MANUFACTURING SYSTEM DESIGN EXPERIENCES FOR ENGINEERING STUDENTS: MEANS TO ADDRESS COMPETENCY GAPS

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Abstract – Engineering students are employed to design and improve manufacturing systems at the Advanced Manufacturing Institute at Kansas State University (KSU). AMI created the Manufacturing Learning Center (MLC) to accomplish a two-fold mission: to enhance the education of engineering students and to promote economic development in the state. During the past two years, with support from the Society of Manufacturing Engineers (SME) MEP program, we have developed the capability to accomplish this mission by employing engineering students to design, improve, and operate real manufacturing processes and systems for client companies under the tutelage of experienced engineers. This paper presents the KSU AMI model and discusses how it is used to close the SME critical competency gaps.

1.0 Introduction
Since 1995, the Advanced Manufacturing Institute (AMI) at Kansas State University has developed a manufacturing education and training entity, the Manufacturing Learning Center (MLC). The MLC was patterned after the teaching hospital model used in medical schools. To enhance the education of engineering students, the MLC provides internship opportunities for engineering students to work on real engineering projects for client companies. These projects have resulted in new products and machines and improved production processes and systems. Ultimately, AMI projects have increased sales, saved and added jobs, and reduced costs for Kansas companies. The experience gained by students working in the MLC fills many of the competency gaps identified in the SME/MEP Critical Competency Studies.

In this center, undergraduate and graduate students from engineering, computer science, and business colleges work as interns on product and process development projects contracted with industrial partners. An interdisciplinary group of interns is assigned to work under the supervision of an experienced staff member to accomplish each project. This operation provides a unique and innovative active learning environment for students from several engineering disciplines. Students learn to perform as members of an interdisciplinary team, develop communication skills and realize the business side of engineering activities.

Last year, the MLC employed more than 70 undergraduate and graduate student interns to work on real design and manufacturing engineering projects. Since its inception in 1995, the MLC has employed more than 300 students from 56 of the 105 counties in Kansas. They have worked with more than 250 different companies from 37 Kansas counties and have accomplished more than 1100 projects.
This paper describes the Manufacturing Learning Center at Kansas State University and outlines the way in which the MLC has been used to close the engineering graduate competency gaps identified by SME. With the model presented in this paper, the industrial community not only receives the long-term benefits of more experienced and better trained engineering graduates, they also receive immediate benefits from the on-going services provided through this program.

2.0 Background
The Manufacturing Learning Center (MLC) of Kansas State University is housed in a 22,000 sq. ft. facility located in the Manhattan area industrial park. The plant is equipped with state-of-the-market manufacturing equipment, engineering design tools, and modern office and project space, a multimedia conference room and a meeting room. This facility and its operations were built with support from a combination of federal, state and private grants. Major grants have been provided by the National Science Foundation, National Institute of Standards and Technology, the Society of Manufacturing Engineers, the Kansas Technology Enterprise Corporation, and Kansas State University.

The MLC is part of the Advanced Manufacturing Institute (AMI) at Kansas State University. AMI is a multi-disciplinary center sponsored by the Kansas Technology Enterprise Corporation (KTEC). Its mission is to create and build enterprises through the advancement and utilization of manufacturing technologies.

3.0 The MLC Model
The MLC was patterned after the teaching hospital model used in medical schools. The analogy is presented in the Table 1. To enhance the education of engineering students, the MLC provides internship opportunities for engineering students to work on real engineering projects for client companies. Project teams are formed by AMI on the basis of project needs. Each project team is expected to work within time and budget constraints.

<table>
<thead>
<tr>
<th>Hospital</th>
<th>Manufacturing Learning Center</th>
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<tbody>
<tr>
<td>Medical Doctors</td>
<td>Experienced Engineers</td>
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<tr>
<td>Medical Interns</td>
<td>Engineering/Business Interns</td>
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<tr>
<td>Patients</td>
<td>Manufacturing Companies</td>
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<tr>
<td>Medical Equipment</td>
<td>Manufacturing Equipment</td>
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An engineering staff comprised of nine engineers (mechanical, industrial, and manufacturing engineers) is employed to work on technology development and technology assistance projects for client companies. Each member of the MLC engineering staff has a technical undergraduate degree and most have a graduate degree. Each MLC engineer has, on average, fifteen years of industrial experience. They are results oriented, have outstanding interpersonal and communication skills and are passionate about mentoring students. They have experience in: direct sales/marketing, company assessment, proposal development, project management and implementation, and customer service.
Most of AMI’s clients are manufacturing companies, but AMI also works with entrepreneurs and start-up companies. The majority of AMI’s contracts are with Kansas companies, but projects are not restricted to Kansas organizations.

KSU students are recruited from engineering, computer science and business programs according to the needs of the project portfolio. Students have to meet the minimum GPA requirements and be within 3 to 4 semesters of graduation. Interested students submit applications and are interviewed for the limited number of available internship positions. Applications are accepted throughout the year. Staff members screen applicants and conduct interviews three times each year. The resumes of successful candidates are put into a pool of potential employees. When interns leave the program or when project needs exceed current resources, project managers select new employees from the pre-screened pool of qualified students.

Students are paid to work at the MLC for 12 hours a week during the academic semesters. Some students continue to work on a full-time basis during the summer. In order to receive a certificate of completion of the internship they are required to spend a minimum of three semesters as interns. Usually they start their internship at second semester of their junior year and graduate from the MLC at the same time they graduate from the college.

A faculty advisory group and an industrial advisory board provide guidance and feedback to the staff to build and develop the MLC. This group of faculty also constitutes the education steering body of the MLC. They set the policies and procedures that govern the experience interns receive during their internship. They also function as consultants for many of the technical projects conducted at the MLC.

4.0 Project Assignment
Projects begin with a proposal to a client to meet some need that the client has brought to the attention of one of the MLC staff members. Proposals include the list of deliverables, the promised completion date, and the cost to the company. Upon receiving the signed contract from the client and a down payment, the project is assigned to an interdisciplinary team consisting of between two to five student interns depending on the needs of the project. One of the full-time MLC engineers is assigned as the project manager to supervise and coach students to complete the project. The interns assigned to these projects do the majority of the work involved in completing a client project. AMI staff members serve as client liaisons, mentors, and technical support to the interns assigned to them.

The team works with the client to transform the client’s needs and ideas into a new/improved product or manufacturing process, which meets the client’s stated goals. A typical project may consist of transforming an idea or a concept into a design, prototype and an actual manufacturing system for producing the product. The deliverables typically include documentation of all designs, cost analyses, prototype(s), and in some cases a limited production run.

5.0 Competency Gaps Addressed
The MLC provides experiences for students that helps to close four of the five critical professional competency gaps and all five of the technical skills gaps identified by SME in the Manufacturing Education Plan: 1999 Critical Competency Gaps document. The primary mechanism for achieving these results is to assign students to multiple projects (sequentially) that provide direct, mentored, hands-on experience with real product and production system
projects. On average, each intern will work on as many as three or four projects before leaving the program. Contrary to some industry internships or co-op assignments, students work as project engineers, not simply a pair of hands performing busy work. The specific ways that this program addresses competency gaps are detailed below:

**Professional Skills:**
- **Business knowledge/skills and professional aspects of engineering activities:** Students work on projects for existing businesses under the same conditions they will experience upon graduation. They must understand and support AMI’s business processes during the duration of the project. This includes supporting the customer quote/bid process during the development of the project proposal and being able to understand the business impact of their work in order to effectively communicate with industrial clients. They are mentored on personal professional behaviors and expected to work effectively with clients, fellow AMI staff members, and the general public in a professional manner.
- **Teamwork:** Students gain experience with real world, multidisciplinary teams. Since all members are paid employees they must actively contribute to the project or risk losing their position. Each person’s responsibility is defined in the beginning of the project. The project manager makes sure that all team members contribute.
- **Project Management:** Students are responsible for managing projects for clients that are important to the client and have real deadlines and budgets. They must work effectively in teams, set goals, plan, and manage the completion of the project. They are accountable for meeting project deliverable expectations.
- **Written Communication:** Students are expected to document their work. They create a variety of documents including: progress reports, detailed work instructions, system documentation, management reports and letters and memos.
- **Oral communication/listening:** Students work in teams to accomplish their work and must participate in effective business meetings, supervise the work of others, give progress and final presentations, and interact with a variety of people such as clients, suppliers, officials from the university and regulating agencies, and other students.

**Technical Skills:**
- **Supply Chain Management:** Students are responsible for working directly with suppliers to obtain the products and services they need to accomplish their projects.
- **Specific Manufacturing Processes:** Students produce products that will require them to learn about specific manufacturing processes.
- **Manufacturing Process Control:** Students develop manufacturing processes that can consistently produce products that meet design specifications and satisfy the customer.
- **Manufacturing Systems:** Students design, build, and run a manufacturing system.
- **Quality:** Students are expected to provide a quality product utilizing modern principles of quality management.

**6.0 Example MLC Projects**
Students in this program have successfully designed new products, machines, and manufacturing systems. They have also analyzed and improved existing designs. In some cases, AMI has even developed and implemented a production system in our own building and have delivered batches of products to meet client needs.
6.1 Fit, Form, and Function Application
The following photos are of a circular saw rotating laser for Laser Tools Inc. In this product, a laser creates a line for the saw-cut to follow. After designing the product for an entrepreneur, the MLC made two rapid prototype casings. Later, 20 metal prototypes were made on a milling machine. Sears is currently marketing this product.

6.2 Major Products/Production Systems Developed
Below is a sampling of the work that AMI has performed as part of this program. The work can be grouped into three categories: piece parts, simple assemblies, and complex assemblies.

Major Products Developed: Piece Parts
- Farrar Cluster Gear
- Disk Doktor
- Gable Speedlead
- Enlow Golf Grips
- Heatron Job-Shop Work
- Longford Job-Shop Work
- Emporia Machine Tool Job-Shop Work
- Aero-Mod Job-Shop Work

Major Products Developed: Simple Assemblies
- Q-Kaddy
- Gable Speedlead
- Inside Corner Speedlead
- Golf Club Chauffeur
- Christi-Wheelchair Lift
- Acoustic Pie
- Laser Trac Disc
- Spider & Fly Puzzles
Major Products Developed: Complex Assemblies

- Phase Transition Analyzer
- Mega Press Brake Pedestal
- Smart Hitch

6.3 Examples of Rapid Prototyping Projects
A key addition to AMI’s learning center capabilities was the addition of rapid prototyping made available through the acquisition of a stereolithography system from 3D Systems. Shown below are some examples of rapid tooling and design validation work completed by student teams.

6.4 Injection Molding Applications

- The original Q-Kaddy part was 4 or 5 separate pieces
- This assembly was re-designed in PRO/E, an RP prototype was made, and then the plastic injection mold was made.

- The Disk Doktor product was designed in PRO/E
- One RP part was made, changes were noted, then another final RP part was made
- The MLC made the injection mold, then plastic parts were made by an outside supplier using the mold
6.5 Thermoforming Application
Acoustic Pie Development
- The MLC made several prototypes on laser and waterjet cutting systems
- It was eventually determined that the best manufacturing process was thermoforming
- The client agreed to try using an RP thermoform master to speed development of his product
- A thermoform master was made oversize to accommodate plastic shrinkage during thermoforming
- Air slots were put on the bottom of the RP master
- The part was built hollow, then filled with a casting resin
- First production run was for 1000 parts was completed by an AMI industrial partner

6.6 Metal Foundry Casting Applications
AMI has produced several tools for metal casting for clients to help the company get sample castings into their client’s hands within 48 hours. By using an RP master fastened directly to the match plates, our foundry clients are able to give their customers better visualization of the finished casting they will receive. Shown below is an RP master door handle. Note the parting line drawn with a marker for the cope and drag plates.

Views of the completed cope and drag plates are shown below.
6.7 Heater Core Casting Application

An aircraft sensor heater core is shown above. The first prototype was made by sanding a room-temperature-vulcanizing (RTV) silicon extrusion. This was very time-consuming and prone to error. The client agreed to try using a rapid prototype mold to speed the manufacturing of their product. The mold allowed much easier manufacturing of the product.

7.0 Problems Encountered and Lessons Learned

The following is a brief summary of some of the lessons learned by AMI while developing our production capability. The lessons learned are grouped into the following areas: development lessons, business lessons, production project types, student workforce management, and student experiences.

Development Lessons

The MLC requires a steady flow of good projects to provide rich experiences for the students. Many new clients do not believe projects done by student interns in a university operation are going to be of much use to them. To overcome this perception and gain the trust of potential industrial partners, AMI developed its operations following these keys:

- Start with smaller projects with little risk to these companies and do a great job in delivering what they want. This process will take time, but there is no shortcut. Our experience shows that a great deal of patience will be needed to succeed.
- Deliver on time and within budget. This requirement is essential to both training students and getting companies to come back for another project.
- Hire experienced engineers to mentor students. Faculty members are usually too busy with other work to be the primary project managers. Faculty members play a major role in directing the development of the center and consulting with the project teams when needed.
- Find resources to support the operation. Client fees fund a major part of the MLC operation, but it takes time to establish your business reputation. Regardless of how well you satisfy the client, it is very difficult to accomplish the student-mentoring function without additional resources provided from other sources.
- An industrial advisory board is essential to provide input to improve operations and to advocate the use of the MLC by their peers.

Business Lessons

- It is important to develop a sound investment strategy to acquire and maintain current operating equipment.
• Clients understand the “market value” of the service they request. Many are unwilling to pay a premium for the service simply because students are working on the project. Therefore, the MLC must continuously seek funds to support its operation.

• Cash flow must be managed. To operate a “business” within the university is extremely difficult. University procedures often slow down the contracting, purchasing, payment, and invoicing processes.

• Quality is in the eye of the beholder. Some clients have a built in bias that prevents them from seeing the quality work that interns are capable of performing with proper management and mentoring. Even when they produce a product to the client specifications, if it doesn’t work, the client may perceive it to be a problem of “student labor.”

Production Project Types
Finding suitable production projects presents some challenges. Historically, the MLC shop has focused on product and process design and improvement projects. The addition of the production-oriented function requires shop personnel to manage common students and equipment to accomplish both prototype shop projects and production projects. This blending has required a change in the mindset of both the shop staff and the internal customers that have historically used the shop for prototyping services and design advice.

AMI has found the best combination of production work to perform in our particular setting is that of a cross between being a contract manufacturer for products that we have been improving for our clients as well as performing job-shop related work for piece parts and simple assemblies. This work is low risk and enables the interns to focus on the recurring element of production.

• Must find the “right” projects. Some jobs have proven to be too aggressive in terms of cost and time, which is to be expected since our clients are normally in the mode of aggressively shopping around their job shop work.

• Must be willing to say **NO** to some work, no matter what the $$$.

• Must not be too aggressive in bidding for work of this nature so that AMI is not perceived as taking work away from the local manufacturing base.

Student Workforce Management
• Depth of experience depends on the complexity of the product being produced and the volume of production. Products with a long production run allowed team members to cross-train and to take turns serving as production supervisors.

• Must develop an efficient repeatable training process in order to balance intern education and productivity that is required to meet cost objectives. In most production projects, it is likely that new students will be assigned to the production team and old students leave before a production run is complete.

• Must document production operations for easy hand-off to new production teams.

• Must find ways to schedule around student schedules.

• Must find ways to keep the workforce motivated. Some of the students don’t realize the value of the production experience and would rather be designing things or solving problems, not performing the same function over and over.
Student Experiences

- Two interns participating in the program at the same time will have very different experiences. Each student gains experience related to the projects that they work on. To try to fill as many of the competency gaps as possible, students are assigned to as many projects as possible during their time at the MLC.
- Need to promote cross communication among interns so that they can share what they have learned and learn from what other interns are learning as well.
- The job is not just about solving technical problems. The interpersonal relationships often are the most complicated part of any project.

8.0 SUMMARY AND CONCLUSIONS

This paper presented a model for enhancing engineering education that provides students with an environment similar to that of a teaching hospital where medical students intern under the supervision of experienced professionals and provide a valuable service to the community. In the Manufacturing Learning Center model presented here, students, under the supervision of experienced engineers and their professors, work in a university-operated factory and deliver new products and manufacturing processes to private companies. Through an AMI internship, students receive hands-on experience related to their technical skills and knowledge while practicing and developing strong professional skills.

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References

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