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Effective Manufacturing Laboratory Arrangement for Large Classes

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Abstract

Manufacturing requires collective knowledge of material, metrology, and processes. Hands-on laboratory and lecture helps students to learn, appreciate, and be motivated for further study. Learning effectiveness in a large class, however, is reduced due to limited interaction, delaying feedback until after an exam, and tediousness of many repeating laboratory sessions.

We are implementing steps to teach manufacturing laboratory to a large class of 250 students each semester. Complementary online instructional videos and class lectures, Clicker assessment, regular grade feedback, and cellular manufacturing laboratory exercises are utilized. Laboratory exercises are grouped into cellulars to save resources, space, and are synchronized with relevant lectures to facilitate students' understanding. For each laboratory exercise, the overall lab objectives are covered in class, but details of tooling and machine operation are shown using online professional videos so that students can view and learn at their own paces before going to their laboratory. A clicker quiz is conducted at the beginning of a lab session to gage students' understanding while encouraging them to be punctual. This online lab instruction approach allows more hands-on time for students in a lab while reducing communication gaps from lab instructors who English is not their native language. A student would have access to handouts, announcement, and cumulative grades via individual password-protected eCampus account so he/she can easily monitor the progress and know his/her ranking in class.

Despite teething problems when implementing these steps, very positive student feedback, less tedious work for laboratory assistants, punctual laboratory schedule, and better exam outcomes prove the success of this approach.

I. Introduction

The available funding for manufacturing research and national strategic directions have inspired researchers and produced a surge in manufacturing education and research among educational institutes including high schools, community colleges, vocational training centers, and universities. Although there are more students interested in manufacturing, some institutes have to balance between the steep increment of student enrollment and available resources. A proportional increasing of resource to the student population growth would solve the problem if there is unlimited resource; however, when resource is limited then creative ideas are sought to modify the current teaching practice for large classes without compromising class standards.

This paper presents an integrated approach to teach a large manufacturing class that combines hands-on group cell laboratory with Clicker assessment and online resources.

II. Literature Review

II.1. Group Cell

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 BC) during Spring-Autumn period of Chinese history. Leighbody and Kidd also concluded "learning requires active experiences" in their survey[1].

Nowak[2] ranked teaching strategies and learning activities within technology education. The author concluded that 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[3] 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[4] 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 such laboratory work was more difficult to develop as compared to the traditional teaching practice, the benefits of the former approach were numerous since it would:

a) Simulate industry practice,
b) Develop specific hard-skill and soft-skill to students,
c) Provide opportunity for lab instructors to be creative and organized, and
d) Significantly enhances team communication and cooperation among team members.

II.2. Clicker Assessment

Clickers started during 1960s in Hollywood to collect opinions on unreleased movies or television shows before spreading into academic areas [6,7]. The latest Clickers with multiple-choice and numerical input options had been popular in many disciplines including psychology and sociology [8], operation management [9], engineering dynamics [10], physics, astronomy [8,11], astrophysics [8], chemistry [12,13], chemical engineering [8], mathematics [14], engineering mechanics [15], and thermodynamics [16]. Published literature showed both qualitative and quantitative assessments of how Clickers helping students and instructors to achieve their academic objectives. Studies were based on data collected from a small class, to large classes over 100 students, to campus wide large classes, and even to a collective study from seven universities and involved more than 1500 undergraduate students [11].

Both negative and positive assessments of Clicker had been published. Bugeja[6] concerned of the implementing cost of Clickers from both students and school administrative views. Others identified top benefits of Clickers as instant feedback for both students and instructors, and strong correlation of Clicker participation and final grade outcome. Fang[10], King and Joshi [12] found statistically significant correlations between clicker performance and exam performance. King and Joshi [12] studied how gender responded to Clickers in a chemistry class. They found that female students were more active participant than male, and 62% of female students were active compared to 48% of male in one semester; these statistics changed to 64% and 54% respectively in another semester. Both genders, who actively participated in Clicker sessions, received higher final grades than the rest of the class. Debourgh [17] concluded that the most powerful impact of Clickers on student achievement was the opportunity for instant feedback. Formative feedback allowed students to correct their misunderstanding, gain clarity, and to identify gaps and flaws. The timely feedback also allowed instructors to adjust and find a more effective teaching method. Lantz [18] highlighted the benefit of Clickers when students have to generate an answer without being judged by peers, therefore, promoting memory though "generation effect." Keller et al. [8] surveyed more than 10,000 students in 94 lecture sessions. They suggested the maximum Clicker benefit could be achieved if 3-4 questions would be given per quiz in practically every lecture (90-100%). Both students and instructors agreed that it would be best to let students discuss during a quiz to foster interaction and improve learning.

II.3. Online Learning

The advance of computer technologies and manufacturing techniques has been driving down the cost of computer ownership. It is a norm for a student to have his/her own computer with high speed internet connection. Education should take advantage of online resources to lighten classroom workload.

In a study sponsored by US Department of Education [19], it was concluded that on average, students in blended learning conditions performed better than those who received face-to-face instructions alone. The blended condition referred to the combination of both online learning and face-to-face instruction. The reason was due to the fact that blended conditions often included additional learning time and instructional elements not received by students in control conditions.

Meyer [20] reported that students with certain learning styles (e.g., visual) or behavioral types (e.g., independent) would do learn better in online learning environment. However, the students who were more aural, dependent, and passive may not do as well. To maximize learning results, instructors should design the material with supportive and appropriate technologies to match students' learning styles. Furthermore, students with a high motivation to learn, greater self-regulating behavior, good computer skills, and strong belief that they can learn online would learn better as compared to students who struggled because of a lack of motivation or self-confidence. The study also found that online students were more likely to make important statements and link ideas, although they contributed fewer novel ideas than the face-to-face comparison group such as in a brainstorming group.

Garrison and Cleveland-Innes [21] concluded that teaching presence in the form of facilitation was crucial in the success of online learning. The leadership role of instructor required powerful in triggering discussion and facilitating high levels of thinking and knowledge construction. Garrison and Anderson [22] also suggested three conditions for creating and effectively sustaining cognitive presence in an online educational environment.

- *Design*. Instructors should define clear expectations and selecting manageable content, structuring appropriate activities (collaborative and individual), and conducting assessment congruent with intended goals.
- *Facilitation*. Instructors should provide clear participation requirements in terms of length, content expectations, and timeliness.
- *Direction*. Instructors should provide engaging questions, focus discussion, challenge and test ideas, model appropriate contributions, and ensure that the discourse is progressive. It is not educationally desirable to have the teacher respond to each comment. But it is crucial that the teacher moderate and shape the direction of the discussion.

III. Approach

To cope with the large number of students in a manufacturing class that offers hands-on laboratory, we are implementing (i) online instructional videos for each lab, (ii) clicker quiz at beginning of each lab session, and (iii) group cell practice in our manufacturing labs.
Our current introductory manufacturing class is very popular with more than 250 students registering each semester. There are three class sections, each with about 90 students for better control of class flow and utilization of available classrooms. Students are further grouped into smaller lab groups of 16 for lab practice. By increasing the number of lab teaching assistant (LTA) from one to two, the original 3-hr lab period is effectively reduced to a 2-hr period without compromising the learning outcomes and scope of a lab exercise. An LTA typically explains relevant part of a manufacturing process, demonstrates techniques, and highlights possible hazardous scenarios. Such lab introduction may take 10-20 minutes from a 2-hr lab session. Students might not comprehend 100% of the instruction due to noisy/large lab environment, complexity of machinery, inexperienced LTAs, or language barrier of some international LTAs.

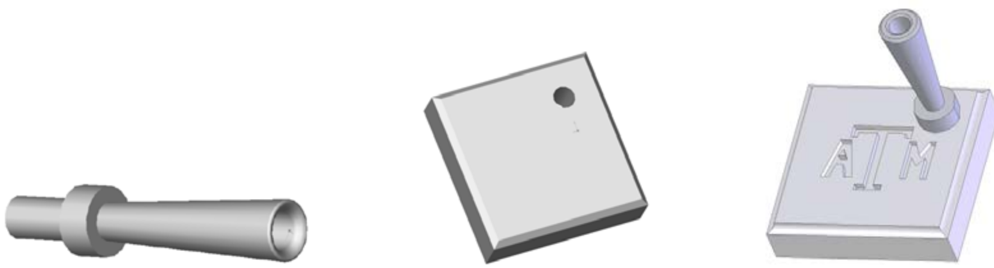
To reduce tedious instructional steps in many different lab sessions for LTAs, short and professional video clips that describe specific lab content and equipment are made. In future, it is possible to include closed caption for students with special needs. After viewing these short video clips at beginning of each lab, students would take a clicker quiz to show their understanding of the lab objective and procedure. These videos will be uploaded next semester so students can view those clips online at their own time and pace before coming to their lab, therefore, they would have more time to practice and utilize equipment in their labs. To encourage students viewing the instructional videos before going to a lab, we will have clicker questions at the beginning of a lab session so that bonus points are awarded to students who do view and understand the video objectives, while “filtering out” students who do not. The professional videos can be shared among different manufacturing classes that utilize the same labs. The cost to implement these online videos is about $7/student.

A traditional manufacturing lab employs full time technicians or experienced students as LTAs to guide students operating different types of machine tools. A typical lab requires large floor space for multiple machines, and does not provide opportunities for students to interact during a lab session. Such Traditional laboratory approach provides hard-skills to students, while Group-Cell laboratory approach provides both hard-skills and soft-skills to university graduates. Group cell requires unique machines to fabricate similar products, simulates industrial practice, and is suitable for teaching since an instructor normally repeat the exercise to different batches of students. Although it is more cost effective, group cell approach requires more 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. A team of 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 processes for all machines, and suggests flow among different machines.
Industry relevant	Less	More
Overall cost	More	Less

IV. 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 a pen-holder assembly that we previously used as exercise in Traditional approach. The same design has been used since Spring 2013 in Group-Cell approach for comparison. There are 16 groups with 16 students in a group, and it takes five 2-hour sessions to complete this introductory machining exercise in this introductory 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 task breakdown for the same exercise in Traditional Lab and Group-Cell Lab. The former lab has 15 machines compared to 8 machines in the latter. The new approach reduces required floor areas from 1420 ft^2 to 600 ft^2, and lowers the overall operating cost due to less number of equipment.

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

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 4. 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 LTA 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 types (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.

V. Results

We have transformed our Traditional machining laboratory into Group Cell laboratory within a smaller area –about half of the previous floor area, and utilized the remaining floor space to build a multimedia discussion room. The brand new machines at two group cells, although having similar functions and capabilities, are technically 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. A surface grinding machine is in one cell while a cylindrical grinder is in the other cell. 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. 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.

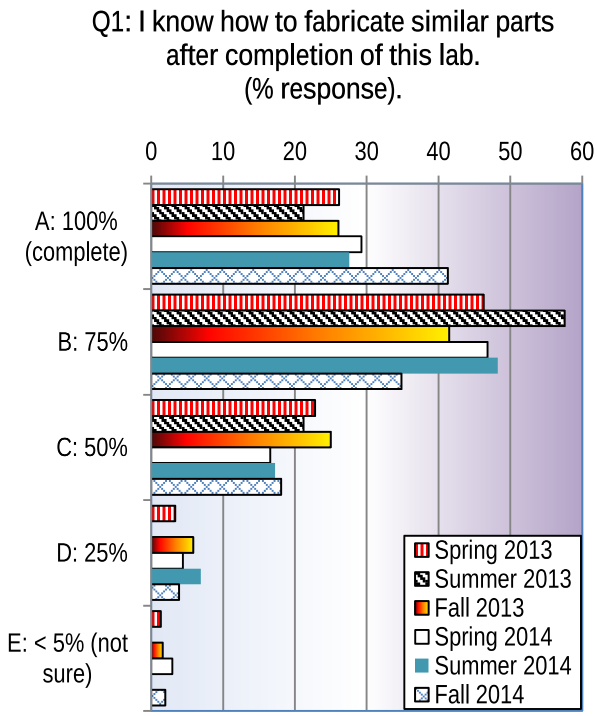
The new Group-Cell approach for machining exercise has been implemented since spring 2013. The same part designs, inherited from previous Traditional machining exercise, are used in the Group-Cell exercise. This way we can (i) minimize training effort to our current LTAs, (ii) have the same base to gage the student subject comprehension, and (iii) let the students keep the parts that they have proudly manufactured by themselves. Data from student feedback, comment from Industrial Advisory Committee, and laboratory quizzes are used to gage the success of this Group-Cell approach.

We exposed 983 students to Group Cell exercise during 2013-2014 and had 84.6% responded in the follow-up surveys. Although there were teething problems, the benefits of Group Cell approach were obvious from the students' feedback and positive comments from Industrial Advisory Committee members. Some students' comments include:

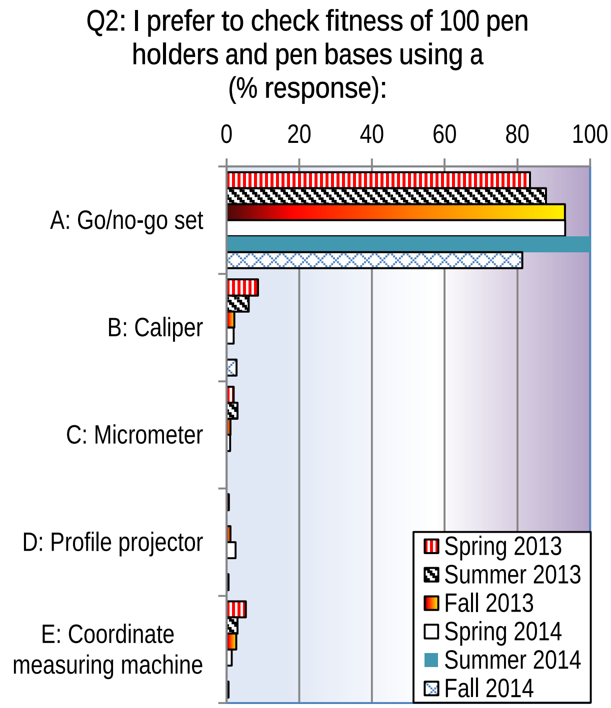
- "I liked how everything was organized and how everyone had a part to play. I think we should have milled first (before drilling). I really appreciated how both LTAs answered any and all questions."
- "I like the teamwork aspect, being completely hands-on, using the same machine every day and got very 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 LTAs 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!"

Figures 2 a-f show the survey questions and student responses during 2013-2014. The survey indicates that (i) students understand the idea behind Group Cell concept in manufacturing and manufacturing fundamentals (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).

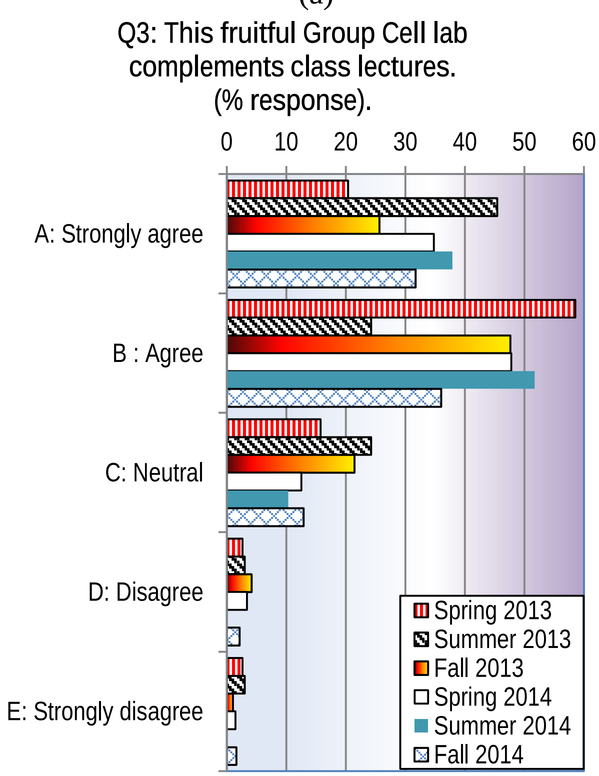
In previous Traditional lab exercise, there were always some students who needed extra time to complete their parts. This strained the LTAs and caused lab scheduling problems. We eliminated such making-up sessions when implementing the Group-Cell approach for the same lab exercise. In fact, some groups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


Q1: I know how to fabricate similar parts after completion of this lab. (% response).
0 10 20 30 40 50 60
A: 100% (complete)
B: 75%
C: 50%
D: 25%
E: < 5% (not sure)
Spring 2013
Summer 2013
Fall 2013
Spring 2014
Summer 2014
Fall 2014

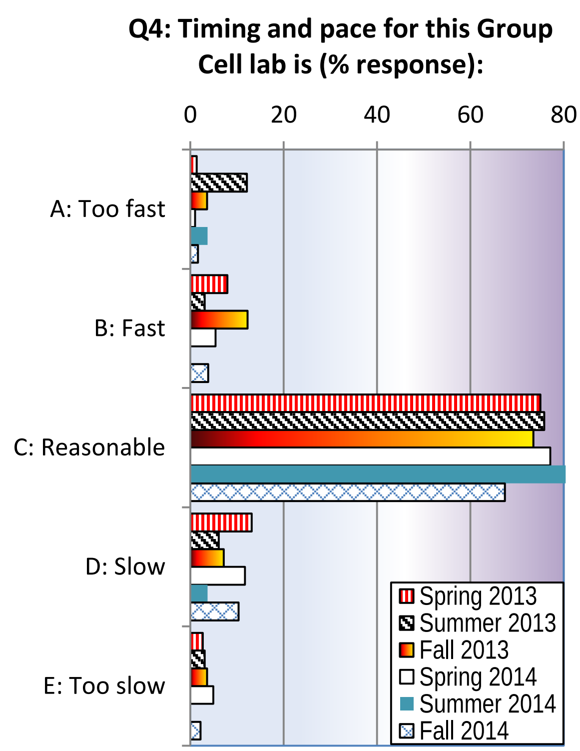
(a)


Q2: I prefer to check fitness of 100 pen holders and pen bases using a (% response):
0 20 40 60 80 100
A: Go/no-go set
B: Caliper
C: Micrometer
D: Profile projector
E: Coordinate measuring machine
Spring 2013
Summer 2013
Fall 2013
Spring 2014
Summer 2014
Fall 2014

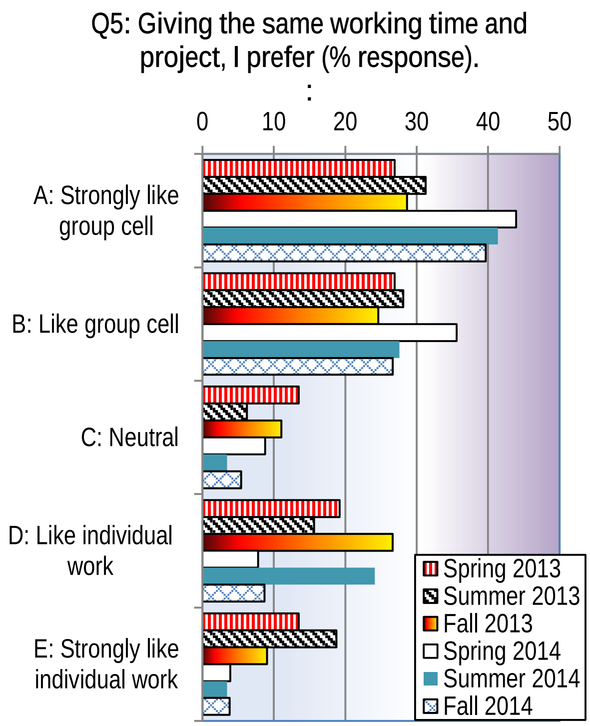
(b)


Q3: This fruitful Group Cell lab complements class lectures. (% response).
0 10 20 30 40 50 60
A: Strongly agree
B : Agree
C: Neutral
D: Disagree
E: Strongly disagree
Spring 2013
Summer 2013
Fall 2013
Spring 2014
Summer 2014
Fall 2014

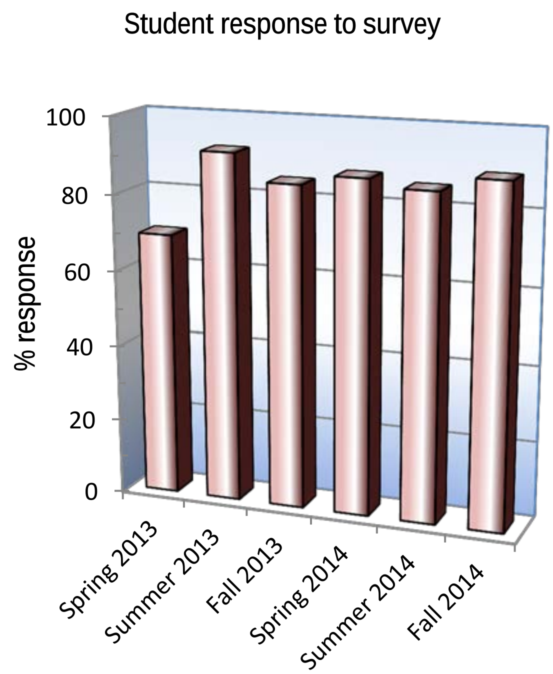
(c)


Q4: Timing and pace for this Group Cell lab is (% response):
0 20 40 60 80
A: Too fast
B: Fast
C: Reasonable
D: Slow
E: Too slow
Spring 2013
Summer 2013
Fall 2013
Spring 2014
Summer 2014
Fall 2014

(d)



(e)



(f)

Fig. 2. Student feedback for two consecutive years 2013 and 2014. Total 831 responses from 983 students.

Clicker quizzes in class and lab not only encourage students to attend class/lab punctually, but provide instant feedback to both students and instructors on how manufacturing concepts and practices are comprehended. By using eCampus as a teaching tool, students in a large class can keep track of their grades and progresses when logging in with their own passwords, or download additional handouts, homework and view solutions.

VI. Conclusion

We implemented Group-Cell practices to replace the Traditional machining exercises, used professional video clips of specific task and equipment as laboratory instructional tool, and utilized Clicker for fast assessment and feedback in large manufacturing class. Space saving, lower maintenance cost, positive image of manufacturing, and the survey data from 983 students from two consecutive years 2013 and 2014 prove the success of this implementation. 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.

Our next step will be to upload the lab introductory videos online and give more hands-on time to students in their labs. Follow-up survey and observation of student confidence in the labs will gage the total success of teaching manufacturing for a large class.

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