AC 2009-841: INTRODUCING A FLEXIBLE ADAPTATION FRAMEWORK FOR IMPLEMENTING LEARNING-FACTORY–BASED MANUFACTURING EDUCATION

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INTRODUCING A FLEXIBLE ADAPTATION FRAMEWORK FOR IMPLEMENTING 'LEARNING FACTORY' – BASED MANUFACTURING EDUCATION

1. Introduction

The Learning Factory (LF) model was first developed as part of the TRP/NSF funded Manufacturing Engineering Education Partnership with the goal of developing a practice-based engineering curriculum that balances analytical and theoretical knowledge with integrated physical facilities for product realization in an industrial-like setting[1-2]. The model has been successfully implemented in several other institutions[3]. However, full implementation of the LF model can be expensive. In 2002, Wayne State University was awarded an NSF grant to develop an adaptation of the LF model that would be less costly to implement. This goal was achieved by introducing the use of coordinated hands-on projects in standard laboratory settings across selected courses, using a model engine as the unifying theme[4-6]. This proved to be a more cost-effective way to give students hands-on experience in a range of issues involved in product realization.

The lack of hands-on experiences in specific manufacturing processes has been identified as one of the major competency gaps in manufacturing engineering education. In 1997, the Society of Manufacturing Engineers (SME) launched its Manufacturing Education Plan (MEP) to address key engineering competency gaps of new graduates that it had identified[7]. The gaps identified in 1997 were revised in 1999 and revised further in 2002-03. The latest rankings are shown in Table 1. (Note: higher ranking indicates larger competency gap and greater need.) Since the institution of the MEP, SME has funded more than $15 million for diverse projects throughout the nation to expand and improve manufacturing, engineering, science, and technology education so as to help close these competency gaps.

Table 1: Ranked SME Competency Gaps

1. Business knowledge/skills	2. Supply chain management
3. Project management	4. International perspective
5. Materials	6. Manufacturing process control
7. Written & oral communication	8. Product/process design
9. Quality	10. Specific manufacturing processes
11. Manufacturing systems	12. Problem solving
13. Teamwork/working effectively with others	14. Personal Attributes
15. Engineering fundamentals	

In 2008, Wayne State University was awarded a follow-on NSF grant to broaden the implementation of the results from the first award. The goal of the current project is to distill a core of course-level learning outcomes from our previous work and develop an approach for mapping these to higher program-level outcomes that help to meet industry-defined competency gaps. We are taking the successful approach of using coordinated hands-on activities across multiple courses to provide students with specific competencies, and testing the broad efficacy of this approach by implementing it simultaneously in five diverse departments at four different institutions. Students will learn by trying things out, and working with others in a holistic, systematic way. The following specific tasks will be by undertaken to accomplish this goal:

- Implement educational innovations resulting from the original LF adaptation by developing and implementing new curricula to suit the needs of diverse institutions. Curricula will be developed to satisfy ABET Criterion 3 (a-k) for program accreditation, as well as selected SME competency gaps.
- In the process, we will develop faculty expertise in curriculum writing and validation with particular focus on developing learning materials that provide students with specific hands-on skills.
- We will develop assessment tools based on accepted industry practices to assess how well students learn using the new curricula learning materials and strategies.

This approach is being implemented across diverse institutions namely: Wayne State University, New Mexico State University, Prairie View A&M University, and Macomb Community College and their programs. The work is organized in a creative and original manner in which courses both within and across these institutions can continue to evolve products and processes together. Knowledge sharing between institutions is facilitated by the multi-institution team structure. The adaptation of the LF concept to diverse programs provides a model for other institutions to follow. The diversity of approaches is expected to provide a wealth of "lessons learned" for broader dissemination.

2. Goals and Objectives of Project

The high cost of setting up a manufacturing facility means that colleges and universities have to make difficult choices about the resources they dedicate to courses in manufacturing and related areas. Thus, many college courses are skewed towards theoretical concepts with limited (if any) hands-on experience for students. Frequently, students' exposure to actual processes is limited to observing demonstrations or watching videotapes, but with the students not getting their hands on the equipment. Yet these are the experiences that help most engineering students learn[8]. This phenomenon helps to explain the causes of the competency gaps identified by SME. We have demonstrated in our previous work that fabricating a simple mechanism such as a model engine is an effective way to give students realistic hands-on experiences related to select competency gaps. Most importantly, it is a cost-effective approach that does not require investment in equipment beyond what is typical for a college-level manufacturing laboratory.

The goal of this project is to create a consortium of academic institutions with varied strengths and needs, and use these as a test-bed for a more wide-ranging implementation of the results of our previous work. Faculty at the partner institutions will be trained in how to develop appropriate teaching materials in courses involving the design and manufacture of a chosen mechanism. In-depth evaluation of the resulting courses will be carried out to assess student learning under this model. In the process, we will develop a standardized curriculum development model that could eventually be adopted nationwide.

ABET, Inc.; the recognized leader in assuring quality and standards in engineering and technology education; has defined high-level educational outcomes for programs seeking accreditation. In our previous work, we developed a series of course-level outcomes that help to meet industry-defined competency gaps. In this project, we are creating a bridge between ABET program-level outcomes and these course-level outcomes. Other institutions will be able to use our curriculum model to map relevant course-level outcomes to the mission as reflected in the high-level ABET outcomes. This will help institutions satisfy accreditation requirements and meet industry needs, while maintaining proper flexibility in educational offerings.

This project directly addresses NSF's cyclic model of STEM education, as shown in Figure 1. Our original NSF project to adapt the LF for implementation in a laboratory setting addressed the first part of the NSF model: *Creating New Learning Materials and Teaching Strategies*. The current project will address three of the other components of NSF's model namely: *Implementing Educational Innovations, Assessing Student Achievement, and Developing Faculty Expertise.*

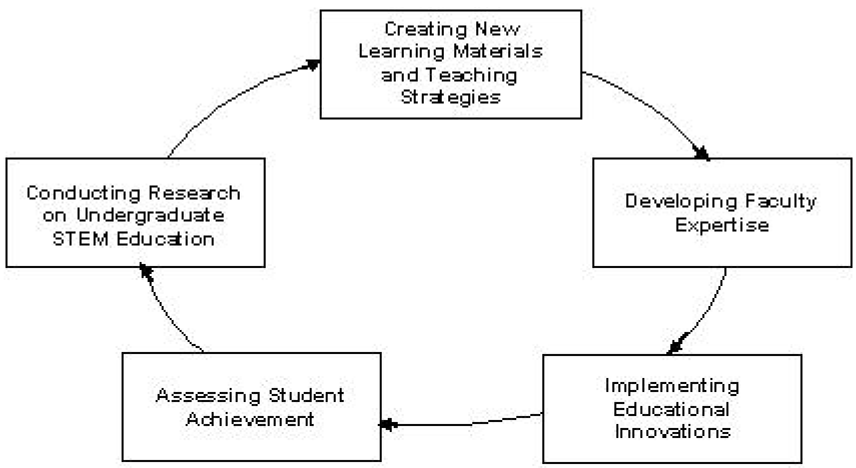

Figure 1: NSF Cyclic Model for STEM Education[9].

3. Project Plan

The consensus of industry needs expressed in the competency gaps identified by SME will be our measure of industry needs. ABET's *Criterion 3: Program Outcomes* (given in Table 2) constitute a widely accepted standard and they will be our measure for educational program-level outcomes. While institutional educational outcomes can vary widely, ABET's Criterion 3: Program Outcomes (also known as 'a through k') is a well accepted standard for program-level outcomes. The specifics of Criterion 3 vary slightly between engineering and engineering technology programs but as can be seen in Table 2, they are similar enough between them that either can serve as a basis for implementing our proposed LF adaptation. Consequently, this adaptation can work for either engineering or engineering technology programs. Details about the various institutions participating in this project and their course offerings relevant to the project are given in Sections 5 and 6. Because of the variety of institutions involved, it is important to emphasize that the glue holding the consortium together is the need to meet institutional program-level outcomes while satisfying industry needs.

Table 2: ABET Criterion 3 – Program Outcomes

ABET EAC Criterion 3: Program Outcome[10]	*ABET TAC Criterion 3: Program Outcomes*[11]
(a) ability to apply knowledge of mathematics, science, and engineering (b) ability to design and conduct experiments, as well as to analyze and interpret data (c) ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability (d) ability to function on multidisciplinary teams (e) ability to identify, formulate, and solve engineering problems (f) understanding of professional and ethical responsibility (g) ability to communicate effectively (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context (i) recognition of the need for, and an ability to engage in life-long learning (j) knowledge of contemporary issues (k) ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.	a. an appropriate mastery of the knowledge, techniques, skills, and modern tools of their disciplines b. an ability to apply current knowledge and adapt to emerging applications of mathematics, science, engineering, and technology c. an ability to conduct, analyze and interpret experiments, and apply experimental results to improve processes d. an ability to apply creativity in the design of systems, components, or processes appropriate to program educational objectives e. an ability to function effectively on teams f. an ability to identify, analyze and solve technical problems g. an ability to communicate effectively h. a recognition of the need for, and an ability to engage in lifelong learning i. an ability to understand professional, ethical and social responsibilities j. a respect for diversity and a knowledge of contemporary professional, societal and global issues k. a commitment to quality, timeliness, and continuous improvement

4. Targeted Course-Level Learning Outcomes

This project focuses on the course-level learning outcomes established from the original LF adaptation as the basis for the wider implementation to be undertaken. Focusing on the learning outcomes makes it easier for other institutions to implement the adaptation by using products that are more relevant to their respective program-level outcomes. The outcomes that were identified are shown in Table 3. Between them, they cover a broad range of issues involved in product design, planning, fabrication, assembly and testing. These constitute a core body of knowledge that all graduating engineers and technologists in manufacturing related fields should master. The institutions participating in the project will map these course-level outcomes to their respective program-level outcomes. When fully implemented, these outcomes address a large portion of industry identified competency gaps and can help meet program-specific goals and objectives.

Table 3: Core Course-Level Learning Outcomes

Drafting/Design Area 1. Sketch objects freehand to convey concepts 2. Create orthographic views of objects 3. Visualize objects 3-dimensionally 4. Draw isometric and oblique pictorials of objects 5. List and recognize the six major types of sectional views. 6. Use a CAD program to complete 2D drawings. 7. Use drawing, editing tools, and command line. 8. Organize drawing entities into layers, add text and dimensions, and prepare to plot in CAD. 9. Use a CAD program to create 3D drawings using wire modeling and solid modeling. 10. Use a CAD program to create parametric solid models of parts and assemblies. 11. Use CAD concepts like expressions, drafting. 12. Create constraint-based models, top-down and bottom-up models and assemblies. **CAD/CAM/CIM Area** 1. Describe and identify geometric modeling in CAD domain. 2. Perform computer-aided NC programming. 3. Perform manual NC programming by means of editing, trouble-shooting, and optimizing 4. Apply PC-based CAD/CAM system 5. Define and recognize the applications of concurrent engineering and computer-aided-process-planning 6. Recognize and apply computer control in manufacturing 7. Analyze group technology and apply it in cellular manufacturing 8. Plan and design flexible manufacturing systems.	**Manufacturing Processes Area** 1. Distinguish between design and manufacturing, and describe the relationship between them. 2. Specify fit and tolerance of standardized and/or interchangeable mating parts. 3. Use preferred numbers in selection of sizes 4. Describe the internal structure of metals, and its impact on metal properties and processing. 5. Describe how at least two common engineering materials are extracted from their ores 6. Describe selected manufacturing processes, including their capabilities and limitations. 7. Select appropriate machining processes and tools to make a given part 8. Describe safety procedures that need to be followed in a machine shop 9. Identify and operate a lathe, drilling, and milling machines 10. Determine the important operating parameters for each of these machines 11. Use standard shop gages to inspect parts 12. Effective oral and written communication. 13. Work successfully as a member of a team. **Process Engineering Area** 1. Apply logical design of a process plan 2. Plan and analyze part design for productivity 3. Analyze tolerance charting in part design 4. Plan the manufacturing process of a given part 5. Analyze and improve manufacturing processes 6. Select the optimal manufacturing equipment 7. Perform analysis and selection of cutting tools, coolants, jigs & fixtures, and support systems 8. Effective oral and written communication.

5. Organizational Structure

The institutions that have been brought together under this collaborative effort were deliberately chosen to demonstrate the expected wide impact of the proposed work. The institutions are Wayne State University, an urban Carnegie I research university; Prairie View A&M University, a comprehensive, historically black university; New Mexico State University, a land-grant Carnegie I research university that is also designated as a Hispanic Serving Institution; and Macomb Community College, a fully accredited publicly funded Community College. Participating departments at the respective institutions include Engineering Technology, Mechanical Engineering, and Industrial Engineering. Each institution is working to implement the core learning outcomes identified during the WSU LF adaptation as needed to suit its particular program-level outcomes. Figure 2 shows how the partner relationships are organized.

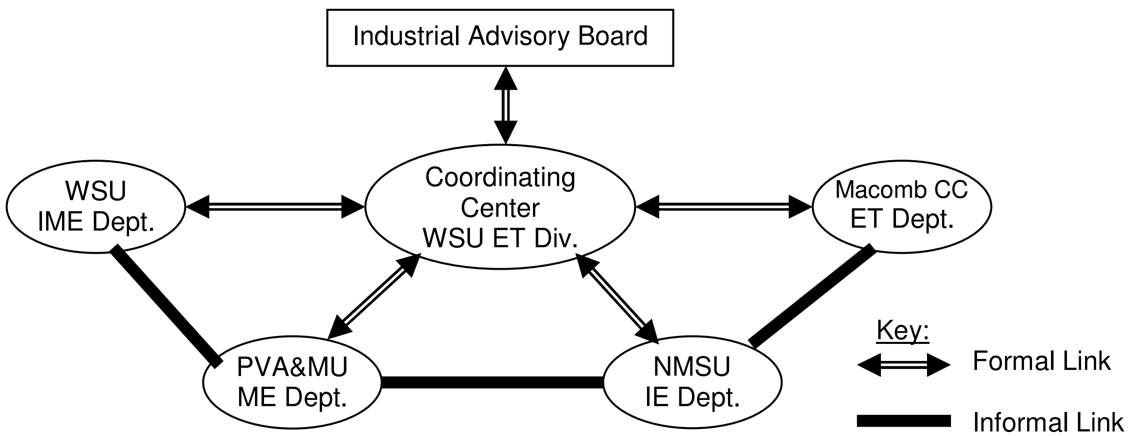

Figure 2: Consortium Organizational Structure

As the pioneers of the Learning Factory adaptation on which the proposed work is based, Wayne State University's Engineering Technology Division serves as the coordinating center for this project. The investigators who led the original adaptation effort are also leading this coordinating activity. In its coordinating role and in consultation with other participants, the Coordinating Center has formulated an Industrial Advisory Board (IAB) to provide industry input and feedback regarding the project. Each of the other participating institutions has identified courses to be targeted for this development activity as shown in Table 4.

The concept of using a common project across several courses to meet curricular requirements is starting to gain popularity as evidenced for example by work at Arizona State University[12]. The major contribution of this project is expected to be in developing a generalized model that can be easily adopted and adapted to meet the needs of diverse institutions.

Table 4: Targeted Development Courses by Institution

Institution	Course	Description
WSU-IME	Materials Science (BE 1300/1310)	Fundamentals of materials science, emphasis on effect of material properties and behavior on engineering applications
	Manufacturing Processes (IE 3450/3455)	Fundamentals of manufacturing processes
	CAM (IE 4410)	The use of microprocessors in the design of CAM systems.
	Concurrent Engineering Design (IE 4450)	Integration of product and process design, design for manufacture and assembly, material selection, producibility
PVA&MU ME	MCEG 1021	Introduction to design methodology, use of CAD tools.
	MCEG 3033 Manufacturing Processes.	Conversion of materials into products. Includes measurement, quality assurance, and selected processes.
	MCEG 3031 Manufacturing Processes Laboratory.	Experiments for metal identification, machinability, effects of factors on cutting forces, roughness, material removal rates.
	MCEG 3043 Machine Design I	Fundamentals of mechanical design methodology, design of machine elements, and design projects.
NMSU IE	ME159 Graphical Communication and Design	Sketching and orthographic projection. Detail and assembly drawings, dimensioning, tolerancing, and design projects.
	IE217 Manufacturing Processes I	Manufacturing methods and industrial processes which include casting, forming and machining (includes lab).
	IE375 Manufacturing Processes II	Review of IE217. Advanced topics in selected processes, process parameters, economics of processes.
	IE 480 Senior Design	Multi-disciplinary team design project for external clients. Includes design report and presentation.
Macomb CC ET	PRDE 1700 Teamcenter Engineering	Creating, revising, finding, viewing, and managing product data and data structures through the product life cycle.
	PRDE 2000 Product Development Processes	Product Development Process used in industry: planning, specifications, development processes, and economics.
	QUAL 2400 Project Management	The Project Management Institute methodology. Visual tools for planning and scheduling, diagramming, time and cost.
	PRDE 2420 Capstone Project	Integration of multiple design disciplines: emphasis problem solving, time & team management, process change.

6. Project Overview

Table 7 gives an overview of how each institution addresses the SME competency gaps through this project and how the individual efforts compare with Wayne State's original LF adaptation. The different combinations of competencies addressed demonstrate the adaptability of this model. In addressing the various competency gaps, the institutions will also be addressing their respective ABET accreditation requirements. It is anticipated that the project will result in a standard curriculum model for participating institutions to use in developing their respective educational programs. A key driver at this stage will be to ensure that the curricula that emerge from this process will meet institutional program-level objectives, contribute to meeting ABET accreditation criteria, and help satisfy industry-defined competency gaps.

Table 7: Summary of Competencies Addressed by this Project

SME Competency	**Original WSU ET**	**WSU IME Dept**	**PVA&M ME Dept**	**NMSU IE Dept**	**Macomb CC ET Dept**
Materials		BE1300			
Manuf Process Control		IE4410			
Product/Process Design	ET2140 MIT3600	**IE 4410** IE4450	MCEG1021, 3043,	ME159 IE480	PRDE2000 PRDE2420
Specific Manufacturing Processes	MIT3510 MIT4700	IE3450 IE3455	MCEG3031, MCEG3033	IE217 IE375	
Manufacturing Systems	MIT4700	IE4410			
Teamwork/working effectively with others	MIT3510	*PLM / IPD*		IE480	PRDE1700 PRDE2420
Project management		*PLM / IPD*		IE480	QUAL2400
Problem solving				IE480	PRDE2420
Written & oral communication	MIT3510			IE480	PRDE1700 PRDE2420

The fully refined curricula will be implemented in the programs of the participating institutions and there will be ongoing assessment to verify the effectiveness of the curriculum in meeting stated program objectives. Successful implementation of this project at each institution should prove to be self-sustaining because the concepts are being implemented into existing degree programs that will continue to be offered by the respective institutions even after the conclusion of the project. Finally, we will open up project participation by offering a series of faculty development workshops to a limited number of faculty from non-partner institutions. Interested faculty will be brought in for training to familiarize them more intimately with our work to train them in the curriculum writing and concept mapping procedures appropriate for adapting and implementing this approach at their respective institutions. The workshops will be modeled after ABET accreditation workshops. Participants will be recruited nationwide through avenues such as professional organizations like SME, ASEE, IIE or ASME, and through email lists they maintain to which the investigators subscribe.

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