing system controls and strategies. The undergraduate textbook *Computer Control of Manufacturing Systems* authored by Yoram Koren (McGraw-Hill, 1983) is being updated to accompany this course, including research results obtained by ERC faculty in the Center. This book, although written some 20 years ago, is still being sold worldwide, though revisions are required not only because the field has dramatically changed since the book was published, but also because the collaborative work in the Center has changed the way that Professor Koren views his own research. Material being added to the new edition includes control of large systems and the relationships between markets and manufacturing system strategies. But what is perhaps more important is that the ERC/RMS research has affected the pedagogical approach in the new version – it will now be based on a systems perspective. With this approach we see how the market dictates the manufacturing system strategy, and the selection of machines and their controls comes consequently only as the last step.

Another new textbook, *Reconfigurable Manufacturing – Product, Process, Business Integration* has been written for the ME587 “Reconfigurable, Agile Manufacturing” course. This completely new work presents RMS from its core in product development through a detailed survey of production systems including marketing models, reconfigurable machines and system configuration analysis. It also covers reconfiguration as it effects business practice, including responsive business models, organizational structures and the enterprise as a whole. This book is currently being test marketed.

Modified Undergraduate Courses. Reconfigurable Manufacturing Systems-related modules have been introduced into the following undergraduate courses:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>IOE201</td>
<td>Economic Decision Making</td>
</tr>
<tr>
<td>IOE452</td>
<td>Capital Budgeting</td>
</tr>
<tr>
<td>ME250</td>
<td>Design and Manufacturing I</td>
</tr>
<tr>
<td>ME381</td>
<td>Manufacturing Processes</td>
</tr>
<tr>
<td>ME450</td>
<td>Design and Manufacturing II</td>
</tr>
<tr>
<td>ME482</td>
<td>Machining Processes</td>
</tr>
</tbody>
</table>

Proceedings of the 2005 American Society for Engineering Annual Conference & Exposition  
Copyright © 2005, American Society for Engineering Education
Graduate Curriculum

Changes in the graduate curriculum include the development of new courses as well as the development of course modules.

New Courses. The ERC has created two new graduate courses based on research coming from the ERC: ME587, “Agile, Reconfigurable Manufacturing” and ME583 (599) “Science Base for RMS”. These two courses, developed by ERC faculty, are derived from the ERC interdisciplinary research. The “Agile, Reconfigurable Manufacturing” course is also offered simultaneously to students in the School of Business Administration as a “Corporate Strategy” course. A major component of both courses is an interdisciplinary team-project to develop students’ understanding of manufacturing strategies and technologies aimed at changing markets (in terms of products, demand, global competition and process technology). There are no plans to add additional new courses on RMS to the graduate curriculum but rather to continually assess and adjust the content of these courses in order to prepare textbooks on these subjects at a later time.

Modified Graduate Courses. In order to broadly impact the student population by teaching RMS concepts to a broad student audience, Reconfigurable Manufacturing Systems content has been used by the ERC faculty in a number of departmental courses at the graduate level as well as those at the undergraduate level. Examples include:

- IOE691 In-Process Quality Improvement
- ME554 Computer Aided Design Methods
- ME584 Control of Manufacturing Systems
- ME585 Machining Dynamics and Mechanics
- ME588/IOE591 Assembly Modeling for Design and Manufacturing
- MFG501 Strategies and Technologies for Manufacturing
- OM617 Issues in Flexible Manufacturing Strategies

As ERC research continues and concepts are demonstrated and proved in the testbed, we anticipate that further RMS modules will be introduced into current courses taught by ERC faculty.

Impacting Culture

The Engineering Research Center for Reconfigurable Manufacturing Systems research must be done with multi-disciplinary teams. Over the course of time we communicated this concept to our ERC researchers and students and gradually we created a cultural change in the Center. The ERC has constructed an interdisciplinary environment for graduate students to work in teams, guided by the systems perspective. With nearly a 1:1 ratio of graduate students to undergraduate students in the Center, we have successfully drawn the two groups together by requiring participation in ERC events, presentations, testbed tours and demonstrations. Both groups participate in student meetings, research
update sessions and social events. In addition, the graduate students make themselves available for mentoring.

The ERC/RMS has a powerful and successful Student Leadership Council that is involved in all of the Center activities. They welcome ideas and suggestions from all of the students and have been instrumental in the success of Center-sponsored events, organizing volunteers, initiating special study sessions and countless other ways that have drawn our diverse group of students together.

All graduate students are housed together in the Student Office Space in the Integrated Manufacturing Systems Laboratory and are assigned desks based on their research Thrust Area affiliation. As a result, students within each Thrust Area consult with their peers on a daily basis and assist each other. This space helped in creating the “ERC spirit” among students and was highly beneficial for team development. In the words of Dr. Shirley Jackson, president of Rensselaer Polytechnic Institute, “it takes a village comprised of intergenerational support and peer support that enables students of diverse backgrounds, levels, and interests to interact with each other routinely and intensely. They key element enables undergraduates, graduate students, postdoctoral fellows and junior faculty to provide mutual support, guidance and advice for each other, creating an atmosphere of family responsibility”. We feel that we have successfully achieved this atmosphere in the ERC.

ERC students are from several different engineering departments as well other areas of the University (School of Art and Architecture, School of Business Administration, School of Information and Program in Manufacturing). In addition, our learning environment is made richer by the presence of various cultures and backgrounds of the students. Our students come from 22 different countries and include a growing number of women and ethnic minority students at both the graduate and undergraduate levels. All students work together in the ERC lab (Integrated Manufacturing Systems Laboratory – or IMSL) and utilize the Learning Center and the ERC testbed to do hands-on research.

### Changing Graduate Student Culture

**Systems Perspective.** The systems perspective and knowledge of other students’ projects is achieved through several mechanisms:

- Thrust Area-level research issues are presented in regular Thrust Area meetings.
- Systems-level issues and particular projects are presented in bi-weekly student/faculty lunch meetings by the Director, Deputy-Director and Research Leaders.
- Individual project research progress is presented at weekly student meetings to give all students an understanding of the importance of their own work in the overall scope of the Center.
- Student poster presentations at Technical Advisory Committee meetings and National Science Foundation Site Visits ensure student understanding of the integration of ERC research projects.
Industrial Interaction. Students receive exposure to industry views in several ways. First, there are bi-monthly project meetings with industry in which the students make presentations and obtain feedback from industry. Second, there are semi-annual poster presentations by students to industry members. Thirdly, the ERC staff and faculty work to arrange summer internships on ERC-related topics, if possible, in member-industry plants and research labs.

Workshops and Seminars for ERC Students. Workshops conducted by professionals are offered to the ERC students on various topics every semester. Topics include Teambuilding, Communications, Resume and Cover Letter Writing and Interviewing Strategies. Teambuilding and Communications are offered every year and are required to be taken one time by all graduate students. Undergraduate students are invited to attend but it is not a requirement. Teambuilding was requested by our industry partners to teach unity and trust. The Communications workshop teaches different styles of learning and teaching, effective speaking skills for various audiences and presentation methods and poster making. These workshops are very popular and we open them to students seeking manufacturing-related degrees such as the Wu Manufacturing Center and students in PIM (Program in Manufacturing).

The ERC, jointly with the Program in Manufacturing (PIM), the Tauber Manufacturing Institute (TMI) and the Industry/University Cooperative Research Center (I/UCRC), sponsors weekly seminars with invited experts from academia and industry to lecture on manufacturing issues and topics. These seminars also provide students with the opportunity to interact with industry representatives who attend the seminars.

The degree to which the ERC has succeeded in changing culture for the graduate students in the Center is addressed in the following statements by two of our graduates who were recently hired by industry. These testimonials amplify the unique educational focus that the Center offered to assist them in their careers.

“One of the most important aspects of my experience that helped me tremendously in developing my career was the higher, system-level view we gain in our ERC. I thank ERC’s management for creating this high-level vision in the Center.” – Frashid M. Asl, Ph.D., Vice President, Risk Analytics, GMAC Enterprise Risk Management.

“…during my first year at Bayer, I identified a number of important problems regarding the production quality, maintenance and productivity, and proposed feasible solutions. One of my solutions was accepted by the management and is currently saving the company at least $2 million annually. Without the ERC systems-level background I could not come to this solution. Also, I have been honored with a ‘Special Recognition Award’ this year. I truly believe that my successful start in the company would have not been possible without the valuable education and research experience from the ERC.” Weiping Zong, Ph.D., Senior Associate Quality Assurance Engineer, Bayer HealthCare, Diagnostics Division.

Changing Undergraduate Student Culture
The ERC has a strong commitment to involve undergraduates in research during the academic year. We maintain an average 1:1 ratio of paid undergraduate to graduate student researchers in addition to supporting undergraduate students on research projects for academic credit.

Over the past 8 years, we have had many students who worked in the Center as undergraduates who have chosen to seek graduate degrees in manufacturing and have been supported by the ERC in that effort.

The ERC continues to advertise ERC undergraduate research projects in various University of Michigan pipelines, such as the Undergraduate Research Opportunities Program and the Marian Sarah Parker Programs, to generate undergraduate interest in the Center. Both programs are designed to attract students to graduate school by providing them with a research project during their freshman or sophomore year. Offering research projects through these diverse undergraduate research clearinghouses channels undergraduate students into the ERC, allowing the ERC to attract motivated and intelligent students into manufacturing.

In addition, we offer scheduled tours to prospective students and their parents who visit the College of Engineering for Tech Day in the fall and to incoming freshman orientation groups.

**Outreach**

In an effort to disseminate the knowledge generated by the Center as well as attract new students to the field of manufacturing, the ERC has developed some unique and successful programs.

**Outreach to Other Universities**

**REU Site.** The ERC has been a Research Experience for Undergraduates (REU) site since 1997. We have actively recruited underrepresented minority students from Hispanic Serving Institutions (HSI), Historically Black Colleges and Universities (HBCU’s), Tribal Colleges and Women’s Colleges as well as other REU sites and other ERC’s. We have hosted between eight and thirteen students each summer who have worked with faculty and graduate students on manufacturing research projects for eight weeks on the Ann Arbor campus. One unique element of our REU program is that we hold a contest to solicit research proposals from our graduate students and the best proposal receives a $500 prize, second place is $300 and third place is $200. The top three proposals are used as REU projects and those 3 graduate students become mentors for one of the groups of undergraduate REU students. Along with the faculty leader for the research Thrust Area and the graduate student, the Center is able to provide a rewarding experience for the REU students.
REU participants are given a competitive stipend, free room and board, transportation to and from Ann Arbor and the Graduate Record Exam preparation course. Nearly all of our past participants have continued on to graduate school. Many students have been recruited to the College of Engineering as a result of their REU experience.

Outreach to Pre-College

The ERC has accomplished successful and far-reaching programs to pre-college students.

Detroit Area Pre-College Engineering Program (DAPCEP). The University of Michigan in cooperation with the Detroit Area Pre-College Engineering Program (DAPCEP) offers a program of introductory classes in engineering to students in grades 7 and 8. The program is designed to expose students of color to opportunities in several areas of engineering including Aerospace, Computer, Transportation, Chemical, Industrial Operations, manufacturing, Mechanical, Naval, and Nuclear Engineering and Radiological Sciences. Goals of the program are as follows:

• Provide weekly learning experiences in engineering
• Present University of Michigan students as successful role models
• Provide information on career opportunities in engineering
• Enhance student personal growth
• Sharpen participants’ technical, analytical, and problem solving skills.

In 1999, the ERC began with 15 students who attended Saturday classes on campus for 5 weeks in March and April. The program was so successful that we soon were working with two different groups of 25 students each. One session is called “The Making of the Automobile” and is coordinated by students in Mechanical Engineering. The other session is titled “Learning New Ways of Making Things” and is taught by students in the Program in Manufacturing (PIM) and students in the ERC. We have several masters and doctoral students in the ERC who were first introduced to the University of Michigan and to the ERC through the DAPCEP program.

Science Club. ERC students have, for several years, volunteered their time to work with small groups of children (usually 1:2 or 1:3) on science projects at the Pattengill Elementary School.

SE Michigan Science Fair. One of the most prestigious high school science fairs in the country is the Southeast Michigan Science Fair in Ann Arbor. ERC students volunteer their time as project judges at the fair.

Portable Manufacturing Project. Area middle and high school students are introduced to manufacturing engineering through this innovative, hands-on engineering program. Students are first taught a course on CAD and simple computer programming. Building upon these skills, they then learn about and use a robot and milling machine. This project allows students an opportunity to see a project to completion from the concept and design phase to manufacturing a simple product, and with the use of web-cams, they can remotely access and view the production process from their classroom.
**Museum Project.** An interdisciplinary team of students (industrial design, computer engineering, mechanical engineering, art & architecture), faculty, and museum professionals worked together on the development of a manufacturing-oriented, interactive museum exhibit. ERC/RMS has successfully partnered in this endeavor with the Ann Arbor Hands-On Museum, which provided advice in development, network of contacts, and exhibit space at the museum at no cost. Since it’s installation in August 2004, the piece has proven to be extremely popular. Members of the team are also involved in the launch of a new, multidisciplinary Museum Studies Program at the University of Michigan.

**Facility Tours.** The ERC welcomes groups to visit the testbed at any time. We host groups of students of all ages whenever they come to campus, as a regular stop on the north campus tour and as an additional event to students visiting for any engineering-related field trip. We have guides available during campus events such as Tech Day, the Sally Ride Festival, departmental recruitment visitations and the IMPACT recruitment weekend. (IMPACT weekend is a joint recruitment effort created to enhance (to impact) diversity in the University of Michigan’s graduate programs in science, technology, engineering and math (STEM) disciplines. We provide demonstrations of the equipment and machines and also have several projects that the students can participate in themselves (such as robotics, assembly line operation, remote access drilling machine and web cam activities).

**International Exchanges**

The ERC hosts many visiting scholars and students in response to requests from abroad. In addition, the Center hosts one undergraduate student each summer from the IAESTE program who works on a research project for three months. We have hosted students from countries such as Poland, Korea, Israel, China, Italy, Ecuador and Belgium. Although we do not actively recruit these international students, we have had a few that have later applied to graduate school at Michigan because of their positive experience in the ERC.

**Summary**

The initial goal of the ERC/RMS Strategic Plan was to develop an education model that was responsive to the needs of students as well as industry. The initial goal was accomplished through the development of the Manufacturing Systems Concentration, the creation of new courses in manufacturing and the infusion of RMS concepts into existing engineering courses. Student culture was enhanced through student collaboration, team-building and communications workshops, industrial internships and seminars. The Center’s educational program has been greatly enriched through many successful outreach initiatives. We are on target in all areas of our education plan and we remain confident that this momentum will continue.
YORAM KOREN, Director of the NSF Engineering Research Center for Reconfigurable Manufacturing Systems, and also Paul G. Goebel Professor of Engineering at the College of Engineering, U of M. His most significant contributions have been in the field of manufacturing automation and machine tool control. Member NAE, Fellow ASME and SME, a Senior Member of IEEE, and an active member of CIRP.

ELIJAH KANNATEY-ASIBU, JR., Associate Director for Education, NSF Engineering Research Center for Reconfigurable Manufacturing Systems, and also Professor, Department of Mechanical Engineering, U of M. Distinguished awards from ASME, American Foundrymen and American Welding Society. Research includes multi-sensor monitoring of manufacturing processes and laser processing of materials.

LENEA HOWE, Education Coordinator for the Engineering Research Center for Reconfigurable Manufacturing Systems, received her BFA in Fine Arts and Education from the University of Michigan. She has 15 years experience in all aspects of graduate recruitment and undergraduate summer research program administration.

“The work was supported primarily by the Engineering Research Centers Program of the National Science Foundation under Award Number EEC-9529125.”