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TEACHING MANUFACTURING WITH GROUP CELL PRACTICES

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ASEE 8742: TEACHING MANUFACTURING WITH GROUP CELL PRACTICES

Abstract

In traditional manufacturing lab exercises, students would learn to operate one type of machine tool at a time. After learning a machine type, they then move to another type and learn all operations on new machine tool. There is little connection and interaction among students since each person will produce his/her own individual part. At the end of training lessons, some instructors may verbally describe the link of different processes and how a product would flow among those processes. A manufacturing department typically has to purchase many identical machine tools and different tooling sets for variety of possible operations on each machine type. The operating cost of such manufacturing laboratory is high and some students might not comprehend the link among different processes. This model is popular among community colleges or vocational schools, but may not be best for engineering students since the latter only need to understand the manufacturing processes and flow sequence rather than acquiring hands-on manufacturing skills.

We propose a new manufacturing teaching practice at our university by introducing group cells and simulated production lines. Teaching manufacturing through mini production line and group cell would (i) simulate industrial practice, (ii) provide opportunity for students to interact and be responsible, and (iii) reduce floor space and expenses, and (iv) achieve the prescribed educational objectives. A group of students is responsible to produce products for the whole group. After learning and practicing basic machine tool operations in a cell, each subgroup of two students operates a machine tool and produce identical components for the whole group. When all components are produced to drawing dimensions and tolerances, students then assemble components to form the final products that are carefully designed for process integration while having meaningful value and ecstatic appearance for students to keep.

The Group Cell laboratory practice was implemented in the 2013 for a total of 503 students while keeping the same laboratory exercise, student group size and number of instructors. We reduce the number of machine tools from 15 to 8 while adding two new surface and cylindrical grinders, and shrinking the required floor space from 1420 ft^2 to 600 ft^2. Positive feedback from Industrial Advisory Board and students verified the success of laboratory Group Cell approach.

Introduction

Group cell technology is a popular practice in industry. This technology utilizes group of specific machines to fabricate family of parts that have common features. Manufacturing using group cells, or cellular manufacturing, would reduce setup time, engineering cost, inventory, product development time, and purchasing time while simplifying process planning and procurement [1,2].

A typical manufacturing laboratory is equipped with rows of identical machines, where students learn in sequence from one type of machine to another. Although students would repeat a demonstration and interact with their instructor, they rarely interact among themselves and often miss the link among different processes. The concept of group cell and all of its advantages can be applied in academics since students normally practice to fabricate similar components in different semesters. This new approach is proposed to replace the traditional manufacturing laboratory practice. Group cells with different machines are utilized rather than having duplicated of same machines. The objectives of this paper are to:

a) Compare the Traditional and Group Cell approaches for university students,
b) Presents an example of machining laboratory exercise.

Literature Review

Hands-on laboratory practice is the key to effective learning. "I hear and I forget. I see and I remember. I do and I understand" was preached by the famous teacher and philosopher Confucius (551–479 BCE) during Spring-Autumn period of Chinese history. Leighbody and Kidd also concluded "learning requires active experiences" in their survey[3].

Nowak[4] ranked teaching strategies and learning activities within technology education. The highest ranked strategy was the one with product-oriented and laboratory-based content. The second highest rank was for strategy using technology focus, and the lowest was for strategy that relied heavily on classroom orientation.

Having hands-on laboratory is one condition, but the laboratory practices should be relevant to prepare graduates for their manufacturing career. Miller[5] surveyed 25 department heads of US manufacturing programs and concluded that an exemplary manufacturing program should:

a) Require more technical coursework,
b) Require or strongly encourage cooperation with industry,
c) Maintain closer relationships with industry,
d) Has more manufacturing faculty and students,
e) Place a greater emphasis on teaching,
f) Provide numerous, well-equipped facilities, and
g) Produce graduates with more knowledge on materials and processes.

Nelson[6] analyzed inputs from directors of ABET accredited programs to identify key technical competencies for manufacturing graduates. Among 264 competencies, the highest ranked competencies related to quality, communication, and personal ethics. Baird[7] proposed a laboratory exercise to simulate mass production environment. Although is more difficult to develop this type of exercise compared to the traditional teaching practice, the benefit of the latter approach is numerous since:

a) It simulates industry practice,
b) It develops specific hard-skill and soft-skill to students,
c) It provides opportunity for lab instructor to be creative and organized, and
d) It significantly enhances team communication and cooperation among team members.

Approach

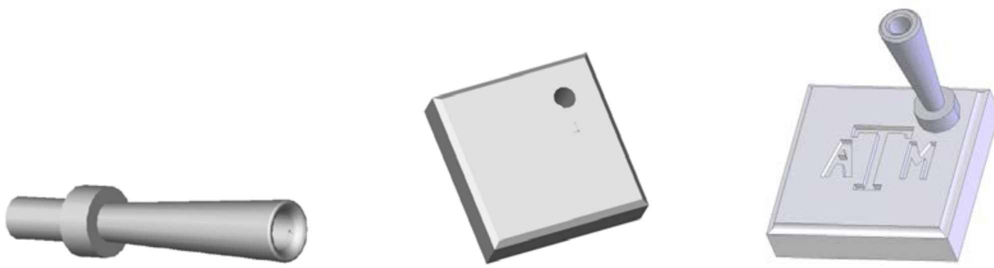
Typical laboratory exercise would identify the purpose, list required equipment and materials, and provide detailed step-by-step procedure. A laboratory instructor would demonstrate the steps and let students repeating on identical machines. The next laboratory exercises would be similar on different type of machines. This traditional approach employs laboratory instructors with specific expertise to manage each type of machines, requires a large floor space for multiple machines, and is lack of interaction among students.

The traditional laboratory approach provides hard-skills to students, while group-cell laboratory approach provides both hard-skills and soft-skills to the graduates. Group cell requires unique machines to fabricate similar products. Although it is more cost effective, group cell approach requires lots of preparation and effective communication. The following table compares the two approaches.

Table 1: Comparing laboratory approaches

Criteria	Traditional Laboratory	Group-Cell Laboratory
Equipment	Multiple numbers of identical machines.	Duplicate cells, each with unique machines.
Tooling	More (due to number of machines)	Less
Lab floor space	More	Less
Maintenance and operating cost	More	Less
Instructor	Central expertise. Each instructor is an expert of one machine type.	Broad expertise. Each instructor must be familiar with all machines in a cell.
Teamwork	Limited. Each student repeats what the instructor did.	Significant. Students manage the flow of material from one machine to the next.
Material flow and parts	Single part. Does not see part variation.	Group of parts. Measure dimensional variation.
Preparation	Less. Instructor demonstrates process on one machine at a time.	More. Instructor demonstrates process for each machine, and suggests flow among different machines.
Industry relevant	Less	More
Overall cost	More	Less

Example of Group-Cell Exercise



(a) (b) (c)

Fig. 1: Parts for machining exercise (a) pen-holder, (b) pen-base, and (c) complete assembly.

Figure 1 show the pen-holder assembly that we used in the past for Traditional approach and is used after Spring 2013 in Group-Cell for comparison. There are 14 groups with 16 students in a group, and it takes five 2-hour sessions to complete this introductory machining exercise in freshman level course. Time study is done during a separate study in the Traditional approach, while it is embedded in the Group-Cell approach. At the end, each student will have his/her own set for CNC engraving in the next exercise. Tables 2 and 3 compare the setup and scheduled activities in each case.

Table 2: Laboratory setup

Criteria	Traditional Laboratory	Group-Cell Laboratory
Equipment	- 5 lathes - 5 vertical mills - 2 drills - 2 vertical saw - 1 horizontal saw	2 cells, each with: - 1 lathe - 1 mill (horizontal or vertical) - 1 drill - 1 saw (horizontal or vertical)
Lab floor space	1420 ft^2	600 ft^2
Instructors	2 per session	2 per session

Table 3: Schedule breakdown

Session	Traditional Activity	Group-Cell Activity
1st	Lathe	Introduction
2nd	Lathe	Saw, drill, mill, lathe, time study
3rd	Saw, mill	Saw, drill, mill, lathe, time study
4th	Drill, mill	Mill, lathe
5th	Time study	Mill, lathe

In the first session of Group-Cell practice, an instructor for each cell will cover the basic operation for each machine in the cell. Eight students per cell will learn how to set up tooling for each machine, and practice basic machining. In the following sessions, it is flexible for students to choose their roles while working together in a cell.

- The group will produce parts for everyone to simulate production mode
- Time study will be imbedded in selected operations
- Students work in subgroup of 2. They can choose to stay with one machine as "master" or rotate to learn other processes
- Students are responsible for checking dimensions of their parts
- Label parts number 1-16
- Students to select group representative and choose their roles

Table L5.1. Role assignment. Select the preferred role and enter names in following blocks.

#	Duty	Description	1st session	2nd session	3rd session	4th session
1	*Group Rep.	– Keep overall record – Report issues				
	Assistant Rep.	Assistant				
	Metrology	*Master				
2	Metrology	Assistant				
3	Saw	*Master			N/A	N/A
4	Saw	Assistant			N/A	N/A
5	Drill	*Master			N/A	N/A
6	Drill	Assistant			N/A	N/A
7	Mill	*Master				
8	Mill	Assistant				
9	Lathe	*Master				
10	Lathe	Assistant				
11	Grind (surface)	TA	N/A	N/A	N/A	Demo
12	Grind (cylinder)	TA	N/A	N/A	N/A	Demo

* Student who will have the same role and stay with same machine/equipment

The following tables are provided to guide students in each operation. There are four main activities: sawing, drilling, lathe turning, and milling. Time study is included in some activities.

<u>Sawing operation:</u> Student will saw the round rod or rectangular bars at different combinations to study the effect of setup.

- Saw rods and bars to required lengths
- Use different sawing setup for time study
- Record sawing time for block sawing

Table 5.1: Activity for sawing operation for each cell. Note the bar orientation and number of bar for each cut.

	Sawing operation		
	Horizontal saw → ϕ0.75x4" rod	Horizontal saw → 3x3x0.75" block	Vertical saw → 3x3x0.75" block
1st session	8* 	2*  + 4* 	2* 
2nd session	8* 	2*  + 4* 	2* 

*This indicates numbers of parts after cutting.

Record the observe time (setup time + machining time) to produce a single part.

Table 5.2: Time study in sawing for each cell. Note the bar orientation and number of bar for each cut.

Sawing setup	Horizontal saw		Vertical saw	
	Start/End time	Time for 1 part	Start/End time	Time for 1 part
				
				
				
				

Conclusion: The best setup is ___________

Drill, mill, and lathe operations: Parallel activities are expected at these stations. Time study is included for milling only.

- Mill the blocks using either horizontal or vertical machine
- Use different milling setup for time study
- Record milling time

Table 5.3. Activities for drill, mill, and lathe. Note the block orientation and number of blocks in milling operation.

	Drill/Grind	Mill (choose one) __horizontal __vertical	Lathe
1st session	• Center drill • Drill →4 blocks	• 2 (single side)  • 1 (double sides)  →4 blocks (2.9x2.9x0.75")	• Face, center drill, drill →8 rods
2nd session	Repeat 1st session	Repeat 1st session	• Machine 5° taper →8 rods
3rd session	Grind	• Mill to thickness →8 blocks (2.9x2.9x0.70")	• Turn ϕ0.6" and ϕ0.5" • Groove square shoulder →8 rods
4th session	Grind	• Groove edges →8 pen-bases	• Knurl ϕ0.6" surface • Part off →8 pen-holders

Record the observe time (setup time + machining time) to produce a single part.

Table 5.4. Time study for milling. Note the block orientation and number of blocks in milling operation.

Milling setup	Horizontal mill		Vertical mill	
	Start/End time	Time for 1 part	Start/End time	Time for 1 part
Single 				
Tandem 				

Conclusion: The best setup is ___________

When all components are fabricated, the quality assurance group will verify critical dimensions of the parts. They will use no/no-go gages rather than measure the dimensions individually to speed up the checking process.

Table 5.5. Quality assurance using Go/No-go gages.
Pen-bases. Check (√) if within tolerance.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Thickness 0.7±0.01"																
Hole size ϕ0.500-0.510"																

Pen-holders. Check (√) if within tolerance.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
End cylinder ϕ0.487-0.497"																

At the end of the exercise, a Teaching Assistant will lead the group discussion and highlight:

- Critical dimensions of the parts and how to control them.
- Capability of each machine.
- Contrast of different machine type (e.g., horizontal versus vertical mill).
- Flow of material.
- Possible shape change of the product giving the same machines in a cell.

A follow-up clicker quiz and anonymous written feedback are implemented to gage the student comprehension of manufacturing processes, and to study the impact of Group-Cell practice.

Results and Discussion

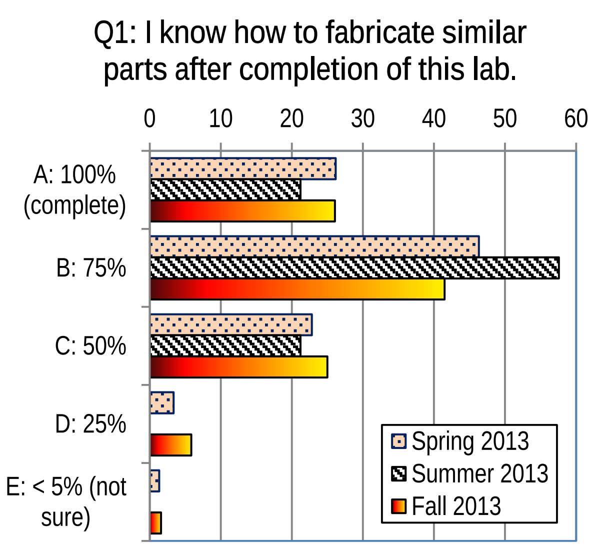
We have transformed our current machining laboratory into two group cells in a smaller area, and allocated the saved floor space to other activities. The brand new machines at two group cells, although can have similar functions and capabilities, are different so students can experience and compare. One cell has a horizontal mill and horizontal saw while the other is equipped with a vertical mill and vertical band saw. The two lathes and two drills also come with different accessories and options. All students will have a chance to practice basic machining operations and rotate to other machines during the first session and then select their roles for the remaining sessions. Therefore, some students can choose to work on specific tasks to gain deeper knowledge, e.g. metrology or lathe machining, while others can opt to rotate and work on different tasks to gain a broader perspective.

The new Group-Cell approach for machining exercise has been implemented for the spring, summer, and fall semester of 2013. The same parts, inherited from previous Traditional machining exercise, are used in the Group-Cell exercise. This way we can (i) minimize training effort to our current Teaching Assistants, and (ii) have the same base to gage the student subject comprehension. Data from student feedback, comment from Industrial Advisory Committee, and laboratory quizzes are used to gage the success of this Group-Cell approach.

Table 2 compares the set ups for Traditional Lab and Group-Cell Lab. The former lab has 15 machines compared to 8 machines in the latter. The new approach results in significant saving of floor space (from 1420 ft^2 to 600 ft^2) and lower operating cost due to less number of equipment.

We exposed 503 students to Group Cell exercise in 2013 and had 82% responded in the follow-up survey. Although there are teething problems, the benefits of Group Cell approach are obvious from the students' feedback. One area for improvement could be to let students have different roles during four sessions. Some students' comments include:

- "I liked how everything was organized and how everyone had a part to play. I think we should have milled first (before drilling). I really appreciated how both TAs answered any and all questions."
- "I like the team work aspect, being completely hands-on, using the same machine every day and got very familiar with it."
- "Benefits: machining experience, team-building, working under time constraints. Problems: time constraints, only got to use one or two machines."
- "Enjoyed the hands-on aspect of the lab. The TAs were all very helpful and make sure safety was first. Teamwork was encouraged and I like working with one machine and mastering the techniques of that machine. I learned more in lab than lecture without a doubt."
- "Sometimes it can get monotonous if you use the same machine for too long."
- "I cannot make my own parts!"



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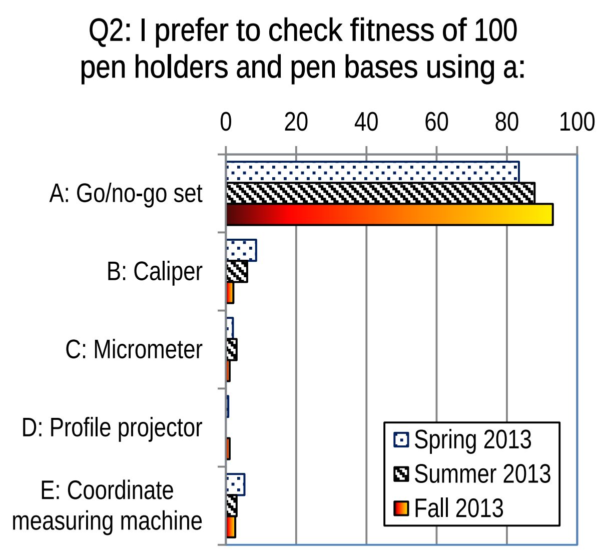

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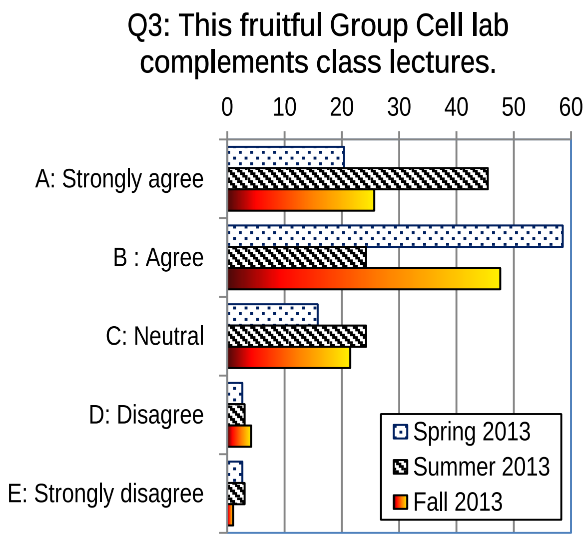

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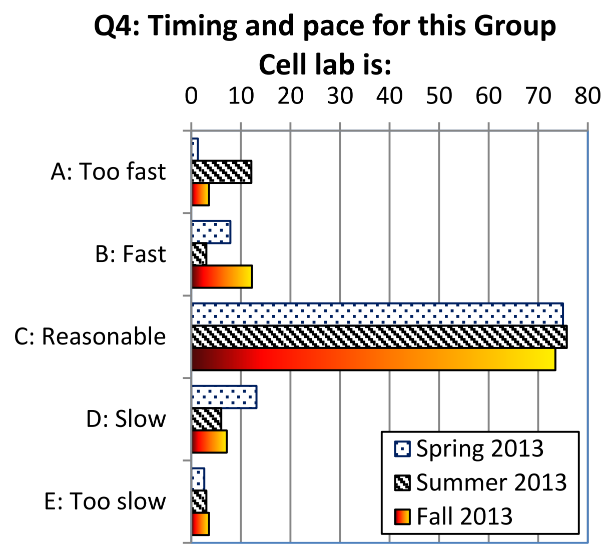

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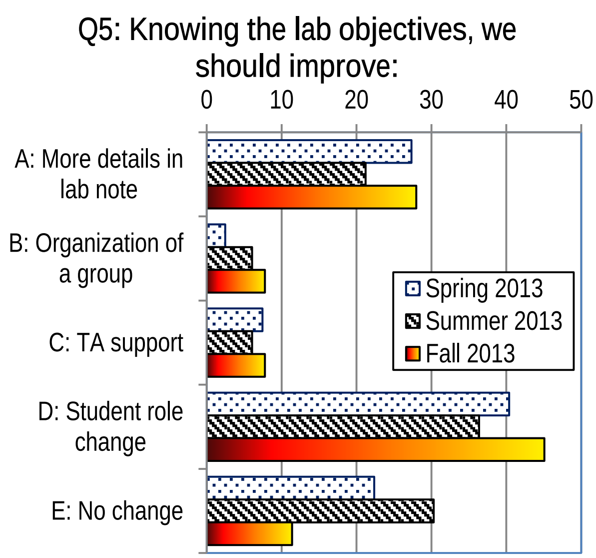

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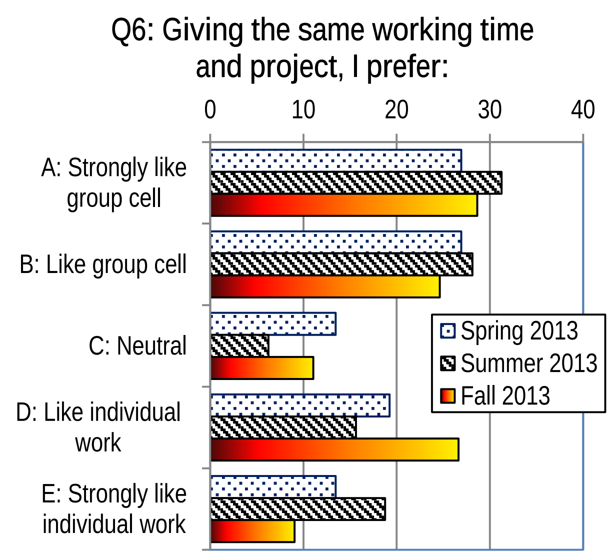

(f)

Fig 2: Student response to Group Cell laboratory survey. Results of 82% response from 503 students in 3 semesters.

Figures 2 a-f show the survey questions and student responses in three consecutive semesters. The survey indicates that (i) students understand the idea behind Group Cell concept in manufacturing, basic manufacturing processes, and can suggest improvement (questions 1, 5), (ii) students understand metrology techniques and can select an appropriate metrology tool for a specific task (question 2), and (iii) students think the exercise is reasonable and complement class lecture (questions 3, 4).

In previous traditional lab exercise, there were always some students who needed extra sessions to complete their parts. This strained the TAs and caused lab scheduling problems. We eliminated such making-up sessions when implementing the group-cell approach for the same lab exercise. In fact, some groups even finish the task ahead of schedule.

Summary

We implemented Group-Cell practices to replace the Traditional machining exercises. Survey data from 503 students in three semesters in 2013 indicates the success of the group-cell practice. Teaching manufacturing through simulated production line in a Group Cell would provide both hard-skills and soft-skills to students since this approach:

a) Simulates industrial practice,
b) Provides opportunity for students to interact and be responsible, and
c) Reduces floor space and operating expenses by having less number of identical machines and tooling.

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