"The Integrated Learning Factory: An Educational Paradigm's First Year of Operation"

Dale Calkins, Jens Jorgensen, Michael Safoutin, Joseph Heim
University of Washington

Abstract

The Integrated Learning Factory (ILF) is a facility that supports product realization within a new practice based engineering curriculum developed and adopted by the participating universities of the Manufacturing Engineering Education Partnership (MEEP). MEEP comprises the University of Washington, Penn State University and the University of Puerto Rico at Mayaguez with Sandia National Laboratories. The first year of operation of the University of Washington's ILF is described including the successes and problems.

1) Manufacturing Engineering Education Partnership (MEEP)

The Manufacturing Engineering Education Partnership (MEEP), which consists of Penn State University, University of Washington, University of Puerto Rico Mayaguez, and Sandia National Laboratories, was formed in order to provide a new, practice-based, manufacturing-oriented engineering curriculum. MEEP provides a new paradigm for the undergraduate engineering experience by providing a proper balance between engineering science and engineering practice. The partnership, with essential input from industry leaders, established an Integrated Learning Factory (ILF) at each school and intimately coupled it with an alternative Core Curriculum. The ILF concepts at each of the partner schools are described in DeMeter, et al.[1] and Lamancusa, et al.[2]

2) Integrated Learning Factory (ILF) Description

The Integrated Learning Factory at the University of Washington is now operating in its second year. As a new instructional laboratory of the College of Engineering, it simulates a design and manufacturing workplace and supports the new interdisciplinary Product Realization minor, which encourages a hands-on approach to integrating design, manufacturing and business. The Integrated Learning Factory is a new approach to design and manufacturing engineering education. It combines curriculum revitalization with coordinated opportunities for application and hands-on experience.

The original Engineering Annex at the University of Washington, ***Figure 1,*** was built for the Alaska-Yukon-Pacific Exposition in 1909. It is one of only two Exposition buildings that survive today. During the Exposition, the ground floor housed exhibits by manufacturers hoping to supply the growing Northwest with the latest in industrial equipment. ***Figure 2*** shows a steam-powered generator in what is now the Integrated Learning Factory. Now, some eighty-eight years later, the lab area has been transformed into a contemporary learning center for the latest in design and manufacturing technology.

Figure 1: Engineering Annex in 1909

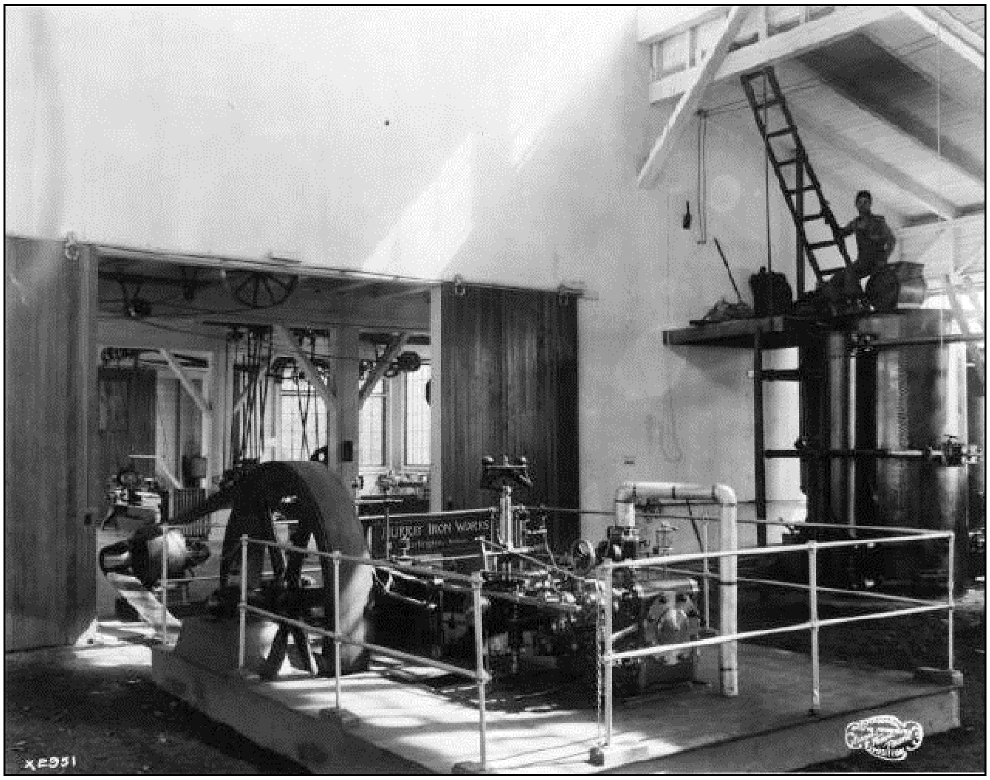

Figure 2: Engineering Annex Interior View (1909)

This "activity based" approach erases the traditional boundaries between lecture and practice, classroom and laboratory, academia and industrial practice. The Integrated Learning Factory (ILF) at the University of Washington, ***Figure 3***, covers approximately 5,500 $ft.^2$ The ILF includes the following components:

- •Design Studio
- •Design Lab
- •Product Dissection Lab
- •Manufacturing Integration Center
- •Factory Floor Work Cells (five)

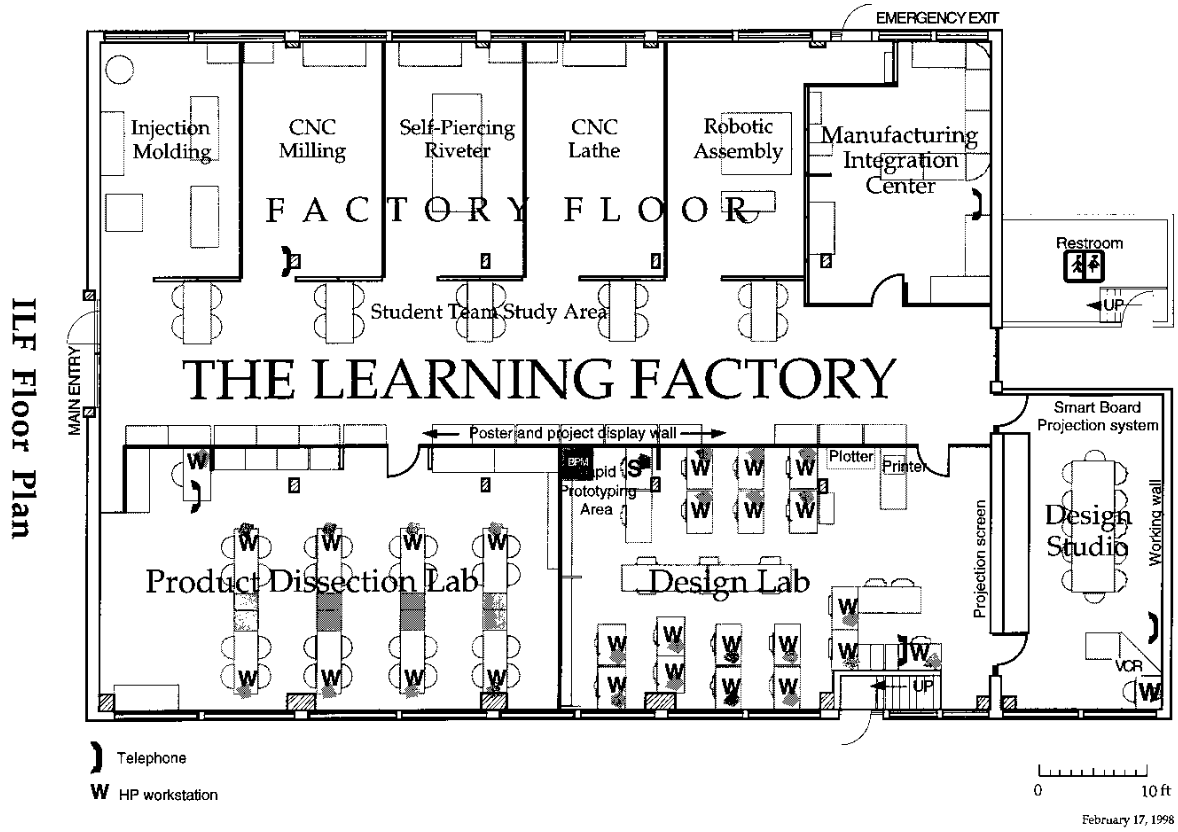

Figure 3: UW "Integrated Learning Factory" Layout

Design Studio

The Design Studio, ***Figure 4,*** is for use by students for design collaboration. Included are a floor-to-ceiling cork working wall for use in brainstorming exercises, an overhead computer and video projector, a "Smart Board" projection screen and two whiteboards. ILF Coordinator Mike Safoutin is shown in ***Figure 5*** demonstrating the touch-sensitive Smart Board projection system. Distance conferencing software also allows for student/client collaboration.

Figure 4: Design, conferencing, and presentation facilities in the Design Studio.

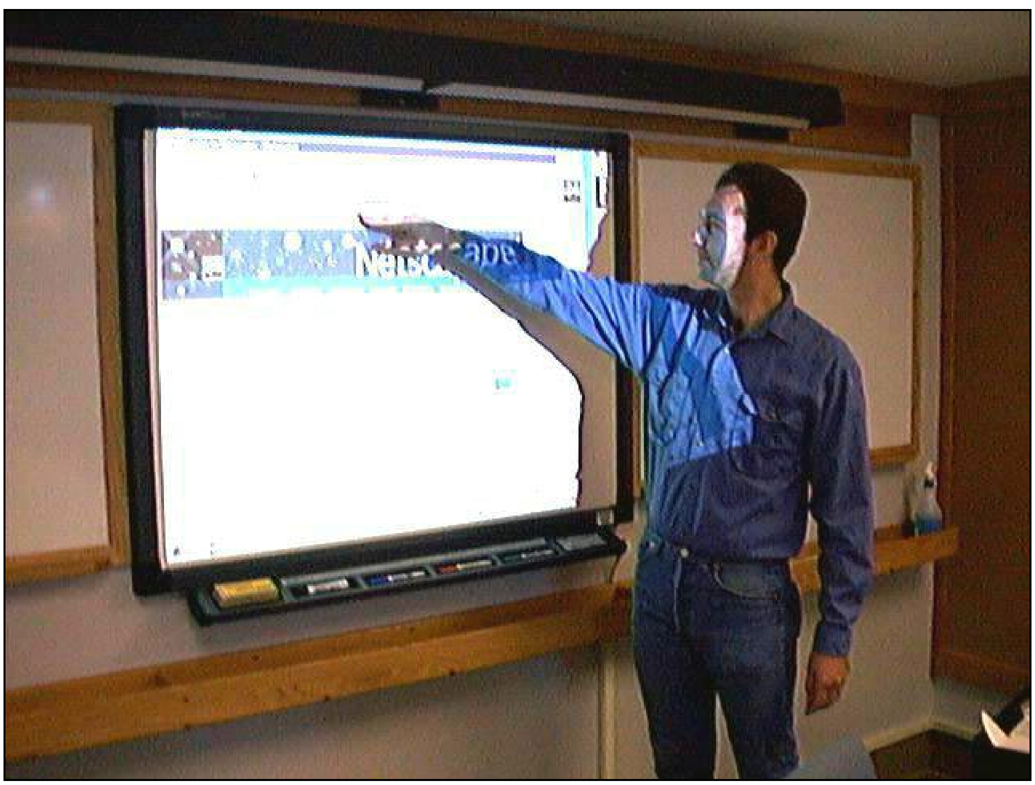

Figure 5: Learning Factory Coordinator Mike Safoutin (Industrial Engineering) demonstrates the touch-sensitive Smart Board projection system in the Design Studio.

Design Lab

The Design Lab, ***Figure 6***, consists of fourteen HP Vectra PC workstation hosting a variety of software for use in the design, manufacturing, and report production process. Output capability includes a laser printer, plotter, and a 3-D rapid prototyper.

Figure 6: The Design Lab provides computer workstations to support student team design collaboration as well as in-class teaching.

Product Dissection Lab

The Product Dissection Lab area, ***Figure 7***, was designed to support dissection activities of eight groups of four students at a time. There are eight workbenches, each equipped with a set of common tools. Certain special tools are also available.

Manufacturing Systems Integration Lab

The Manufacturing Integration Center, ***Figure 8,*** provides hands-on opportunities for students to utilize the concepts and principles of integrated manufacturing, that is, the efficient transformation of customer requirements into product designs, and the coordination of product information, materials, and production processes to satisfy those customer needs.

Factory Floor Work Cells

The Robotics Assembly work cell houses a Seiko industrial robot donated by Hewlett-Packard. The robot is interfaced with a PC controller. The robot was originally designed to assemble small parts on HP printers. For a student design project, the robot is being reprogrammed to play checkers, using as game pieces the same parts it was designed to manipulate in the factory.

Figure 7: The Product Dissection Lab provides bench space, tool sets, and project storage space for up to eight student teams.

Figure 8: The Manufacturing Integration Lab supports graduate students in robot control, simulation, and automation, interfacing with the Seiko industrial robot in the Robotic Assembly work cell.

The Self-Piercing Riveter work cell, ***Figure 9,*** contains a state-of-the-art HENROB self-piercing riveter. Metal pieces are riveted together without the need for a pre-drilled hole, much as a stapler staples paper. In industry, this technique takes the place of spot welding. The riveter has been used in the SAE Formula Car design competition to construct portions of the vehicle frame.

Figure 9: The HENROB Self-Piercing Riveter work cell was used to fabricate part of the frame for the 1997 SAE Formula Car.

The CNC Lathe and CNC Milling work cells will house CNC horizontal and vertical milling equipment for creating prototype parts in metal and plastic.

The Injection Molding cell contains an injection-molding machine and facilities for moldmaking and duplicating prototype parts in plastic and resin. This cell is often used to create durable copies of the fragile 3-D models output by the rapid prototyper in the Design Lab.

Student Team Study Area

The Student Team Study Area, ***Figures 10 and 11,*** include a series of conference tables that can the student team can use on an "as needed" basis to meet and work. The area also includes a display wall to highlight student team work. The posters are removable so that they are easily changed as the school year progresses. This wall facilitates an understanding of student learning to ILF visitors. Product Dissection Lab Coordinator Kristina Westvang, a former Mechanical Engineering graduate student, shows a photo exhibit, ***Figure 12***, that outlines the history of the Engineering Annex, the building that houses the ILF.

Figure 10: Tables on the Factory Floor provide for impromptu student collaboration.

Figure 11: A Display Wall is dedicated to student project exhibits.

Figure 12: Product Dissection Lab Coordinator Kristina Westvang (Mechanical Engineering) shows a photo exhibit that outlines the history of the Engineering Annex, the building that houses the Learning Factory.

3) New Design and Manufacturing Curriculum

The Learning Factory supports the new curriculum by providing an industrial manufacturing environment. Students participate in projects that range from rapid prototyping to the finished product by utilizing the model shop, production, assembly, test, and design studio facilities in the ILF. Five new courses were added in manufacturing and industrial engineering that utilize the Learning Factory: Product Dissection, Concurrent Engineering, Technology-Based Entrepreneurship, Process Quality Engineering, Interdisciplinary Senior Design Projects and Knowledge-Based Engineering (KBE).

In the Product Dissection course, Lamancusa, et al.[3], students examine the way in which products and machines work. By taking apart products, students learn about their physical operation, the manner in which they are constructed, and the design and societal considerations that determine the difference between success and failure in the marketplace.

The Concurrent Engineering course presents case studies from various industries to examine the effects of concurrent engineering practices on issues like safety, reliability, and maintainability. Speakers from local industries present a practical perspective on these issues.

The Technology-Based Entrepreneurship course allows students to gain appreciation of the relationships among product performance, customer needs, and business constraints by developing their conceptual ideas into marketable products and services. The emphasis is placed on innovation and creativity.

The Quality Engineering course provides a laboratory experience allowing students to design their own experiments, collect data and apply appropriate statistical tools. Students are exposed to statistical methods in the total quality manufacturing culture.

The interdisciplinary Capstone Design course provides students with the opportunity to practice the design of products and processes from conceptualization to implementation. Students work on interdisciplinary team projects from industry, student inventions, and design competitions. The learning-by-doing experience gives students a firmer grasp of fundamentals, teamwork skills, increased communication skills, enhanced creativity, and most importantly skills to synthesize, design, and build. Industry plays a key role by providing feedback on the curriculum, by participating in the classroom, and by providing student projects.

The most extensive design project experience available to the students is participation in the SAE Formula Car competition through a special three quarter capstone design, Calkins[4,5]. "Formula SAE" is an intercollegiate engineering competition in which engineering students are to conceive, design, build, test and race a Formula Style car. The competition is based on the concept of a hypothetical manufacturing firm that has engaged a student design team to produce a prototype car for evaluation for production at a cost of $9,000 for a production run of 1000. The class is a structured Design /Build team concept for offering students an introduction to and an experience in an environment which is based on systems design technologies. The students must not only fulfill the engineering duties required in the design of the car, they must also participate in the administration functions such as fundraising, financial control, records keeping, documentation and inventory control.

Concepts such as part and sub-system ownership, Design to Cost and Concurrent Engineering are embedded in the course structure as the students work in technology based "Design/Build" teams. To help in the design process, the students rely on the use of the Computer-Aided-Design and Engineering tools available in the ILF Design Lab. SDRC, an ILF sponsor has donated the CAD/CAE program “I-DEAS” which is being used to design the 1998 entry, which is an evolution of the 1997 car, ***Figure 13***.

Figure 13: UW 1997 SAE Formula Car

The Design Studio is also used for the graduate level course, ME 570, which is based on the new design technology known as Knowledge-Based Engineering or KBE. KBE is used to develop a true virtual prototype with both geometric and non-geometric attributes. The working wall facilitates team discussions, while the Product Dissection Lab is used for product decomposition exercises as the first step in the development of the virtual prototype. One product that is being used as the basis for a generic virtual prototype is the hand held battery powered vac. The students first map the product through a decomposition tree, ***Figure 14*** and then model the parts using parametric geometry, ***Figure 15.***

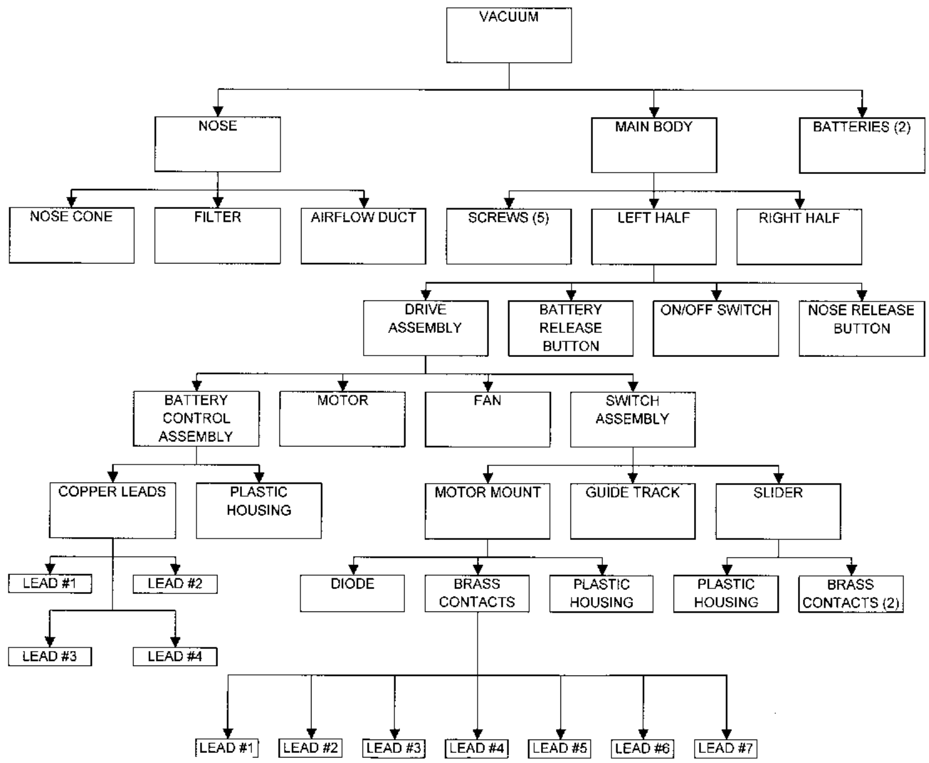

Figure 14: Hand Vac Product Decomposition

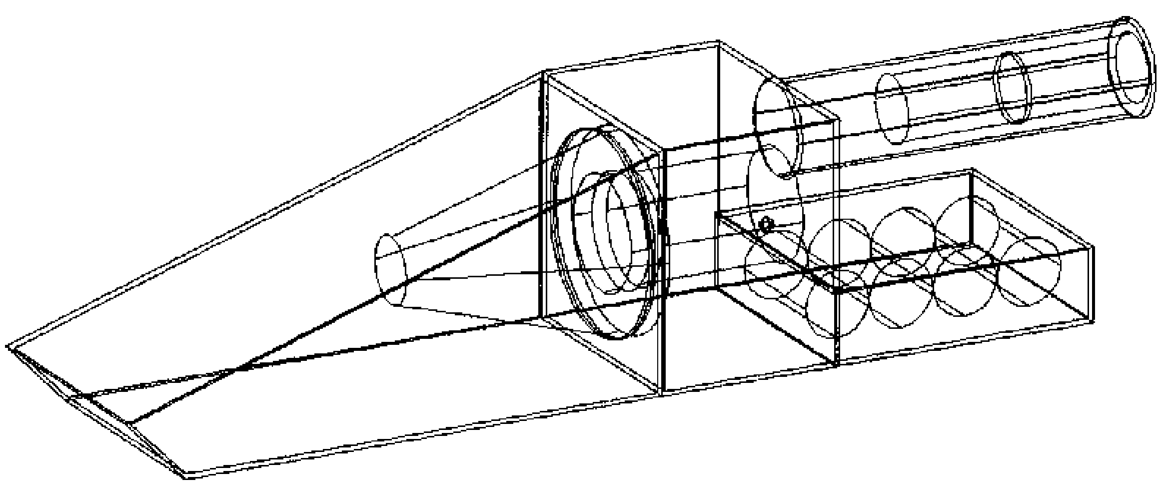

Figure 15: Hand Vac Parametric Geometry

4) First Year "On-Line"

The initial concept of the University of Washington ILF is described in Lamancusa, et al.[1] After the first school year of operation of the UW ILF, we now have achieved the following:

- Full utilization of the Product Dissection lab for freshman through graduate design courses including:

Engr 100,	Introduction to Design Engineering
ME/IE 295	Product Dissection
ME 395	Introduction to Mechanical Design
ME 495	Mechanical Engineering Design
ME 570	Knowledge-Based Engineering - Design Methodology

- Program Sponsors

Industrial Partners

Hewlett-Packard	Boeing
Henrob	Fluke Manufacturing
PACCAR	Microsoft
K2 Corporation	Tektronix
Kimberley-Clark Corporation	FORMOST
PRECOR USA	MARCO
PAC Northwest	North Pacific Fishing
Holman, Inc.	HealthTech
Olympia Orthotics & Prosthetics	FLOW Int. Corp.
Innoteck, Inc.	Jack Ogle & Co.
Seafirst Bank	

Non-Industrial Partners

Sandia National Laboratories	USDA, Forest Service
Washington State Recycle Assist. Program	
Washington Technology Center	

- We have executed over one hundred industry projects in the last three years, in addition to the national competition projects such as the SAE Formula Car. With a new grant from Hewlett Packard of seventeen additional workstations, we have the capacity to carry out large scale design exercises at any level.

- The ILF usage is growing and becoming more interdisciplinary with participation, in addition to mechanical and industrial engineering, from the departments of electrical, aeronautics, Computer Science and Engineering. Also the yet to be assigned freshman in the "Introduction to Design Engineering" class make the participation truly interdisciplinary.

- It is rapidly changing student and faculty attitudes toward "hands-on" activities. While they may have been thought of as "less scientific" in the past, we are slowly convincing everyone that they are complimentary and by having the integration in the ILF, it is a "win-win" situation.

5) First Year: Lessons Learned

After the first year of operation, we have learned much, in particular it is a full time job to make it work. During the first year, we dealt with issues such as a facility whose construction was incomplete, labs that were not fully furnished, the on-going computer lab architecture issue, scheduling classes and student use issues, staffing the facility so that students have access when they want it, etc. We have learned that the Learning Factory has unique needs, in contrast to other labs such general use computer labs. The philosophy of the Learning Factory is so different from other labs in the department that there have been unexpected difficulties in setting up the lab and administering it. Policies that we experimented with included the basic ILF Concept: How to provide a relatively unfettered, supportive design environment for engineering design students, both for in-class and for individual use.

Computer system administration is more difficult than in other open-access non-teaching labs. Other labs in the department are relatively simple; each computer has an identical configuration, all software is installed system-wide, there is no individual storage space, and students have little need to have control over the configuration. In contrast, in the ILF Design Lab, a greater diversity of software and hardware is necessary to support the full design cycle and thus uniformity cannot be ensured.

The lab should be amenable to instructors who request installation of one or two educational copies of software for their students to use for a single project, without requiring that the instructor purchase a site license for the whole lab. Likewise, students need increased control. They should be able to download and install utility shareware that supports their design project and have a way to store large design files data files. Also, since work is team-oriented and all design activity takes place in the Learning Factory, disk space fills quickly because individual storage space directly on the hard drive is more desirable than having team members carry floppy disks.

Sophisticated design software (I-DEAS, AutoCAD, Pro-E, etc.) is often difficult to install and maintain without professional help. All this called for more administrative effort than in other labs, compounded by the department's lack of experience with Windows NT. While an NT-based system provides some benefits, it requires more sophisticated training than we expected.

Since the Learning Factory was established by an NSF grant, once the grant expired there was a transition to departmental support. One element of this process is providing accurate usage data. We are studying ways to instrument the lab to collect statistics on in-class and individual usage. Monitoring computer login is not enough because often several students gather around a single machine. Mandatory sign-in requires full-time staff to monitor. In negotiating for lab support, one should make clear the unique needs as described above.

Ongoing operation continues to require a lab administrator and hourly student help. The lab administrator manages purchasing, performs scheduling, computer system administration, trains students and instructors in use of equipment, conducts tours coordinates remote conferencing with industry deign projects sponsors, issues lab access codes, designs the web page, and works with instructors to develop the lab. Hourly help is useful to monitor sign-in, answer questions, maintain the web page, supply paper in printers, handle emergencies and general upkeep.

The diversity of equipment in the Learning Factory presents difficulties in managing access. Currently, labs are kept open during the day and kept under combination lock at night. Combinations are given out to design students who complete a lab access agreement form. Here it is important to instill a sense of membership and stewardship to encourage students (and professors) to self-police the lab. There are too many chances for entropy to take over since there is no full-time staff at present. Dangerous or sensitive equipment should be made secure, though there have been remarkably few security problems to date. An individual key-card access system could instill more accountability and provide automatic usage data.

6) University of Washington Presidential Recognition

In his October seventh annual address to the university community, University of Washington president Richard McCormick described models of change at the University. Of the four examples mentioned, only one was from the College of Engineering: the Learning Factory in Mechanical and Industrial Engineering. He said:

> "This is a facility in which students actually practice industrial design and manufacturing. The students experience a continuum of learning from freshman year through graduate studies where they can combine hands-on experience with the opportunity to learn analytical skills where they can work either singly or in teams where they can drop in any time. Freshman use it to use its product dissection lab to take things apart and see how they work. Intermediate work in the design lab design studio and simulated factory floor. Advanced students end up in the "manufacturing Integration Center putting things back together."

7) Conclusions

Throughout its first year of operation, the ILF became a "destination facility" for tours of the College of Engineering. Tour participants included students at all levels from elementary and high school through university level, faculty from other institutions, and potential industrial sponsors. Using the ILF as focal point for COE tours serves to introduce and recruit young students to the world of design engineering and manufacturing. It also serves as an existing model for evaluation and adoption by other universities. Most importantly, it introduces local industries to the quality and work of our students to facilitate recruiting and develop working relationships for student project sponsorship and ILF monetary and equipment support.

The basic conclusion is that the ILF is a success in spite of the myriad of problem details that had to solved. Having a "team" of dedicated, hard-working graduate students was the key to this success. Some of the problems were foreseen, others were not and had to be solved on an ad-hoc basis. Leading the team as the Technical Director is a full-time job and should not have been taken on as an “overload”. In spite of the problems, there are no team members that would not do it again. Teaching in the facility is a joy because the facility encourages team participation.

From a teaching standpoint, the ILF has provided the correct type of teaching facility for a project-based design and manufacturing curriculum. A strong sense of collaboration is encourged by the environment. Students are able to work in a team setting whether in a formal class or on their own. Tools of various types (from those required for product dissection exrcises to those required for technical report production and presentation preparation) are available for the complete “hands-on” experience. In this environment, the students are observed to take more personal responsibility for their work.

References

[1] DeMeter, E., Jorgensen, J., and Rullan, A., “The Learning Factory of the Manufacturing Engineering Educational Program,” *Proceedings of the International Conference on Manufacturing Education*, SME, San Diego, CA, March 1996.

[2] Lamancusa, J., Jorgensen, J., and Zayas-Castro, J., “The Learning Factory-An Approach to Integrating Design and Manufacturing into the Engineering Curriculum,” *ASEE Journal of Engineering Education*, April 1997, pp. 103-112.

[3] Lamancusa, J., Torres, M., Kumar, V., and Jorgensen, J., “Learning Engineering by Product Dissection,” *1996 ASEE Annual Meeting Proceedings*, ASEE Washington, D.C., 1996.

[4] Calkins, D., “Focus-Based Design Education: A Case Study,” *ASME Resource Guide to Innovation in Engineering Design Education*, ASME 1993 Design Education Conference, Orlando, FL, 24-26 March 1993, pp. 109-112.

[5] Calkins, D., “SAE Formula Car Competition: A Study in ‘Systems Engineering’,” *1992 ASEE Annual Conference Proceedings*, Toledo, OH, 21-25 June 1992, pp. 816-823.

DALE CALKINS
Associate Professor, Mechanical Engineering. Engineering career includes industrial, government, academic, and consulting experience in engineering design. Technical specialties include Knowledge-Based Engineering (KBE), Computer-Aided Design and Engineering (CAD/CAE) and transportation systems design.

JENS JORGENSEN
Professor, Mechanical Engineering, Area of specialization is design and control dynamic systems, with concentration on manufacturing systems. He has been actively in undergraduate teaching and was the first principal investigator for the NSF Sponsored ECSEL coalition. In 1996, he received the ASME 1996 Curriculum Innovation Award, with J. L. Lamancusa and J L. Zayas Castro for the MEEP Learning Factory.

MICHAEL J. SAFOUTIN
PhD Graduate Student, Industrial Engineering, received degrees from the University of Oklahoma and the University of Illinois at Urbana-Champaign. He is currently pursuing the PhD at the University of Washington, where he helped create the Integrated Learning Factory and continues to serve as its coordinator. His research interests include engineering education, design theory and methodology, theory of design management, and applications of artificial intelligence to design.

JOSEPH HEIM
Assistant Professor, Industrial Engineering. Primary teaching responsibilities include computer integrated manufacturing systems, simulation, inventory management and scheduling. His research interests include modeling complex collaborative tasks, as well as the design and analysis of manufacturing and service systems. Professor Heim is a member of ASEE.