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Experiences with a Hands-on Activity to Contrast Craft Production and Mass Production in the Classroom*

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For many industrial engineering students, the basic principles of craft production and mass production are easy to grasp and understand; however, students less familiar with manufacturing often have a difficult time appreciating the subtle differences between the two. Explaining the differences between the two using examples and cases is relatively straightforward and easy, but many students have a difficult time comprehending the importance of the learning effect, why bottlenecks occur, or how quality can decrease during mass production. In this paper, the author's experiences with a paper airplane production activity to contrast craft and mass production are discussed. This activity provides a simple, yet dramatic, approach to demonstrate the benefits and drawbacks of craft and mass production in the classroom. After discussing the merits of hands-on activities and the paper airplane production activity itself, sample results are presented along with an evaluation of its impact on students' understanding of the two production methods.

INTRODUCTION

EDUCATORS are constantly seeking new ways to actively engage students in their own learning. Actively involving students in their learning leads to deeper questioning, improved attendance, higher grades, and greater lasting interest in the subject when compared to just lecturing [1, 2]. Traditional lectures tend to encourage passive learning, which often creates a mismatch between the way instructors teach and the way engineers learn [3]. There are many indications that engineers are more likely to be active rather than reflective learners [4], and appealing to multiple learning styles can increase students' retention of course material [5]. In fact, Dale [6] reports that after two weeks, people generally remember 10% of what they read, 20% of what they hear, 30% of what they see, 50% of what they hear and see, 70% of what they say, and 90% of what they say and do; similar figures are given by Stice [7]. All of these findings echo the well-known statement by Confucius, which goes something like 'Tell me, and I will forget. Show me, and I will remember. Let me do it, and I will understand.'

Hands-on activities provide a means to actively engage students in the classroom, allowing students to become 'active, interested, and informed participants in the learning process' [8]. Kresta [9] found that hands-on demonstrations increased attendance from 30% to 80% in the seminars they developed for their large fluid mechanics classes. It has also been found that employee training programs that emphasize learning by doing and incorporate hands-on activities yield substantial benefits for many companies, including Quantum Corp., FedEx, and 7-Eleven [10], and a recent discussion involving educators, architects, and representatives from GE, IBM, Boeing, and other large industrial companies emphasized the need for more in-class involvement, teamwork and experience, and cooperative learning in the classroom [11].

In engineering, hands-on activities and demonstrations have been developed and documented for teaching students about basic fluid mechanics principles [9], mechanics [12], thermal conductivity in materials [13], electric power [14], and concurrent engineering [15] to name a few. Methodologies for structuring hands-on learning in the classroom have also been proposed to help shift the focus from the teacher to the learner [16]. Hands-on activities are also widely used in operations management courses [8, 17, 18], and several activities for manufacturing simulation and operations management can be found online at:

http://web.lemoyne.edu/~wright/learn.htm
http://www.orie.cornell.edu/~jackson.

In this paper, the author discusses his experiences with the paper airplane production activity developed by Benoit and McDougall [19] to help contrast craft production and mass production in the classroom.

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easy to grasp and understand; however, students less familiar with manufacturing often have a difficult time appreciating the subtle differences between the two. Explaining the benefits and drawbacks of craft production and mass production using examples and case studies is relatively straightforward and easy, but few students realize that the flexibility, specialization and niche marketing that are critical elements for many of today's manufacturing firms are the exact same drivers that fueled the growth and development of craft production firms in the 1800s. Hounshell [20] is one of many historians who has documented the transition from craft production to mass production, and Womack, et al. [21] discuss craft production and mass production in the automobile industry. Cammarano [22] examines contributions of key individuals like Simeon North, John Hall, and Samuel Colt to the development of mass production techniques while Pine [23] examines how principles from craft production and mass production have combined to enable mass customization. Materials from these sources and others have been used to develop a series of lectures that complement the paper airplane production activity discussed in the next section.

PAPER AIRPLANE PRODUCTION ACTIVITY

Initially created by Benoit and McDougall [19] to introduce the concepts of work simplification and line balancing to students in operations management, the paper airplane production activity involves fabricating and 'testing' paper airplanes in a simulated production facility. The airplanes are constructed from a template, see Fig. 1, and then tested using the following nine steps [19]:

1. Write an aircraft identification number in the serial number box on Side 2 of the aircraft pattern; turn the pattern over so that Side 1 is facing up.
2. Fold 1: The first right nose sweep.
3. Fold 2: The first left nose sweep.
4. Fold 3: Fold sheet of paper in half lengthwise.
5. Fold 4: The second right nose sweep.
6. Fold 5: The second left nose sweep.
7. Fold 6: The third (last) right nose sweep.
8. Fold 7: The third (last) left nose sweep.
9. Acceptance Test Flight: Stand behind the launching line and fly the aircraft into the box. If the test pilot misses, s/he must retrieve the aircraft, adjust the trim tabs to control the flight, and try again. Each aircraft must be successfully tested (i.e., flown into the box) in order of production before the next aircraft can be tested. The serial numbers on each aircraft help control the flight testing sequence.

The activity can be easily completed in 45–50 minutes, allowing time for set-up and clean-up.

The paper airplane production activity begins with a brief **warm-up period** (approximately 5 minutes) wherein each worker fabricates and 'certifies' an aircraft following the aforementioned nine steps. This first round allows each student to practice folding and flying an aircraft.

Following the warm-up period, the class is randomly divided into 'production teams' consisting of nine students in each team. The students can sit and arrange themselves however they feel most comfortable, provided they have room to fold the template and then walk, or run as many do, to the launching line to 'certify' their airplanes. After the students are comfortably seated and ready to

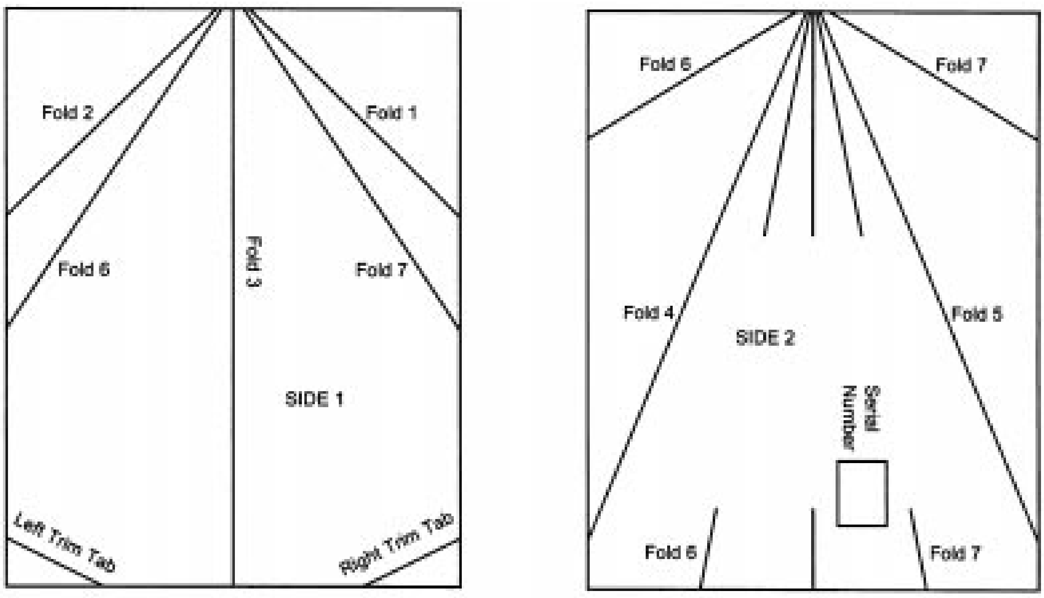

Fig. 1. Airplane template [19]: (a) Side 1; (b) Side 2.

Fig. 2. Airplane flight test 'certification'.

begin, the craft production run begins and lasts for 5 minutes. During the **craft production run**, students fold their own airplanes and 'certify' them by flying them into a cardboard box, see Fig. 2. A student is not allowed to begin fabricating another airplane until the current airplane has been successfully flown into the cardboard box, indicating successful 'certification' of the aircraft.

After the craft production run is completed, each production team forms an assembly line to simulate mass production. During the **first mass production run**, each student performs only one of the nine steps required to fabricate and 'certify' an airplane. This first mass production run also lasts 5 minutes.

After the mass production run is completed, each production team has 5 minutes to analyze and **discuss ways to improve the assembly line**. The assembly lines can be reorganized in any manner, provided that no additional workers are hired and that everyone performs at least one step in the process. If, for instance, flight-testing is a bottleneck, then two students could be assigned to be 'test pilots' while another student would then be responsible for two folds instead of just one. Alternatively, if airplanes are being 'certified' faster than they are being produced then parallel assembly lines could be implemented to increase throughput. After the teams reorganize their respective assembly lines, a **second mass production run** begins, lasting for 5 minutes.

At the end of each production run, the number of 'certified' airplanes is tallied, and the average output per worker is computed for each production team by dividing the number of 'certified' aircraft by the number of students in the team. Additionally, the number of airplanes in process (i.e., waiting to be 'certified' or partially folded) should be recorded to compare work-in-process (WIP) inventory between the craft production and mass productions runs.

MATERIALS AND INSTRUCTIONS FOR STUDENTS

For the paper airplane production activity, each production team needs:

- *200 aircraft templates* (approximately 60–80 airplanes can be manufactured by one team in a 5 minute production run);
- *a cardboard box* (about 1 ft wide and 2 ft deep; an empty paper box works well); and
- *a table or row of desks* (on which students can fold the airplanes).

A *tape measure* and *masking tape* are also useful for marking launching lines 5–6 ft away from each cardboard box for the 'flight test pilots' to stand behind, see Fig. 2. A *clock or stopwatch* can be allocated to each production team; however, it is easier for the instructor to maintain time, announcing minute increments and the last 30 and 10 s of production. Finally, a *large recycling bin* is useful since many paper airplanes are produced during the activity.

At the beginning of the activity, students are randomly assigned into production teams consisting of nine workers each. After the craft production run, the students count off 1, 2, . . . , 9 within each production team and are randomly assigned to one of the nine fabrication and testing steps. Teams need not be of the same size, however. For smaller classes, groups of 7 or 8 students can be accommodated by combining Folds 1 & 2 and/or Folds 4 & 5. For larger classes, groups of 10 and 11 students have been successfully implemented by adding 'time keepers,' 'line supervisors,' and/or 'inventory control supervisors.' 'Line supervisors' are instructed to motivate the production team while monitoring the location of bottlenecks and determining how the mass production line can be improved during the second mass production run. Meanwhile, 'inventory control supervisors' maintain the stack of aircraft templates, handing them to the first person in line and grabbing more unfolded templates whenever the team starts to run low. Example results follow.

SAMPLE RESULTS

The paper airplane production activity has been used each Spring for the past four years as part of a course cross-listed in both mechanical and industrial engineering [24]. The activity follows a series of 1 or 2 lectures that focuses on craft production and is held prior to 2 or 3 lectures on mass production. The exercise serves as a nice segue from craft production to mass production since it can be referred to frequently as the principles of mass production (for example, how the focus on operational efficiency and the degree of specialization increase worker output) are introduced and contrasted against craft production.

In terms of Kolb's four-stage learning model [4] the paper airplane production activity engages students in Active Experimentation ('doing') while the experience itself provides Concrete Experience ('feeling'). The lectures (Reflective Observation) and discussions (Abstract Conceptualization) complement the activity and traverse the remainder of Kolb's learning model, thereby improving students' learning. Stice [7] writes that students' retention of knowledge increases to 90% when students are engaged in all four stages of learning compared to only 20% when only Abstract Conceptualization is involved. Kresta [9] also notes that it is important for students to see important topics in a course at least three times and that reinforcing hands-on demonstrations with lectures and assignments improves the learning environment for students.

In Spring 2000, four teams of 11 students participated in the exercise, and the results from each production run are summarized in Table 1. For the craft production runs, the average output per worker was comparable for all four groups, ranging from 1.27 to 2.45 airplanes/student. It is interesting to note that the groups with higher output tended to have less work-in-process (WIP) inventory, which ranged from 5 to 9 airplanes (0.45 to 0.81 airplanes/student); however, this is not always the case.

During the first mass production run, 3 of the 4 teams increased their output by as much as 21%. This increase in output came with a price, however, in that WIP increased dramatically; Team #3 had almost 50 airplanes in process at the end of the first mass production run. Meanwhile, Team #4 actually 'certified' fewer airplanes when they implemented mass production, decreasing their output per worker by almost 30%. This was primarily attributed to a poorly skilled 'flight test pilot' who was subsequently replaced during the second mass production run, allowing them to achieve the largest output per worker for any production run: 3.18 airplanes/student. Team #1 did not improve its output per worker during the second production run as discussed in the next section; however, it was able to reduce its WIP by 48%. Team #2 saw a modest gain in output per worker (18.2%) but at the expense of an increase in WIP (37.5%). Finally, Team #3 improved output slightly (12.5%) while reducing WIP by 57.1%. Similar trends have been observed in the other three semesters.

CLASS DISCUSSION

At the end of the activity, each production team is asked to discuss and answer the following questions about each of their production runs.

- During the **craft production run**:
  - What did you observe about the process?
  - Did all the aircraft take the same amount of time to produce and test?
  - If not, to what can you attribute the variation?
- During the **first mass production run**:
  - How did the assembly line process differ from the craft production process?
  - What were the implications for the workers?
  - What are the implications for the process as a whole?
- During the **second mass production run**:
  - What recommendations did your group make and why?
  - Did the recommendations improve the line? If so, how? If not, why not?
  - What effect did the recommendations have for the process as a whole?

Table 1. Sample results from paper airplane production activity

Team #	# Students	Output	Output/Student	WIP
Craft production				
1	11	19	1.73	9
2	11	21	1.91	7
3	11	14	1.27	9
4	11	27	2.45	5
Mass Production, Run 1				
1	11	23	2.09 (+21.05%)	35 (+289%)
2	11	22	2.00 (+4.76%)	24 (+243%)
3	11	16	1.45 (+14.29%)	49 (+444%)
4	11	19	1.73 (−29.63%)	9 (+80%)
Mass Production, Run 2				
1	11	23	2.09 (+0.00%)	18 (−48.60%)
2	11	26	2.36 (+18.18%)	33 (+37.50%)
3	11	18	1.64 (+12.50%)	21 (−57.10%)
4	11	35	3.18 (+84.21%)	23 (+155.6%)

Fig. 3. Typical assembly line layouts in first mass production run: (a) inefficient layout (Team #1); (b) efficient layout (Team #3).

Typically there is insufficient time to discuss responses to these questions during the same class period; therefore, each team is asked to select a *recorder* to take notes during the discussion which is then reviewed at the beginning of the next class. Also, it is very helpful to have a digital camera on hand to take photographs of the different production teams during the activity for later discussion. For instance, assembly lines can be laid out efficiently or inefficiently depending on how the students seat themselves as seen in Fig. 3. Pictures like the one in Fig. 3 are usually a very good starting point for discussing the impact of assembly line layout on productivity.

During the **craft production run** in Spring 2001, teams noted the low productivity and output, high variability and differences in quality. The variation was attributed to a bottleneck in the test area, differences in people's learning curves and ability to produce an aircraft, and the difficulty of having 'too many skills to master'. The initial craft production run also lacked coordination. Many production teams became disorganized, the testing area got overcrowded, and several workers became 'idle,' which was interpreted as being lazy. One team noted that they 'took more pride in your plane' when they produced the entire aircraft rather than just making one fold.

After the **first mass production run**, everyone noticed how productivity increased and tasks were simpler to master because of the division of labor. This specialization, however, required less skill from each worker and resulted in a 'loss of a total picture of the process', which upset many students 'because they couldn't see the end result'. Students also felt more pressure and became stressed as the speed of production increased because they 'didn't want to be the bottleneck'. One team was jokingly trying to unionize and seek medical benefits because a student complained that her 'thumb hurt from repetitive motion' because she had to work so fast in order to keep up.

Despite the increases in productivity, the teams were surprised to see such large increases in WIP (due to bottlenecks in their processes) and decreases in product quality (since each worker was only concerned about one step in the process). In Spring 2000, for instance, the quality was so poor in one team that it did not 'certify' its first plane until nearly 4 minutes had passed because the plane—which better resembled a crumpled piece of paper than an airplane—would not fly, leaving less than a minute to try and reduce the WIP that piled up near the tester. Consequently, teams are allowed to reorganize their assembly lines to reduce bottlenecks and achieve a more balanced flow line during the **second mass production run**. These modifications ranged from adding more testers to implementing parallel assembly lines to increase output as seen in Fig. 4.

As shown in Fig. 5a, Team #1 implemented a 'manufacturing cell' consisting of their two best folders who made multiple folds before passing the airplane to the last folder. Meanwhile, Team #3 implemented a 'flexible manufacturing system' comprised of three folders who moved to help reduce bottlenecks as seen in Fig. 5b. Team #2 conducted a brief training session to ensure that each worker knew how to fold the airplane template properly; the result was improved quality and more airplanes. While many of these modifications helped reduce bottlenecks, improve quality, lower WIP, and increase output, Team #1 found that performing several tasks at once was 'too complex for the assembly line' after becoming accustomed to performing one step during the first mass production run. Combined with a lack of quality control and inspection, their quality suffered, making 'rework more difficult' so that output stayed the same.

ASSESSMENT OF STUDENT LEARNING

In Spring 2002, an assessment component was added to help evaluate students' understanding of craft production and mass production before and after the paper airplane production activity. Thirty students completed the twelve-item questionnaire shown in Table 2. Each item was rated on a scale of 1–7, with 1 being the worst and 7 being the best. As noted in the table, dependent t-tests of the

Fig. 4. Assembly line layout for team #4 during mass production runs: (a) first mass production run; (b) second mass production run.

means before and after the activity showed significant differences in the students' understanding of craft production and mass production and the word bottleneck before and after the activity. There was no significant difference in the perceived levels of stress during any of the production runs, although the noise levels in the classroom always seem to increase substantially when moving from craft production to the mass production runs.

In terms of achieving the course objectives, the students felt that the activity related well to them, giving an average rating of 5.77 out of 7 for this item. The students also gave an average overall rating of 5.89 out of 7 to this in-class activity when compared to other in-class activities. When asked how well they still remembered this activity at the end of the semester, students rated it an average of 5.94 out of 7, indicating good retention of the activity itself, and hopefully the lessons learned from it.

CLOSING REMARKS

While many students are usually familiar with the concepts of craft production and mass production, few of them have experienced either first hand. The paper airplane production activity described in this paper provides a simple, yet dramatic, approach to demonstrate the benefits and drawbacks of craft production and mass production in the classroom. This activity allows students to gain a better understanding of the importance of the learning effect, why bottlenecks

Fig. 5. Improved assembly lines for second mass production run: (a) manufacturing cell (Team #1); (b) flexible manufacturing system (Team #3).

Table 2. Assessment of impact of paper airplane production activity

Assessment Questions (Rated on scale of 1–7: 1 = worst, 7 = best)	Mean	Std. Dev.
Rate your understanding of craft production *before* the activity.	4.49[a]	3.34
Rate your understanding of craft production *after* the activity.	5.76[a]	1.22
Rate your understanding of mass production *before* the activity.	4.63[b]	3.29
Rate your understanding of mass production *after* the activity.	5.92[b]	1.18
Rate your level of stress during craft production.	3.52	1.45
Rate your level of stress during mass production—run 1.	3.98	1.43
Rate your level of stress during mass production—run 2.	3.94	1.36
Rate your understanding of the word bottleneck *before* the activity.	4.88[c]	2.82
Rate your understanding of the word bottleneck *after* the activity.	6.07[c]	1.27
Rate the relationship between this activity and the course objectives.	5.77	1.23
Overall rating of this in-class activity.	5.89	1.28
Rate how well you remember this activity.	5.94	1.44

[a,b,c] $p < 0.01$ for dependent t-tests of the differences between these means before and after the activity.

occur, and how quality can decrease during mass production. The activity provides an interactive and fun activity to complement lectures and discussions on craft and mass production—in Spring 2002, seven out of 30 students (23.3%) rated the airplane production activity as the class they liked best during the semester. Only one student has ever rated the airplane production activity as the least favorite class during the semester, citing that there was a 'lot of paper wasted to demonstrate common sense facts.'

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24. Information about this course, *ME/IE 597B: Designing Product Families*, can be obtained from the author's course web page: http://www.me.psu.edu/simpson/courses/me597b/.

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