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Development of a Product-oriented Manufacturing Processes Laboratory

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Dr. Tester's expertise is in Engineering Design with interests in rapid prototyping, manufacturing processes, and engineering education. He has ongoing research in biomedical and biomechanical product design, rapid prototyping and testing. Dr. Tester's scholastic interests frequently integrate Undergraduate Engineering Education topics, typically in the area of the design of effective engineering courses and curricula.

Development of a Product-oriented Manufacturing Processes Laboratory

Presented is the development of a Manufacturing Processes Laboratory for an undergraduate Mechanical Engineering program. The course underwent a comprehensive redesign for several core reasons. The primary goal was to integrate a single product to be manufactured as part of all lab sessions. The product design was developed to integrate mostly machining processes that are conducted throughout the semester. The product, a bench vise, had design criteria that were imposed primarily a result of educational needs. These criteria included generous dimensional tolerances, constrained component dimensional sizes, use of a variety of materials, time-constrained process limits, and use of some commercial off-the-shelf parts in the assembly. A course development objective was to include as many students as possible per section due to the rapid enrollment growth in Mechanical Engineering over the past five years. This objective resulted in a 'flexible manufacturing' approach to the product design, whereby some components could be processed at different stations independently of the order in which the processes occurred. New equipment integration was also included in the laboratory development. Presented are student evaluations of the laboratory plus design modifications implemented and/or planned after two semesters and six sections of the laboratory offering.

Introduction

Northern Arizona University (NAU) one of four Arizona universities offering undergraduate engineering programs; it is the smallest in the context of regular faculty appointments to the Mechanical Engineering program (10 regular faculty, of both tenure and non-tenure position orientation). The NAU Mechanical Engineering undergraduate program is thriving with on-campus enrollment, approaching 800 students as of 2015. In this century, the faculty at NAU has seen a swell of enrollment in Mechanical Engineering, an approximately 390% increase in enrollment since 2008. The result is both a challenge and an opportunity for this department to offer a more industrial-oriented manufacturing laboratory to the undergraduates.

Since the mid-1990's the NAU Engineering programs offer the "Design4Practice," or "D4P," curriculum, a series of innovative undergraduate classes which involve team-oriented learning classes for the students in each of their freshman, sophomore, junior and senior years. The D4P courses engaged students to learn by actively using engineering education tools that address the issues of realizing a design: problem solving, project management, and teaming.

The D4P program provided courses that emphasized team-oriented design and project management. However, traditional manufacturing knowledge and basic skills were not originally addressed, because the program, prior to the 2000's was not sufficiently large to enable an ongoing

manufacturing laboratory. With the advent of increased enrollments and more flexible program fee expenditure spending policies, a manufacturing laboratory was possible for the Mechanical Engineering Department.

Given the current Engineering educational program's emphasis on the design process and product realization, the manufacturing lab development was to require at least the same design context for the laboratory offering. Other universities have shown a similar emphasis, from a curriculum-wide emphasis of design and manufacturing to a constrained laboratory experience where the manufacturing component is present to support the overall design emphasis of the class. An example of the latter was offered by the U.S. Coast Guard Academy. They incorporate a manufacturing lab component to their sophomore design class, through the construction of a small "air engine."[1] This mixed design/manufacture model was initially considered a good model for NAU and the sophomore D4P design course. However, separation between the design classroom and manufacturing facility locations at NAU eventually dictated that merging the two contexts into a single offering would be logistically difficult.

The Learning Factory concept is an example of comprehensive implementation.[2] Developed jointly by Pennsylvania State University, the University of Washington, and the University of Puerto Rico-Mayaguez, the manufacturing laboratories offered were in the context of an overall practice-based engineering curriculum that incorporated collaboration with industry and fully developed laboratories. This curriculum may be considered ideal for a design and manufacturing-oriented program. It was developed with comprehensive resource support through grants from the National Science Foundation (NSF), Sandia National Laboratories, and the federal Technology Reinvestment Program. The Learning Factory model was considered well-conceived and successful, as evidenced by its implementation in the engineering curricula of a number of additional universities, including University of Missouri-Columbia, and Marquette University.[3] Recognizing the limited resources of intuitions that are not as fully supported through research and educational grants, a group of institutions, led by Wayne State University, adapted the Learning Factory Model in a flexible manner to each of the institutions' separate needs. [4,5] Each of the participating institutions addressed their particular core course-level learning outcomes that required improvement, adapting a portion of the educational pedagogy appropriately. NAU chose to adapt this philosophy for their needs in a new manufacturing laboratory experience that supported the existing engineering design product realization curricula.

Any laboratory development must acknowledge the needs of reality in the university facility and resource support. NAU's Mechanical Engineering department had for decades only a limited ability to conduct any sort of fabrication support for its design program projects, much less a fully-implemented manufacturing laboratory. This limitation was due to the historically small enrollment of the undergraduate program as well as having essentially no floor space for a manufacturing laboratory. However, in 2004, the Engineering Building was renovated and expanded. The expansion resulted in the acquisition of a separate building that, in the subsequent 10 years, allowed for the "Engineering Shop" to become a larger "Manufacturing laboratory" that emphasized machining processes, both manual and computer numerical controlled (CNC). However, the university still lagged in Mechanical Engineering faculty support, increasing the ME faculty population to 162% of its original size (8 to 13), while the ME undergraduate enrollment swelled by more than 400% since 2004. Thus, efficiency in the course offering was paramount. One hint at how to accomplish this efficiency metric was offered by Free University of Bolzano. Their

emphasis of a new manufacturing laboratory was to emphasize the design of the manufacturing center itself, as it created an assembled product, allowing simultaneous fabrication within the separate fabrication stations for the product.[6] Addressing Industrial Engineering facility layout was beyond the scope of NAU's Mechanical Engineering program; however, a basic emphasis of having flexibly-scheduled processes was desirable. This flexibility in the process scheduling would prove useful for designing the lab to maximize the number of students participating in any given section offering (to be discussed later).

Development Constraints

All course development processes have constraints, and laboratory offerings have additional constraints associated with equipment and facilities. In particular, the major constraints addressed are noted.

- Existing equipment
- Component sizes
- Laboratory scheduling

Existing equipment

The laboratory was developed over several years and modified as new equipment was acquired and installed. The equipment was initially available only for the purpose of supporting individual senior capstone design project fabrication—thus, manual mills and lathes were available, but mostly only as single machines. Also available were metal-working equipment, such as sheet metal brakes, shears, welders and a variety of hand tools. Over the past decade, the author was successful in securing 2 additional manual mills, 5 CNC mills, 3 CNC/manual lathes, an "Ironworker" (i.e., hydraulic sheet metal shear/punch/brake system) and other support tooling such as taps, machine tools, vises, etc. These later acquisitions were needed to support finishing processes for the selected product that was to be fabricated, a bench vise, as seen in Figure 1. An example of a component's basic drawing is shown in Figure 2. This figure is not a comprehensive drawing, but rather a guide for the reader to understand the final product.

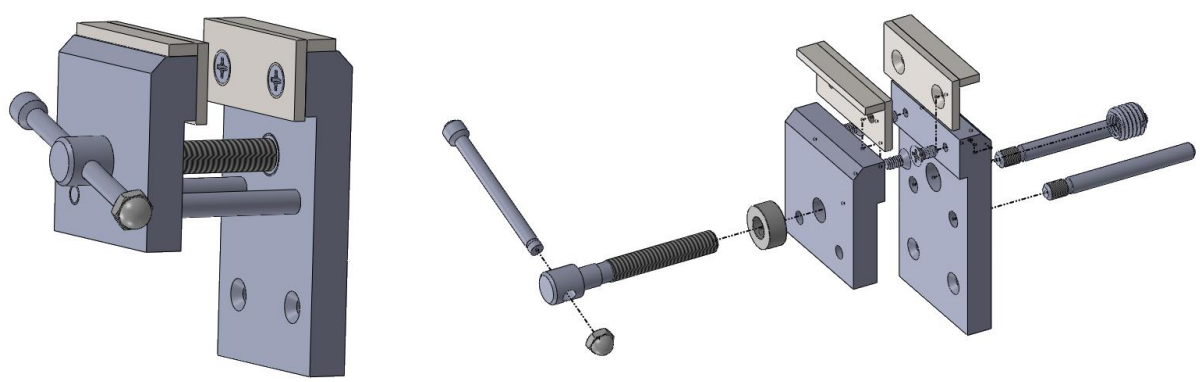

Figure 1. SolidWorks™ assembled (right) and exploded (left) views of Bench Vise assembly.

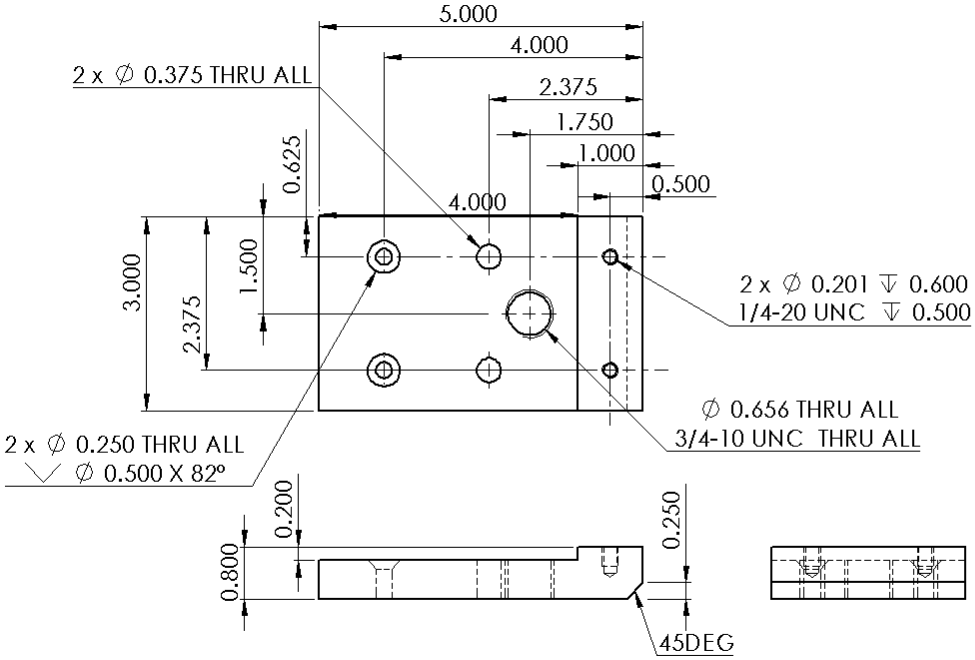

Figure 2. Stationary Jaw component; an example of a drawing included in the student laboratory packet.

Constrained Dimensions

This constraint is tied closely to the issue of existing equipment but also due to limited floor space. The smallest mill initially used had an X by Y envelope of only 12 by 6 inches, respectively. Components for the product must be made from stock and its required setup fixtures that would fit within that envelope. In addition, there was limited space to store the work in progress (WIP) for each week's lab from each student group. Thus, a small device was necessary for the laboratory focus. The bench vise again fit that bill nicely; as of last semester, all three sections' WIP could be tagged and stored on a single rolling cart. There was some preparation fabrication required prior to the start of the semester as well, in order to make the in-semester laboratory activities manageable. For example, the vise's jaws raw aluminum bar stock was delivered as of 1 inch by 6 inch by 12 feet. Similarly, the brass guide pin rods stock was 12 feet in length, as was the steel main screw stock. All these long pieces needed to be preprocessed by the instructor and shop personnel prior to the start of the laboratory, so that storage and movement of the stock was not a problem in the confined spaces for the laboratory offering.

Laboratory Scheduling

There are 15 weeks in the semester and 150 minutes per laboratory session. The product must be fully manufactured and assembled within those related time constraints in order for students to achieve the desired benefit of having a complete product created from raw materials. Part of the process design for the laboratory involved creating the individual operations that will fit within those time restrictions, noting the novice experience levels of most of the students.

Laboratory Development Goals

Several goals in the lab development were established, both pedagogical and practical in context:

- Consider Manufacturing Engineering Program objectives
- Allow for generous assembly and fabrication tolerances
- Use a variety of materials
- Commercial off-the shelf (COTS) parts usage
- Enroll as many students per section as safely possible

Manufacturing Engineering Program Objectives

Manufacturing Engineering laboratory disseminations often cite the 2013 ABET "Four Pillars" as their targets for the overall program development (Table 1). However, NAU's Mechanical Engineering program does not have such a refined specialty program offering or even an emphasis in the degree options. Nevertheless, the four pillars were considered as good standards by which a single manufacturing laboratory development could be guided:[7,8] These pillars are summarized as:

1. Materials and manufacturing processes: understanding the behavior and properties of materials as they are altered and influenced by processing in manufacturing.
2. Product, tooling, and assembly engineering: understanding the design of products and the equipment, tooling, and environment necessary for their manufacture.
3. Manufacturing systems and operations: understanding the creation of competitive advantage through manufacturing planning, strategy, and control.
4. Manufacturing competitiveness: understanding the analysis, synthesis, and control of manufacturing operations using statistical methods, simulation and information technology.

The current NAU Mechanical Engineering program already included a required Materials Science course and was considered sufficient to address the first standard. The second pillar was challenging for a non-manufacturing engineering program, as a comprehensive presentation of all traditional manufacturing processes would be beyond the capabilities of one laboratory; the limitations of the NAU manufacturing facilities were an additional consideration in this context. Given there was a basic set of metal machining and fabrication equipment in place when the manufacturing laboratory was first conceived, a machining-oriented context would be the constraint placed upon the second pillar.

The laboratory could provide a hands-on context for some aspects of manufacturing planning in the third pillar. In particular, a new product planning context would be established, whereby the students would record each operation they performed on the parts in an "Operations Process Sheet" or OPS (example in Figure 3); this sheet was loosely based upon a manufacturing process laboratory managed by the author at Virginia Tech and an industrial technology laboratory at Ohio University-Athens, both offered in the 1990's. The students record all lab processes for each week; at the end of the semester, they tally the final totals of processing times, determining the total makespan for the entire assembly. The entire section of students would combine and compare their results in the last lab for the semester, providing a real-time check on their assumptions and data. Recognizing that they were novices in manufacturing process skills, the activity nevertheless drove home the fact that making products takes planning, thought, and (most importantly for the laboratory), tracking the production so that cost estimates could be realistically calculated by the engineer. The fourth pillar

addressed statistical issues in manufacturing processes, particularly statistical process control. The planned laboratory focused upon the material processing side of manufacturing for this first offering and thus this fourth pillar was not addressed. However, with future planning, an SPC component could be introduced into the end of the semester with a variation of the OPS approach, instead using computer-recorded process data for the final analysis by the students.

	DEPARTMENT OF MECHANICAL ENGINEERING					OPERATION PROCESS SHEET			DATE	LAB NUMBER
	PART NAME		PART #	PROCESS PLANNERS (STUDENTS)						
										PAGE
STOCK MATERIAL										____ of ____
Type		Shape		Size					TOTAL PROCESS TIME (MIN)	APPROVED BY
			TOOLING							
			Cutter		Work-Holding		Measurement / Setup			Operation Process Time (Min)
#	OPERATION	MACHINE or TOOL	Description	Size	Description	Size	Description or Offset	Size or Dim	Spindle speed and/or Feed and/or Program	

Figure 3. Operation Process Sheet.

Generous tolerances

The original equipment consisted of very old lathes and mills, some of which were at last 65 years old. Though extremely reliable, these machines simply were too worn to hold linear accuracies beyond 0.010 inch in any axis. Originally, the laboratory developer wished to create small Stirling or air engines, as noted by other universities.[1] However, the required tolerances for such assemblies were not possible for the original NAU equipment. Thus, the bench vise was developed. The vise could operate after assembly with a range of part dimensional variations without severe performance defects. In fact, many fabrication errors by the novice student could be made on most of the components, yet the vise still had a good chance at being assembled and be functional.

Variety of Materials

The vise could be made entirely of steel if desired. However, the instructor wished to give the students exposure to cutting and assembling with other types of materials. Also, using aluminum and brass would allow novice students a minimum of reliance on coolants during cutting processes. By minimizing coolant flow in a process, the student could more readily observe chip formation. In addition, a “jaw cap” was implemented for a product design reason of protecting the aluminum jaw face from marring during use. As seen in Figure 1, the jaw cap could have been easily redesigned and cut from angle stock. However, by assembling the jaw cap from two separate pieces of strap steel, the instructor is allowed to expose the students to the processes of shearing, punching, welding, and grinding. Figure 4 shows the use of multiple materials: Aluminum, brass, and steel. Additionally, this photo shows the COTS components of ½-20 flat-head machine screws and one 3/8-16 acorn nut. Not visible in the Figure 4 photo is one of the COTS components which is visible in Figure 1: a 1/2" bore, set screw Collar.

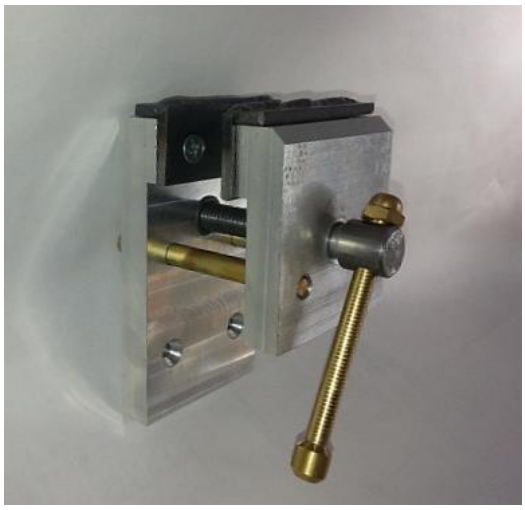

Figure 4. Final product: Multiple materials and COTS components all shown.

COTS

The selection of an aluminum stock for the vise jaws results in an initial and undesirable choice of having a steel main screw being engaged in aluminum threading. Thus, a steel threaded insert was selected to be assembled into the vise jaw; this fixed insert then receives the steel main screw to eliminate the concern of stripping otherwise aluminum threads. A related benefit of this insert selection: Students engaged in learning manufacturing processes may become convinced that they must fabricate all parts in an assembly. In reality, much of product realization in engineering requires specifying retail components, or COTs parts. Sourcing this insert for the assembly, along with the use of machine screws for the jaw caps assembly, helps give the student a broader view of product design.

Enroll as many as possible per section

The NAU Mechanical Engineering program is currently hampered in this laboratory development by having only one faculty member who is qualified to supervise and instruct the offering. Yet, the 75 students enrolled in the Manufacturing lecture session (capped at 75 students) want to also take the laboratory (which currently is optional). A typical laboratory enrollment in Mechanical Engineering is 12 students; if that measure were applied to this laboratory, at least 5 laboratories would be required (the Fall 2013 laboratory enrollment was 52). The problem here is obvious, in that the sole faculty member is engaged in instructing labs for 5 lab sections x 3 hours / lab = 15 hours per week, not counting prep time and cleanup; a standard workweek can become quickly consumed for one faculty member if the enrollment were to continue increasing. However, by engaging as many machines simultaneously as possible in a given laboratory section's offering per week, the enrollment was allowed to be increased to as many as 24 students per lab. This approach does require knowledgeable student lab assistants to be hired in order to ensure all enrolled students are safely and appropriately monitored.

Processes and Schedule

The laboratory had four main areas for processing: CNC/Manual Lathes, Manual Mills, CNC Mills, and Welding & Sheet Metal. The general layout is illustrated in Figure 5. The stick-figures indicate an experienced student employee monitoring the enrolled laboratory students.

Layout

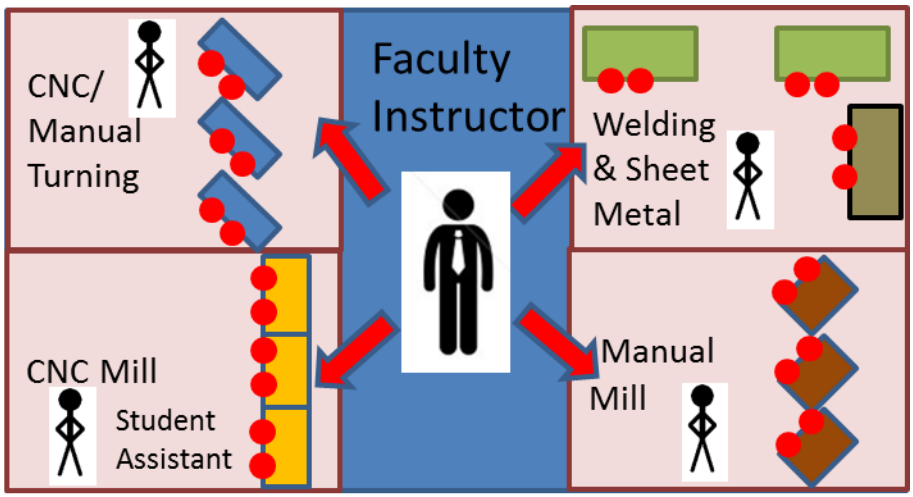

Figure 5. General laboratory layout.

The lathes are designated as "CNC/Manual" because they were purchased with the intent of being operable in either a manual turning or CNC turning mode. This flexibility allows for two different types of turning labs without needing additional space—this flexibility is not a feature of milling, with manual mills and CNC mills being multiples of two different machines. However, such mills, if available in the future, could be used with a dual use capability. The area "Welding & Sheet Metal" has welding and sheet metal operations (shearing and punching) as the same station. This area is used for creating the jaw cap components, where the steel strap is first sheared, punched and drilled, then welded and grinded for the final products.

Laboratories

There were two students per team that accomplished processes at a 'station' (machine). These student pairs are represented by two red dots in Figure 5. Two students, taking turns in accomplishing processes, allows for the observing student to think about the process the other student is accomplishing; both students will swap fabrication work during the 150 minutes of laboratory time. Having two students in a team also allows the department to double the number of students enrolled in a given section offering.

Within each process area, there are 3 stations available; the areas are within 40 feet from each other. The maximum enrollment in a given section's enrollment would be 24. In practice, for any section, the enrollment would often be less than 24 due to students' scheduling constraints. The labs have been offered recently with as few as 12 and as many as 24 in the last year.

The faculty instructor is present and available to any of stations and must be knowledgeable in all areas. Most universities have available machinists or technicians to supervise the laboratory. However, NAU is fairly unique amongst engineering education programs in that there is no such full-time technician in the Mechanical Engineering department to support any of the laboratories. This deficit is remedied in the manufacturing laboratory by employing up to four, part-time student employees to run a specific laboratory process. For practical reasons, only 2 to 3 student employees are available for hire at any section's time—the faculty instructor thus would primarily supervise the fourth position in any section, while still monitoring the other stations throughout the period. This personnel problem is becoming mitigated as more experienced students become are available for hire from previous years' laboratory offerings.

Process Laboratories

The layout shown in Figure 5 illustrates simultaneous operations at all stations for primarily weeks 2 – 9. However, Laboratories 11-13 are single-week offerings (also offered simultaneously to different student teams). The entire semester's Laboratory Descriptions are noted in Table 1.

Semester Schedule

The laboratory schedule, shown in Table 2, is organized into 14 week blocks—15 weeks are not scheduled as there is too much reshuffling of enrollment allowed by the university in the first week of the semester to accomplish any effective organization. A safety orientation is required in the first week of the laboratory offering—after the safety week, all students are placed in their 2-person teams; they begin acclimation to their partners by conducting some basic measurements operations with the measurement tools they will use during the semester. The 4-station rotation is prominent in the 8-week block of the schedule, starting from the third week of lab sessions.

Table 1. Laboratory Descriptions. These description lab numbers are mapped directly into the semester schedule (Table 2).

Lab number	Description	Comments
N/A	Safety Instruction	
1	Intro, basic measurements and safety	Orientation, basic measurements
2	Manual turn 1	Create the two guide pins
3	Manual turn 2	Create the single main screw handle
4	Manual Mill 1	Squaring and facing the two Jaw parts
5	Manual Mill 2	Drilling holes for the two Jaw parts
6	CNC Mill 1	Running the CNC mills on Jaw parts
7	CNC Mill 2	Running the CNC mills on Jaw parts
8	Welding 1	Gas metal arc welding (MIG)
9	Welding 2	Shielded metal arc welding (Stick arc)
10	CNC Programming	Simple CNC Programming for 3-axis mill
11	CNC Milling	Milling the CNC program of lab 10
12	CNC Turn	Creating the Main Screw via CNC turning
13	Hand Operations	Misc operations on parts
14	Assembly	Check fit of assembly; calculate total process time

The lab numbers correspond directly to the Table 2 listings of the different lab processes to be conducted. During week 8, all four labs are running simultaneously in the layout of Figure 5; student teams swap to new stations every two weeks (i.e., two consecutive and different operations are conducted at the same station by a team before swapping locations).

Though Table 1and Table 2 initially are confusing to students who do not study the laboratory materials outside of the scheduled lab time, after the first station swap, all students understand the schedule very well.

Table 2. Schedule for a sample section of 22 students. Last names are for illustration only.

			SFTY	Intro	8-week block								Last set of blocks			
Last Name	**Section**	**TEAM LETTER**	**8/25/2014**	**9/5/2014**	**9/8/2014**	**9/15/2014**	**9/22/2014**	**9/29/2014**	**10/6/2014**	**10/13/2014**	**10/20/2014**	**10/27/2014**	**11/3/2014**	**11/10/2014**	**11/17/2014**	**11/24/2014**
Chambers	1	A	√	1	2	3	4	5	6	7	8	9	10	11	12	**13**
Gonzalez	1	A	√	1	2	3	4	5	6	7	8	9	10	11	12	**13**
Martinez	1	B	√	1	2	3	4	5	6	7	8	9	10	11	12	**13**
Abdulla	1	B	√	1	2	3	4	5	6	7	8	9	10	11	12	**13**
Pan	1	C	√	1	2	3	4	5	6	7	8	9	10	11	12	**13**
Smith	1	C	√	1	2	3	4	5	6	7	8	9	10	11	12	**13**
Acker	1	D	√	1	4	5	6	7	8	9	2	3	10	11	12	**13**
Florez	1	D	√	1	4	5	6	7	8	9	2	3	10	11	12	**13**
Schmidt	1	E	√	1	4	5	6	7	8	9	2	3	10	11	12	**13**
Cook	1	E	√	1	4	5	6	7	8	9	2	3	10	11	12	**13**
Goodwin	1	F	√	1	4	5	6	7	8	9	2	3	10	11	**13**	12
Mitchell	1	F	√	1	4	5	6	7	8	9	2	3	10	11	**13**	12
Pudding	1	G	√	1	6	7	8	9	2	3	4	5	10	11	**13**	12
Contigo	1	G	√	1	6	7	8	9	2	3	4	5	10	11	**13**	12
Marshall	1	H	√	1	6	7	8	9	2	3	4	5	10	11	**13**	12
Anderson	1	H	√	1	6	7	8	9	2	3	4	5	10	11	**13**	12
Penning	1	I	√	1	8	9	2	3	4	5	6	7	10	11	**13**	12
Rudolph	1	I	√	1	8	9	2	3	4	5	6	7	10	11	**13**	12
Carson	1	J	√	1	8	9	2	3	4	5	6	7	10	11	**13**	12
Mohammed	1	J	√	1	8	9	2	3	4	5	6	7	10	11	**13**	12

Results and Conclusion

A paper survey instrument was combined with a graded assignment at the end of the semester. 52 students were enrolled in the Fall 2014 Laboratory; 50 students returned the survey. Most of the survey contained questions specific to certain laboratories. However, three issues were of interest to the author, associated with learning and curriculum development.

Was the student aware of how to modify a part design and/or operation to enable a flexible process (i.e., simultaneous fabrication processes on the same end component at different locations)?

This question was asked to determine if the student understood the need for flexible manufacturing operations through the experience of operations on components occurring simultaneously (i.e., without a required order) for several labs. This topic was covered in the lecture, but not heavily addressed in the laboratory materials. 44% of the respondents were sufficiently clear in their responses that they indeed understood not only the need for flexible manufacturing (economics of using the equipment, scheduling as much product through the system as possible). The respondents also described how to redesign the operations (setups and procedures) of one particular component to enable such operations to be accomplished in any order.

Should the Manufacturing Processes lecture session be required for Mechanical Engineering majors?

This question must be addressed before the laboratory question following is addressed. The Manufacturing Processes Lecture (3 credit hours) is currently not a required course for the NAU Mechanical Engineering department, neither is the Manufacturing Processes Laboratory (1 credit hour, 3 hours contact time). Students are allowed to take the laboratory only if they sign up for the lecture. 44 % of the respondents replied that the lecture should be required for all Mechanical Engineering students.

Should the Manufacturing Processes Laboratory be required for Mechanical Engineering majors?

68% of the respondents replied that the laboratory should be required. This response is taken in light of the fact that the students realize the lecture would also be required for laboratory-enrolled students.

Anecdotal

A question was asked of all students at the start of each section by the instructor: "Have any of you ever had a manufacturing laboratory in college or even a shop class in high school?" Two of the three sections had only 3 students raise their hands (out of 40 students enrolled). The third section had half of the 12 students raise their hands. Four of those students who replied positively in that section were exchange students from Brazil, where hands-on labs were required in both high school and their undergraduate courses in Brazil. The author notes that the NAU Mechanical Engineering Department offers an excellent required laboratory that involves instrumentation of thermo-fluids experiments and statistical measurements. However, it is clearly apparent that this elective manufacturing laboratory now allows students to acquire hands-on experience in the creation of products and manufacturing process organization.

One secondary objective which is currently unmet is to have sophomore-level students enrolled in this laboratory, for the intent of these students to apply their hands-on knowledge to coursework in their Junior and Senior design classes. However, this objective is not satisfied, primarily due to the manufacturing lab being tied to the Introduction to Manufacturing Processes lecture section. That course requires both Strength of Materials (sophomore level) and Materials Science (junior level) as prerequisites. These requirements are not unusual for a manufacturing course or lab; for example, the University of Tennessee-Martin has had essentially those same requirements for years, and other

universities are undoubtedly similar.[9] These requirements are understandable in an engineering program, as a student should understand the basic engineering principles behind the manufacturing process under observation. However, this author recalls the widespread implementation of wood working and metal working in the high schools of the United States in his formative years in the 1970's. At that time, such in-depth materials knowledge was not required in order to gain a basic understanding of fabrication (as opposed to mass production). This laboratory and related courses in manufacturing and design will be continually developed, with the goal of offering the manufacturing laboratory to sophomores on a regular basis.

As noted earlier, equipment acquisitions have allowed more students to be enrolled in the course; Figure 5 illustrates that duplicate machines allow for multiple students to have hands-on education for the same operation in the same location. The new equipment, with more robust capabilities than older and worn-out machines, also enables the faculty to consider more interesting projects than the bench vise that could be also tied into other analytical courses. In particular, an air or Stirling engine could be created in the lab with today's equipment, in a manner similar to those implemented by other universities.[1] The functionality of the engine could be tied into the existing heat transfer course, allowing for the students to experience how their theoretical concepts in other engineering courses translates directly into an actual product realization.

Acknowledgements

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