AC 2011-1573: MANUFACTURING INTEGRATED LEARNING LAB (MILL): A CURRICULUM MODEL FOR HANDS-ON MANUFACTURING EDUCATION

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MANUFACTURING INTEGRATED LEARNING LAB (MILL): A CURRICULUM MODEL FOR HANDS-ON MANUFACTURING EDUCATION

Abstract

The lack of hands-on experiences in specific manufacturing processes has been identified as one of the major competency gaps in manufacturing engineering education. Partly in response to this, funding agencies like SME Education Foundation (SMEEF) and the National Science Foundation (NSF) have supported efforts to address this issue. This paper describes the Manufacturing Integrated Learning Lab (MILL), which is an outcome of these efforts. MILL is an NSF funded multi-institutional project, whose focus is the development of a hands-on approach to manufacturing education. This offers students skills that directly prepare them for careers in manufacturing, design and product realization. Four knowledge areas with corresponding detailed learning outcomes were identified for study namely: (1) drafting/design, (2) manufacturing process, (3) process engineering, and (4) CAD/CAM. Based on these, a core curriculum shared between the partner institutions was developed. This encapsulates the MILL manufacturing competency model. Assessment instruments to measure student learning were also developed. Sample test items were developed for all competencies in a series of internal meetings held among MILL Project staff. The preliminary results from a field test indicate high levels of student achievement under the MILL paradigm, and excellent structure of the assessment instruments.

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

1 Introduction

The lack of hands-on experiences in specific manufacturing processes has been identified as one of the major competency gaps in manufacturing engineering education. Partly in response to this, the Society of Manufacturing Engineers (SME) launched its Manufacturing Education Plan to address the competency gaps of new graduates[1]. The National Science Foundation (NSF) and other funding agencies have also been heavily involved in efforts to address these concerns.

The need for hands-on curricula that involve combinations of practical and analytical approach to engineering education has been addressed to some extent by the Learning Factory (LF) concept[2,3]. However, this original LF model can be expensive to implement. To address this cost problem, an adaptation of the original LF model 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, 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[10].

The Manufacturing Integrated Learning Lab (MILL) concept is the outcome of these efforts. MILL is an NSF-funded multi-institutional project, whose focus is the development of a hands-on approach to manufacturing education. At the heart of the MILL concept is the use of team-based projects that help students gain hands-on experiences in design and manufacturing. It involves the coordination of realistic hands-on experiences in multiple targeted courses around the unifying theme of designing and fabricating a selected functional product. These experiences are suited for easy implementation in the setting of a typical design and manufacturing teaching laboratory. This offers students skills that directly prepare them for careers in manufacturing, design and product realization.

The participating institutions are: Wayne State University (WSU), New Mexico State University (NMSU), Prairie View A&M University (PVAMU), and Macomb Community College (MCC). WSU's Engineering Technology Division serves as the coordinating center. See Figure 1.

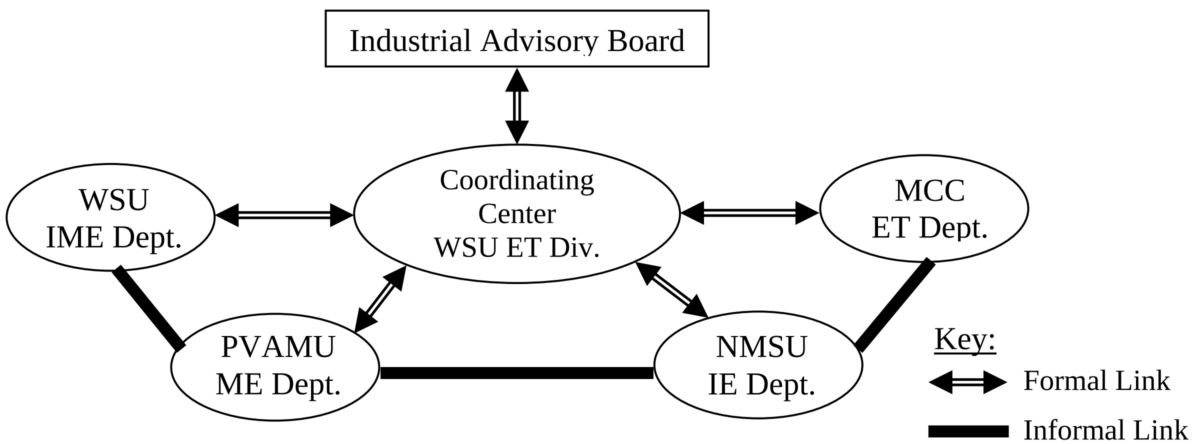

Figure 1: Partner Organizational Structure

In its leading 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 among 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 Goals and Objectives

The goals of the MILL Project 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.

As stated above, a limitation of the LF model is the high cost of setting up a manufacturing facility. It is difficult to get participating companies for this purpose, hence most schools tend to focus on the analytical approach with little or no practical approach. 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 artifact. Below we present the methodology applied to achieve the above mentioned objectives.

3 Methodology

ABET, Inc., the recognized leader in accreditation of 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 (student outcomes), and specified course-level learning objectives. ABET's 'Criterion 3' 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

A comprehensive literature review and considerable expertise from university and business partners suggested potential knowledge areas and specific learning objectives[15 – 18]. A series of weighted ranks by the four university partners led to the development of four knowledge areas with corresponding detailed learning outcomes: (1) drafting/design, (2) manufacturing process, (3) process engineering, and (4) CAD/CAM. A curriculum writing process undertaken at the beginning of the project resulted in a set of core learning outcomes common to all consortia schools. Based on these, a core curriculum shared among the partner institutions was developed. This encapsulates the MILL manufacturing competency model. Subsequently, this educational model was integrated into relevant courses at each participating institution. Standardized assessment pretest and posttest instruments were developed to measure student learning.

The four knowledge areas constituted the subscales of the assessment instruments. Each subscale contains multiple competencies as detailed in the curriculum model, and this formed the test blueprint. Subsequent to the finalization of the test blueprint, a table of specifications was developed to delineate the taxonomy of cognitive abilities to serve as a prompt in item development to assess varying (and generally higher) cognitive levels. Sample items were developed for all competencies in a series of internal meetings held among MILL Project staff. It was determined that all items would follow a paper and pencil multiple choice format to simplify subsequent analysis.

Test-retest and internal consistency reliability studies were conducted, and the subscales demonstrate good psychometrics (e.g., subscales $\boldsymbol{r} = 0.9$). Content validity was assessed via the blueprint approach to test construction and a strong four-factor analytic solution supporting the four competencies. A structural equation measurement model is currently being developed. The first two goals of this project have been well documented indicating the development of new curricula to suit the needs of diverse institutions[10,19]. This is followed by the development of faculty expertise in curriculum writing and validation. The third objective – "*developing assessment tools based on accepted industry practices to evaluate how well students learn when using the new curriculum learning materials and strategies"* is presented in this paper.

3.1 Writing Test Items

An actual physical device was created to accompany the assessment instruments. Sample test items were developed for all competencies in a series of internal meetings held among MILL Project staff at Wayne State University. Test questions frequently referred the examinee to inspect the MILL device, to tie in with hands-on experiences. It was determined that in order to simplify subsequent analysis, all test items would follow a paper and pencil multiple-choice format.

The sample test items were disseminated to all MILL Project sites. Sample physical devices to accompany the assessment instruments were fabricated and also distributed to each participating project site. The sites were charged with developing at least two additional test items per competency listed in the test blueprint following the example of the sample test items. The developed test items were submitted back electronically to Wayne State University, and were collated and then edited for clarity.

3.2 Test Item Validation

A two-day faculty development workshop was held in September 2009, in which faculty from Macomb Community College, New Mexico State University, and Prairie View A&M University joined colleagues at Wayne State University to be trained in the process of developing and validating test items consistent with the MILL Project goals and objectives. The test items were reviewed in accordance with SME guidelines for CMfgT exam item reviews, which included team-based evaluation of: (1) Item Content and Relevancy; (2) Rubric, at the topic learning outcome, ABET criteria and SME BOK levels; (3) Cognitive level (Knowledge, Application, or Judgment). The test items were subject to editing, modification, and in some cases removal from the test bank as needed, to meet requirements. It was determined to create a standardized test, consisting of two forms (Form A and Form B), and allow the test's length initially to be approximately the value of two items per competency on the test blueprint. An answer key was created and validated by the MILL project staff.

3.3 Pilot Test

A pilot test was administered to eight recent graduating students at Wayne State University (four each of Form A and Form B). The results from the pilot and the feedback from participants provided impetus for an additional round of item revision. The efficacy of the time limits imposed on the examination, and the utility of the MILL device, was also examined.

3.4 Field Test

All partner institutions were charged with developing at least two additional test items per competency listed in the test blueprint. The developed items were submitted to Wayne State University and were collated and refined. The final products of this process were:

(1) Revised MILL Form A and Form B standardized instruments,
(2) Verified answer key,
(3) Test Administration Guide,
(4) Scoring System, and
(5) Item Matrix showing isomorphic relationship of each item with the test blueprint.

The revised MILL test instruments were then administered in a field test to graduating students from New Mexico State University and Prairie View A&M University. A second round of testing was carried out in the Fall 2010 semester which included an initial batch of students from Macomb Community College, as well as additional students from Wayne State University and New Mexico State University. A third round of testing is planned for the spring of 2011.

4 Results (Ongoing)

For the field test, Form A was administered to N = 21 students (n = 12 for NMSU and n = 9 for PVAMU), and for Form B, N = 33 (n = 21 for NMSU and n = 12 for PVAMU), for a total of 54 students. A variety of psychometric analyses were conducted. Cronbach Alpha, a measure of internal consistency, was excellent for the total scale, and for each of the four subscales. Spearman-Brown, an adjustment applied to subscales to project full scale internal reliabilities, were also excellent. This analysis suggested three items whose deletion would increase the reliability.

The difficulty of each item was examined. Item difficulty (***p***), has a [minimum, maximum] range of [0, 1], where 0 = difficult and 1 = easy. It is computed as follows. After the administration and scoring, the upper and lower 27½% are determined. ***p*** is defined as the proportion of examinees obtaining the item correct from the upper and lower groups. In order to ensure maximum item discrimination (i.e., the assumption that students in the upper group should have a greater probability of endorsing the item correctly than the students in the lower group), ***p*** was close to 0.5 as it should be.

Another psychometric characteristic, item discrimination (***d***) is a property that indicates an item's ability to differentiate between an examinee who has learned the material, versus an examinee who either has not learned the material or who cannot convey the correct answer in an appropriate method. ***d*** has a [minimum, maximum] range of [-1, 1], where all negative values indicate flawed items, values close to zero indicate no discrimination, and values close to 1 have high discrimination. In order for a standardized test to have high discrimination, ***p*** values must be close to 0.5 (i.e., medium difficulty). ***d*** values will be determined at the conclusion of the field test. The objective at this point is to ensure the item difficulty (***p***) indices are close to 0.50. Summary statistics for ***p*** for Forms A and B are compiled in Tables 1 and 2, respectively. As noted in these tables, the mean ***p*** value per item is 0.58 on Form A and 0.50 on Form B, which are all excellent results.

Table 1. Form A Descriptive Statistics

Form A (27 items)			
		Total Scale	Item
N	Valid	21	21
	Missing	0	0
Mean		15.62	.58
Median		16.00	.59
Mode		16.00	.59
Std. Deviation		2.99	.11
Minimum		11.00	.41
Maximum		24.00	.89

Table 2. Form B Descriptive Statistics

Form B (26 items)			
		Total Scale	Item
N	Valid	33	33
	Missing	0	0
Mean		12.91	.50
Median		13.00	.50
Mode		14.00	.54
Std. Deviation		3.12	.12
Minimum		6.00	.23
Maximum		18.00	.69

Exploratory factor analysis (EFA) was also conducted, although with the extremely small sample size we do not report those specifics at this time. We forced four factors, as well as relied on traditional methods for the determination of factors (e.g., the Kaiser criteria for Eigenvalues, skree plots), using varimax rotation and principle components extraction. Preliminary results indicate excellent structure for a four factor solution. The results of the EFA indicate support for the four-factor solution. Additional testing to provide an increased sample size is underway.

Classical normalization procedures were used to fit the obtained frequency distribution for each scale to normal probability standard scores using Blom's algorithm:

$$r - \frac{3}{8} \Big/ w + \frac{1}{4},$$

where ***r*** is the rank and ***w*** is the sum of weights. Standard scores for scales and subscales, broken down by independent variables, corresponding to the percentiles based on the normal curve were computed using the formula:

$$\boldsymbol{T = 10z + 50.}$$

This creates a well known ***T*** score, which has a [minimum, maximum] range of [20, 80], and a median of 50.

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