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Manufacturing Integrated Learning Laboratory (MILL): A Framework for Determination of Core Learning Outcomes in Engineering Curricula*

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There is a need for engineering and technology curricula which balance analytical and theoretical knowledge with integrated physical facilities that offer students authentic and relevant hands-on experiences. In this paper, this need is addressed with focus on the field of manufacturing. It has been established that fabricating a simple functional mechanism is an effective way to give students realistic hands-on manufacturing experiences. A consortium of five departments in four institutions was formed, and a consortium-wide curriculum writing process was undertaken, in which a core set of common course-level learning outcomes was developed. A statistical analysis was carried out to ascertain those outcomes that contributed most to meeting institutional educational objectives. This resulted in a common core of learning outcomes serving the needs of all participating institutions.

Keywords: engineering curricula; competency gap; hands-on experience; learning factory

1. Introduction

The Manufacturing Integrated Learning Laboratory (MILL) concept is an advancement of the Learning Factory (LF) model originally developed as part of the TRP/NSF funded Manufacturing Engineering Education Partnership. The goal of the LF model was to develop a practice-based engineering curriculum, balancing analytical and theoretical knowledge with integrated physical facilities for product realization in an industrial-like setting [1, 2]. Although its successes are documented [3], a potential drawback for full implementation of the LF model is that it can be quite expensive. An adaptation of the LF model that is less costly to implement was developed 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 simplified approach to providing hands-on manufacturing education has been embraced by a number of other institutions [7–9].

In a follow-on study [10], a core of course-level learning outcomes were identified and mapped to higher program-level objectives that help to meet industry-defined competency gaps in manufacturing. The goals of the new study include:

- Implement educational innovations resulting from the original LF adaptation by developing and implementing new curricula to suit the needs of diverse institutions. Curricula were developed to address ABET Criterion 3 for program accreditation, as well as meet selected industry-defined competency gaps that have been documented by the Society of Manufacturing Engineers (SME).
- Develop faculty expertise in curriculum writing and validation with particular focus on developing learning materials that provide students with specific hands-on experiences.
- Develop assessment tools based on accepted industry practices to evaluate how well students learn when using the new curriculum learning materials and strategies.

This new approach is called the Manufacturing Integrated Learning Laboratory (MILL). It was implemented at the following institutions and their programs: Wayne State University (WSU), New Mexico State University (NMSU), Prairie View A&M University (PV), and Macomb Community College (MCC). Figure 1 shows how the consortium is organized. The implementation was done in a creative and original manner, in which courses both within and across these institutions can continue to evolve products and processes together.

As the pioneers of the LF adaptation on which this work is based, Wayne State University's Engineering Technology Division serves as the Coordinating Center for this work. The investigators

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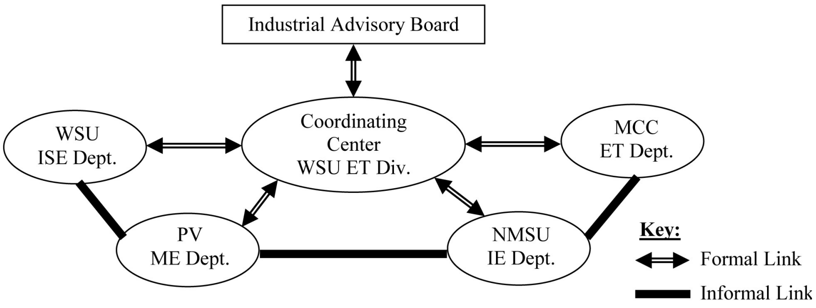

Fig. 1. Consortium Organizational Structure

who led the original adaptation effort are also leading this coordinating activity. In its coordinating role and in consultation with the other participants, the Coordinating Center has formed an Industrial Advisory Board (IAB) to provide industry input and feedback regarding the project.

Knowledge sharing between institutions is facilitated by the multi-institutional team structure. This implementation of the MILL concept 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. Objectives

The high cost of setting up a manufacturing facility means that colleges and universities have to make difficult choices about the resources which 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 video, but with the students not getting their hands on the equipment. Yet these are the very experiences that help most engineering students learn [11]. This phenomenon helps to explain the causes of the competency gaps amongst graduating engineering students as identified by the Society of Manufacturing Engineers [12].

It has been previously demonstrated 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 in manufacturing [6, 11]. The objective in the current study was 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 this previous work. Faculty at the partner institutions were trained in how to develop appropriate teaching materials in courses involving the design and manufacture of a chosen mechanism.

3. Curriculum Writing Process

ABET, Inc., the recognized accreditor for college and university programs in applied science, computing, engineering, and technology in the United States, has defined high-level educational outcomes for programs seeking accreditation. The work described in this paper helps to establish a bridge between those ABET program-level outcomes, and specified course-level learning objectives. (Note: In recent proposed changes in terminology by ABET, 'program outcomes' will become 'student outcomes').

ABET's 'Criterion 3: Program Outcomes' constitutes a widely accepted standard for educational program-level outcomes [13, 14]. Although institutional educational objectives can vary widely, ABET's Criterion 3 provides a uniform benchmark for assessing program-level outcomes. Whereas the specifics of Criterion 3 vary slightly between engineering and engineering technology programs, they are similar enough that either can serve as a basis for implementing the MILL concept. Consequently, the MILL approach can be successful for either engineering or engineering technology programs. It should be noted that ABET is currently working towards harmonizing its criteria between its various commissions [15]. Because of the variety of institutions involved in this particular study, 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 1 shows a set of course-level learning outcomes in four knowledge areas that were identified as helping meet industry-defined competency gaps [10]. This set of outcomes constitutes the consortium-wide outcomes on which this study is based. By applying the MILL curriculum writing approach described below, these were narrowed down to a common set of core learning outcomes that help to meet the needs of all participating institutions. Other institutions can follow a similar process to map the relevant course-level learning outcomes to their own program-specific objectives and the high-level ABET program outcomes (or student outcomes). This approach can help institutions address accreditation requirements and meet industry needs, while still maintaining proper flexibility in educational offerings.

As indicated above, the learning outcomes in Table 1 were used as the basis for the consortium-wide implementation being undertaken. Between them, these outcomes cover a broad range of issues involved in product design, planning, fabrication, assembly, and testing, which constitute a core body of knowledge that all graduating engineers and technologists in manufacturing related fields should master. Focusing on the learning outcomes makes it easier for other institutions to implement the adaptation because instead of force-fitting a new curriculum into their programs, they can simply map their outcomes to the MILL model outcomes. This can be accomplished using only those courses that are most relevant to their program outcomes and the needs of local industry. Similarly, the model engine application used at WSU can be replaced by other products that are more relevant to their respective programs. The adopting institution simply maps the MILL course-level learning outcomes to its institutional program outcomes.

In its original LF adaptation, WSU's Engineering Technology Division used the drafting and making of a model engine as their thematic project. The other institutions participating in the current study have chosen different products that are more suitable for the needs of their respective programs. For example, Macomb Community College students design and make a small windmill. Nevertheless, each institution follows the same methodology of encountering the selected product in different courses as they address design, planning, and fabrication issues associated with the product. 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 [16]. A major contribution of this paper is developing a generalized approach that can be easily adapted to meet the needs of diverse institutions.

The four knowledge areas in Table 1, with their corresponding detailed course-level learning outcomes, were identified for study because they had the greatest degree of overlap with the SME competency gaps. They also happen to be arranged into four courses in WSU's ET program. The other participating schools cover the same knowledge areas using a different set of courses. Consortia participants were asked to identify local courses that are related to the four knowledge areas and

Table 1. MILL Knowledge Areas and Corresponding Course-Level Learning Outcomes

Drafting/Design Knowledge 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 Knowledge 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 Knowledge 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 Knowledge 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.

these would be targeted by this development activity. The resulting set of targeted courses is shown in Table 2. Each course's learning outcomes were identified to facilitate comparison with the outcomes in Table 1.

The individual course outcomes were next ranked with regards to their relative importance in contributing to the respective institution's program-specific objectives. The rankings are indicative of the importance of each outcome as stipulated by the course instructors. Students were not involved at this stage, because the focus was on curriculum development. When evaluation of the project outcomes commences, students will be assessed regarding what they have learned. The assessment process and results will be reported on in a separate article.

To illustrate the process of institutional ranking of course outcomes, an excerpt from the Drafting/Design knowledge area is depicted in Table 3. The applicable proposed project-wide learning outcomes from Table 1 appear in the first column (the Drafting/Design subset is shown in Table 3). For each course to be evaluated by a participating institution, the institution would list that course's learning outcomes in the columns to the right. Columns could be deleted or added to correspond to the total number of course outcomes. The partner instructional faculty then rated each of the project-wide learning outcomes in terms of their relationship and contribution to institution-specific course outcomes on a scale of 1 (Low) to 3 (High). Specifically within each row, cells were identified showing the correspondence between the project-wide outcome and the institution's course outcomes in the intersecting columns.

The value entered in each cell (1, 2 or 3) was a measure of the project outcome's contribution to the institution's course outcome. A blank cell means there is no correspondence between the outcomes. Because of differences in curricular structure and content, the relationship between project outcomes and course outcomes was not necessarily one-to-one, and a given institutional course learning outcome could contribute to more than one project knowledge area (or vice versa). When this ranking process was completed for all the courses, we had a curriculum mapping matrix showing how individual courses related to overall project learning out-

Table 2. Targeted Development Courses by Institution

Institution	Course	Description
WSU ISE Dept.	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) CAM (IE 4410)	Fundamentals of manufacturing processes 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.
PV ME Dept.	MCEG 1021 Mechanical Engineering Drawing I	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 Dept.	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.
MCC ET Dept.	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.

Table 3. Mapping Project Outcomes to Institution-Specific Outcomes

	Rate 1=Low, 3 = High							
	School Specific Course Learning Outcome							
Drafting/Design Knowledge Area Outcomes	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
1. Sketch objects freehand to communicate 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 any modern Computer Aided Design (CAD) Program to complete 2D drawings								
7. Create 2D drawings using CAD drawing, editing tools and command line.								
8. Organize drawing entities into layers, add text and dimensions, and prepare to plot in CAD.								
9. Create 3D models using wireframe and solid modeling								
10. Use software to develop parametric solid model representations of parts and assemblies.								
11. Use software concepts such as expressions, drafting.								
12. Create Constraint-based modeling using sketcher, top-down and bottom-up using software modeling and assemblies.								

comes. A fully populated version of Table 3 showing the results of the mapping process for one course is given in the Appendix.

4. Analysis Methodology

The resulting data from the curriculum writing process for all courses from all participating institutions was collected and subjected to a statistical analysis in order to identify those outcomes that best map to the project goals. This analysis process resulted in a set of learning outcomes that were identified as important to the learning outcomes of all participating institutions. The analysis was carried out as follows:

First, a weighted average score was computed according to Equation (1), where

$$\bar{x} = \frac{\sum_{i=1}^{n} wX_i}{\sum_{i=1}^{n} w_i}, \tag{1}$$

where X is the raw score, w is the weight, and n is the total number of scores. The left hand side of Table 4 below shows the weighted average score for each project-wide outcome in the Drafting/Design knowledge area. A weighted average rank was computed because the number of courses involved, and the outcomes identified within each course, differ among the participating institutions. The weighted averages, however, are only meaningful within an institution (i.e. going down a column), but are not informative across consortia schools. In order to transpose the relative rankings into a common metric, the weighted averages were then converted to a *standard normal score* ($\mu = 0, \sigma = 1$) using Blom's algorithm [17], a proportion estimate based on $r_i (1 \le r_i \le w)$. This produces a normal curve Z score according to Equation (2), corresponding to r_i such that

$$\Phi^{-1} = \left(\frac{r_i - \frac{3}{8}}{w + \frac{1}{4}} \right), \tag{2}$$

where $\Phi^{-1}(\cdot)$ is the Gaussian cumulative density function, w = sum of the case weights, and r = rank. These Z scores appear in the columns to the right hand side in Table 4 (e.g., NMSUZ, MCCZ).

5. Results

In order to make the resulting scores more readily comprehensible to non-statisticians, relative weighted percentiles for each school were calculated from the cumulative probability of the normal distribution for each Z score. The consortia schools naturally differed in emphases. Therefore, a mean percentile for each outcome was computed across participating schools. In Table 5, the project learning outcomes for the Drafting/Design knowledge area previously shown in Table 4 are now presented according to percentile ranking for each of the outcomes. For example, the outcome "Create orthographic views of objects" ranks as number 3 with a 63.57 percentile, which placed it as the third most important outcome, based on the participants'

Table 4. Weighted and Standardized Averages of Outcomes by School

		Weighted Average Score				**Standardized Normal Score**				
		NMSU	**MCC**	**PV**	**WSU**	**NMSUZ**	**MCCZ**	**PVZ**	**WSUZ**	**MeanZ**
Drafting/Design	1. Sketch objects freehand to communicate concepts	0.18	0.07	0.31	0.08	–0.153	0.4059	0.7681	–0.943	**0.0195**
	2. Create orthographic views of objects	0.18	0.10	0.31	0.16	–0.153	0.6508	0.7681	0.1218	**0.3471**
	3. Visualize objects 3-dimensionally	0.32	0.13	0.10	0.20	0.5774	0.7279	–0.341	0.507	**0.3679**
	4. Draw isometric and oblique pictorials of objects	0.18	0.08	0.00	0.14	–0.153	0.5419	–0.992	–0.091	**–0.173**
	5. List and recognize the six major types of sectional views	0.18	0.00	0.10	0.06	–0.153	–0.897	–0.341	–1.434	**–0.706**
	6. Use any modern Computer Aided Design (CAD) Program to complete 2D drawings	0.18	0.15	0.00	0.14	–0.153	0.9434	–0.992	–0.091	**–0.073**
	7. Create 2D drawings using CAD drawing, editing tools and command line.	0.24	0.06	0.00	0.14	0.0608	0.3087	–0.992	–0.091	**–0.178**
	8. Organize drawing entities into layers, add text and dimensions, and prepare to plot in CAD.	0.26	0.00	0.10	0.14	0.3087	–0.897	–0.341	–0.091	**–0.255**
	9. Create 3D models using wireframe and solid modeling	0.12	0.14	0.10	0.29	–0.614	0.8096	–0.341	1.4342	**0.3224**
	10. Use Unigraphics to develop parametric solid model representations of parts and assemblies.	0.09	0.08	0.31	0.29	–0.81	0.5419	0.7681	1.4342	**0.4837**
	11. Use Unigraphics concepts like expressions, drafting.	0.09	0.00	0.31	0.22	–0.81	–0.897	0.7681	0.7681	**–0.043**
	12. Create Constraint-based modeling using sketcher, top-down and bottom-up using Unigraphics modeling and assemblies.	0.09	0.00	0.41	0.20	–0.81	–0.897	1.2816	0.507	**0.0205**

ranking. Following this approach, similar rankings were developed for all four knowledge areas of Table 1. This approach alleviates the challenge of writing learning objectives and outcomes which can be a difficult process for engineering faculty [18].

Common ‘core outcomes’ across consortia schools were defined as the set of outcomes that ranked at or above the 50th percentile. This threshold was chosen because it represented a readily identifiable degree of consensus among the participants. It also seemed to be a good trade-off between keeping the overall set manageable, and capturing the most important criteria for common instruction and evaluation. Those outcomes meeting this criterion for the Drafting/Design knowledge area are shown shaded in Table 5. Thus, based on this threshold, six of the twelve original project-wide learning outcomes in this knowledge area were identified as forming a common core to the area. This proposal was conveyed to partner institutions as well as members of the Industrial Advisory Board. They were provided with the preliminary results of the analysis covering all the 41 project outcomes and invited to comment.

The proposal to use the 50th percentile as a cut-off point proved to be generally acceptable. Consequently, those outcomes that met the 50th percentile threshold were retained as the MILL core outcomes. However, feedback from partner institutions and members of the Industrial Advisory Board led to the inclusion of the study of tolerances. Although the statistical analysis had not shown this to be above the agreed threshold, the partners recommended its inclusion due to its perceived practical importance.

None of the CIM outcomes met the 50th percentile cut off, and because no objection was raised, it was dropped as a core knowledge area. It was also agreed to reword some of the outcomes to eliminate mention of specific computer programs, thus making the outcomes more generic and more widely applicable. The original 41 MILL project-wide outcomes were ultimately sorted down to the final 22 which are depicted in Table 6.

Table 5. Outcomes Rankings and Percentiles for the Drafting/Design Knowledge Area

Rank	Drafting/Design	Percentile
1	Use software to develop parametric solid model representations of parts and assemblies	68.57
2	Visualize objects 3-dimensionally	64.35
3	Create orthographic views of objects	63.57
4	Create 3D models using wireframe and solid modeling	62.64
5	Sketch objects freehand to communicate concepts	50.78
6	Create constraint-based modeling using sketcher, top-down and bottom-up using software modeling and assemblies	50.82
7	Use software concepts such as expressions, drafting	48.29
8	Use modern CAD program to complete 2D drawings	47.09
9	Draw isometric and oblique pictorials of objects	43.13
10	Create 2D drawings using CAD drawing, editing tools, and command line	42.94
11	Organize drawing entities into layers, add text and dimensions, and prepare to plot in CAD	39.94
12	List and recognize the six major types of sectional views	24.01

Table 6. Agreed Core Learning Outcomes of the MILL Model.

Drafting/Design	
D1	Use a state-of-the-art CAD program to develop parametric solid model representations of parts and assemblies
D2	Visualize objects 3-dimensionally
D3	Create orthographic views of objects
D4	Create 3D models using wireframe and solid modeling
D5	Sketch objects freehand to communicate concepts
D6	Create constraint-based modeling using a state-of-the-art CAD program
Manufacturing Processes	
M1	Given a part design, select appropriate machining processes and tools to make the part
M2	Determine the important operating parameters for each of these machines
M3	Describe selected manufacturing processes, including their capabilities and limitations
M4	Identify and operate conventional lathe, drilling, and milling machines
M5	Communicate effectively using written and graphical modes
M6	Work successfully as a member of a team
M7	Specify fit and tolerance of standardized and/or interchangeable mating parts
Process Engineering	
P1	Plan and analyze part design for productivity
P2	Analyze and improve manufacturing processes
P3	Analyze tolerance charting in part design
P4	Apply logical design of a manufacturing process plan
P5	Perform manufacturing process planning of a given part
P6	Communicate effectively in oral and written formats
P7	Select the optimal manufacturing equipment
CAD/CAM	
C1	Describe and identify geometric modeling in CAD domain
C2	Perform computer-aided numerical control programming

6. Conclusions

This paper introduces a methodology to determine the core learning outcomes of manufacturing curricula. This work shows how curricula that differ in their detailed implementation can be developed based on a common set of core learning outcomes. In this case, the core learning outcomes were identified through an extended review process with multiple constituencies and ratings by content experts. Statistical analysis and subsequent rankings helped identify the outcomes that are most important in mapping learning outcomes to diverse institutional program objectives. This analysis process resulted in a set of learning outcomes that were identified as important to the learning outcomes of all participating institutions. The results are easily transferrable to programs outside the immediate partner institutions. This process for developing a core set of outcomes across multiple institutions can be generalized to curriculum writing activities in other fields of knowledge. This approach recognizes pedagogical freedom, builds on best practices among the participants, and increases the probability of 'buy-in' and ultimate adoption by all partner institutions.

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Appendix: Mapping Course Learning Objectives to the MILL Project Learning Outcomes.

The following table shows a fully populated version of Table 3, giving the results of the mapping process for WSU's course MIT 3520 (Manufacturing Processes Theory). This mapping process was repeated for all courses. Table 6 lists the core learning outcomes generated from the analysis carried out on the mapping results for all courses.

Project Learning Outcomes	WSU Engineering Tech MIT 3520 Manufacturing Processes Theory	1. Define Design/Manufacturing and their relationship	2. Specify fit and tolerance of standardized or mating parts	3. Use preferred numbers in selection of sizes	4. Describe metallic structure, and its impact on properties and processing.	5. Describe how select materials are extracted from their ores	6. Describe select manufacturing process capabilities & limitations.	7. Select appropriate machining processes and tools to make a part	8. Communicate effectively using written and graphical modes
Drafting/Design	1. Sketch objects freehand to communicate 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 any modern Computer Aided Design (CAD) Program to complete 2D drawings								
	7. Create 2D drawings using CAD drawing, editing tools and command line.								
	8. Organize drawing entities into layers, add text and dimensions, and prepare to plot in CAD.								
	9. Create 3D models using wireframe and solid modeling								
	10. Use Unigraphics to develop parametric solid model representations of parts and assemblies.								
	11. Use Unigraphics concepts like expressions, drafting.								
	12. Create Constraint-based modeling using sketcher, top-down and bottom-up using Unigraphics modeling and assemblies.								
	Check to indicate a local course objective that <u>should</u> be added to the Project-wide outcomes								
Manufacturing Processes	1. Distinguish between design and manufacturing, and describe the relationship between them.	2							
	2. Specify fit and tolerance of standardized and/or interchangeable mating parts.		3						
	3. Use preferred numbers in selection of sizes			3					
	4. Describe internal structure of metals, and its impact on metal properties and processing.				3				
	5. Describe how at least two common engineering materials are extracted from their ores					3			
	6. Describe selected manufacturing processes, including their capabilities and limitations.						3		
	7. Given a part design, select appropriate machining processes and tools to make the part							2	
	8. Describe general safety procedures that need to be followed in a machine shop								
	9. Identify and operate conventional lathe, drilling, and milling machines								
	10. Determine the important operating parameters for each of these machines								
	11. Use gages such as calipers and micrometers to inspect parts								
	12. Communicate effectively using written and graphical modes								2
	13. Work successfully as a member of a team								
	Check to indicate a local course objective that <u>should</u> be added to the Project-wide outcomes								
Process Engineering	1. Apply logical design of a manufacturing process plan						2		
	2. Plan and analyze part design for productivity						1		
	3. Analyze tolerance charting in part design		2						
	4. Perform manufacturing process planning of a given part							2	
	5. Analyze and improve manufacturing processes						2	1	
	6. Select the optimal manufacturing equipment							1	
	7. Perform analysis and selection of cutting tools, coolants, jigs & fixtures, and support systems.								
	8. Communicate effectively in oral and written formats.								1
	Check to indicate a local course objective that <u>should</u> be added to the Project-wide outcomes								
CAD/CAM/CIM	1. Describe and identify geometric modeling in computer-aided-design (CAD) domain.								
	2. Perform computer-aided numerical control (NC) programming.								
	3. Perform manual NC programming by means of editing, trouble shooting, and optimizing								
	4. Apply PC-based CAD/CAM system in mechanical components								
	5. Define and recognize the applications of concurrent engineering and computer-aided-process-planning (CAPP)								
	6. Recognize and apply computer control in manufacturing								
	7. Analyze group technology and apply it in cellular manufacturing							1	
	8. Plan and design flexible manufacturing system (FMS)						1		
	Check to indicate a local course objective that <u>should</u> be added to the Project-wide outcomes								

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