AC 2009-98: A MANUFACTURING PROCESSES LABORATORY: WHAT BOOK-MAKING AND SHEET-METALWORKING HAVE IN COMMON

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A Manufacturing Processes Laboratory: What Book-Making and Sheet-Metalworking have in Common

Abstract

Book publishing is a multi-billion dollar industry that usually does not have an adequate representation in manufacturing courses or textbooks. With technological advances in printing and copying, the process of making books became affordable even at a small scale. Thus, a book-making laboratory exercise is developed and implemented as a part of the Engineering of Manufacturing Processes course offered in industrial engineering and mechatronics engineering programs at Colorado State University - Pueblo. In one of the lab exercises, each student produces a softbound book of printed lecture notes for the course. This laboratory exercise is developed (1) to introduce students early in the Engineering of Manufacturing Processes course to the broader concepts and complexities of modern production targeting intuitive learners, (2) to facilitate active learning of book-making processes targeting sensing learners, and (3) to provide scaffolding by building on the book-making processes when analyzing other manufacturing processes. Based on student responses to an administered survey, it is confirmed that this laboratory presents an effective active learning tool. Furthermore, as indicated by students' survey results in two consecutive years, significant improvements in this laboratory are achieved by introducing traditional manufacturing processes through the book-making processes. This exercise increases an appreciation for manufacturing topics, and helps students understand the complex nature of many production processes.

Introduction

While it is relatively easy to deliver a broad conceptual picture of the manufacturing processes in lectures, accomplishing this is somewhat more challenging in a laboratory environment. In previous years, a semester-long project incorporated a number of traditional manufacturing processes to produce a working device like a wind vane, a scale, or a desk lamp. However, it took a whole semester to build such a device; therefore, a "large picture" was not provided to the students at the beginning of the semester. Some of the engineering students are intuitive learners, i.e. they learn better when the subject is described and understood first in general terms and then later in necessary detail. The book-making exercise was designed to help intuitive learners.

For the past two years, during the first experiment in the Engineering of Manufacturing Processes course, each student created a softbound book of lecture notes for the course. First, students were introduced to book-making via a short lecture and a demonstration. Then, the course instructor provided printed lecture notes (bookcase) as well as the cardstock paper for the book cover. Finally, students were asked to make their own softbound books. They were encouraged to print their own color book covers using a color laser printer. After the printing, the book covers were laminated using a roll laminator, and then appropriately creased so to provide a perfect bind (a book that lays flat when opened).

During the first year of the lab implementation, students bent the covers directly using a production-type sheet metal bending machine. This year, students creased the cover paper first by using two paper cutters with special creasing blades. Then, they bent the covers by hand or by using the sheet metal bending machine. The book-binding process was accomplished in two steps. First, thermal paper-binding glue strips were cut to size and inserted between the covers and the bookcases. Then, a semi-automatic thermal binding machine was used to bind the covers to the bookcases. Finally, after allowing the books to cool in a cooling rack for about 5 minutes students cut the books to size with a manual guillotine paper cutter to create smooth edges and customize their work.

Engineering laboratories often use active learning. The literature reviewed shows positive results like increased student enthusiasm towards engineering, perceptual and actual increases in students' knowledge, and development of design and team skills[1-11]. Furthermore, "scaffolding" is a method claiming that new knowledge is assimilated best when it is linked to previous experience[12, 13]. The book-making laboratory was developed with the benefits of active learning and scaffolding in mind. Additionally, students walk away from the lab proud of creating a useful product – a set of course notes looking like a regular softbound textbook.

Curriculum Context

Engineering of manufacturing processes is a four credit-hour, one-semester engineering course offered once a year to juniors, seniors and graduate students in the three engineering programs at Colorado State University - Pueblo, BS in Industrial Engineering, BS in Engineering with Specialization in Mechatronics, and MS in Industrial and Systems Engineering. The course is required for students in the two BS programs, industrial engineering and mechatronics. Therefore, students of somewhat varying engineering backgrounds and affinities enroll. The course consists of three hours of lecture and two hours of lab per week.

In the laboratory, students spend two weeks learning how to use micrometers, calipers, various gages, and other measuring instruments. In subsequent weeks, working on various manufacturing steps during production of a device (desk lamp, wind vane, etc.), students engage in casting, machining, polishing, sheet-metalworking, welding, and painting processes. An additional electric discharge machining (EDM) lab is introduced as a demonstration. Assessment of the laboratory experiences is performed in two phases. Regular midterm test questions address metrology topics. At the end of the semester, students write a laboratory report that includes short descriptions and justifications of the processes used, time studies, and a cost analysis for the device produced.

A novel, book-making laboratory is developed and implemented between metrology exercises and the casting experiment. One goal of this laboratory is to expose students early to a complete manufacturing process, providing them with an understanding of the conceptual framework and complexities of producing even simple products like books. Another goal of the book-making exercise is to make a connection between various traditional manufacturing processes and book-making. The experiment targets both sensing (through hands-on steps) and intuitive (provides a whole process) learners as defined by Myers and Myers[14]. A short lecture on producing books and copyright laws is delivered before the lab. The lecture emphasizes a number of traditional manufacturing processes in a context of book-making. The addressed manufacturing processes are referenced to the current text by process name and chapter. Some of the lecture material is adapted from Poynter[15]. In the lab, the instructor demonstrates the whole process by making a book.

Laboratory Assignment and Process Description

Based on the discussions in lectures and the book-making process described below, each student manufactures a soft-cover book of printed class notes or a stack of blank papers (bookcase). The course instructor supplies each student with the bookcase, one sheet of heavier stock paper for the book cover, and one 12 inch x 1 inch strip of special hot-melt glue for book binding. To create a book, students follow the directions below.

1. ***Choose book dimensions, and the type/weight of paper for the bookcase.***
   The bookcase is provided.
2. ***Choose the book type (hard-cover, soft-cover, perfect-bound, etc.).***
   Soft-cover and soft-cover perfect-bound book options are available in the lab. Perfect-bound books lie flat when opened.
3. ***Choose the cover paper stock and an appropriate printer.***
   While there are heavy weight papers suitable for use in ink jet printers, most types of heavy weight paper are designed for use in professional publishing equipment or laser jet printers. The cover paper for use in the lab is Xerox 18”x12” 100 lb cover stock paper that can be used in laser printers. One of the engineering laboratories has a color laser printer that can handle this large paper size.
4. ***Design the wrap-around cover with the spine label and print it.***
   Some simple covers can be designed using Microsoft Word. However, this step is optional since professional results may require a software package like Adobe PageMaker or Adobe InDesign.
5. ***Laminate the outer side of the cover using the EZ27 roll laminator available in the lab and depicted in Figure 1.***
   The laminator is capable of laminating 27” wide paper or card stock up to 80 mil thick using 1.5mil to 3mil laminate film. Before starting the laminating process insure that the heating plates are sufficiently hot to melt the glue on one side of the laminating film. This may take up to 10 minutes. Further instructions are provided in the EZ27 Roll Laminator Operating Instructions[16].

Figure 1. EZ27 roll laminator used in the book-making laboratory

6. ***Crease the cover after lamination.***
   Based on the bookcase determine the size of the spine. Use a pencil to label the spine so the cover can be scored and bent to correct dimensions. Apart from the two creases for the spine of the book, create two more creases approximately one half inch from the spine. These creases will allow the book to bend and stay flat when it is opened (perfect binding). Usually, creasing is performed by using a professional paper creasing or scoring machine. Choose one of the two desktop versions of paper creasing/scoring machines (Figure 2) available in the lab.

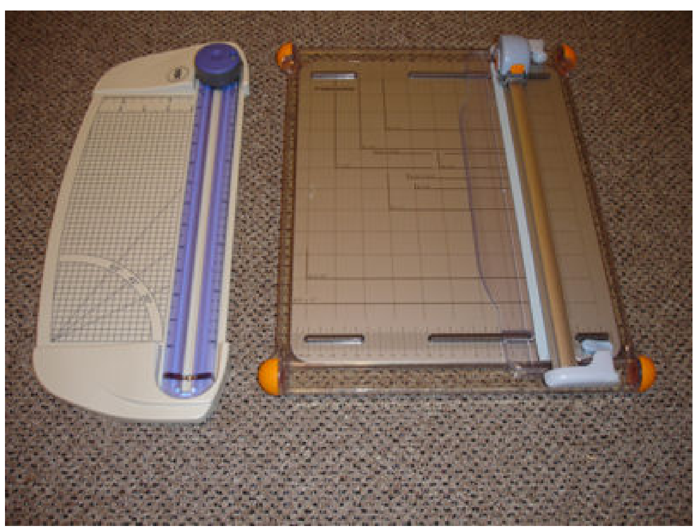

Figure 2. Paper cutters with scoring/creasing blades

7. ***Bend the cover.***
   The cover may be bent by hand. Optionally, once the spine is correctly marked, the sheet metal bending machine depicted in Figure 3 can be used to bend the cover. While scoring of the cover is not necessary for successful bends, the perfect binding requires two extra creases. The sheet metal bending machine requires larger forces to operate, however, it does create more precise 90^{o} bends in the cover. Due to the spring-back effect while

bending paper, bend the paper at an angle slightly larger than 90^o. The same spring-back effect occurs when bending sheet metal.

Figure 3. Sheet metal bending machine used for bending book covers

8. ***Assemble the book for binding.***
   Cut the thermal glue strip to the correct length and width. Use scissors or the professional manual guillotine paper cutter depicted in Figure 4. (This QCM-1200E desktop paper cutter is also used in step 10, after the book is bound, since it can cut up to 280 sheets of 20 lb paper to a maximum cutting width of 12 inches[17].) Then place the glue strip inside the cover on the spine. Take the bookcase, align the papers and place them inside the cover sandwiching the glue strip between the cover and the bookcase. Make sure all the sheets of the bookcase are even at the binding edge. Otherwise, the sheets not touching the glue may not bind properly.

Figure 4. QCM-1200E desktop paper cutter with a paper clamp

9. ***Bind the book using one of the two thermal book binders.***
The book binders available for this lab are GBC 2000XT Therm-A-Bind automatic binder and the Xerox Binder Production Model. Be careful when placing the book ready for binding into the GBC 2000XT Therm-A-Bind since it clamps the book automatically as soon as the book is placed in it. Additionally, the binder automatically sets the heater timer. The binding time depends on the thickness of the book[18]. The GBC 2000XT Therm-A-Bind automatic binder also includes a cooling rack. Other important characteristics of this binder are the warm up time of about 30 seconds, binding time from 36 to 60 seconds, spine width maximum of 2 inches and the spine length of 15 inches. The Xerox binder is similar in size, can bind up to 2.5 inch wide spines, and is of a sturdier metal construction, but it does not have an automatic document clamp. The two binders, a cooling rack and a few glue strips are shown in Figure 5. When the binder beeps indicating that the binding process is finished, take the book out and place it in the cooling rack. Wait at least 5 minutes, and then remove the book from the rack. Inspect the book for loose sheets, an even and square spine, and sufficient binding strength. At this time the glue is not fully set and if there are loose sheets the binding process can be repeated.

Figure 5. Binders with a cooling rack and thermal glue strips

10. ***Square the book and cut it to size by using the QCM-1200E desktop paper cutter.***
Align the book to the appropriate cutting position guided by the gage bars, clamp the book by turning the paper clamp wheel clockwise, pull out the red safety lock knob, and press the cutting bar lever all the way down. Then, return the cutting bar lever all the way up until the safety lock clicks, locking the lever. Finally, release the paper clamp. Repeat this procedure for the other two sides. Be careful at this step since it is possible to damage the book by simply clamping the wrong end of the book. When cutting the top and the bottom sides of the book, make sure the book is clamped with the spine close to the red safety lock knob. When done, show you're the finished product to the instructor for inspection.

Results

Appropriate assessment instruments are developed for this laboratory experiment. Their goals are to re-evaluate widely-known results from literature as the instruments are applied in this particular case (motivation, learning perceptions, quality of learning experience) as well as the specific laboratory objectives such as the degree of increase in practical knowledge of manufacturing processes involved in book-making. Both formative and summative assessment evaluation techniques are addressed. Formative evaluations are based on informal student interviews, topic discussions, and questions students ask in lab or class. Summative evaluations are based on the successful production of books, pre and posttest differences in knowledge, and a survey.

Before running the lab, a number of books were produced using the procedure outlined above. Figure 6 shows some of the books produced.

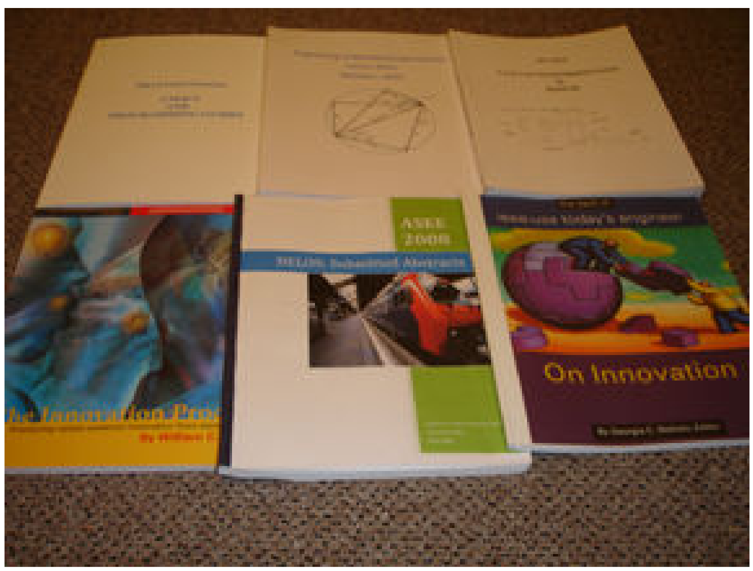

Figure 6. Some sample books produced using the outlined book-making procedure

Figure 7 shows a cover for the book after lamination and bending as well as the final product – a book produced by a student in the lab. The cover had a defect shown in Figure 8. The laminating film was not hot enough when the cover was laminated, so the glue did not melt and the film did not adhere to the paper. The cover was subsequently sent for rework. One of the students with the laminating process experience suggested pressing the surface with a hot iron to melt the glue. In the future, the laminating process will not start until the plates are sufficiently hot.

One more defect was observed after a few days of using the produced books. The covers bent outwards slightly. This was due to the type of laminating film used in the lab. In industry, lay-flat laminating film is often used for book production, instead of the standard laminating film used in the lab. The lay-flat laminating film has perforated holes that allow moisture to enter the outside cover. When both sides of the cover have an equal amount of moisture they equally expand, so the cover does not bend. However, lay-flat laminating film is more expensive than standard laminating film.

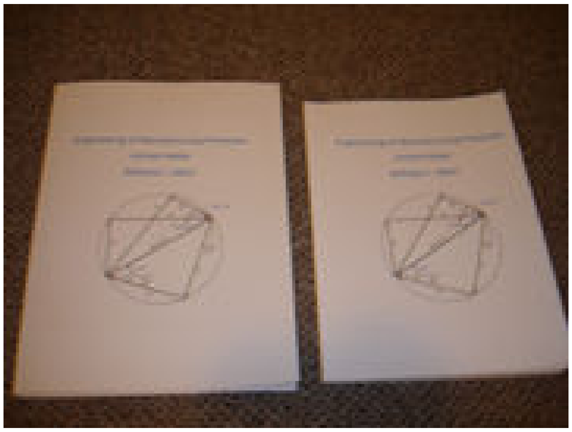

Figure 7. Student-made cover and book

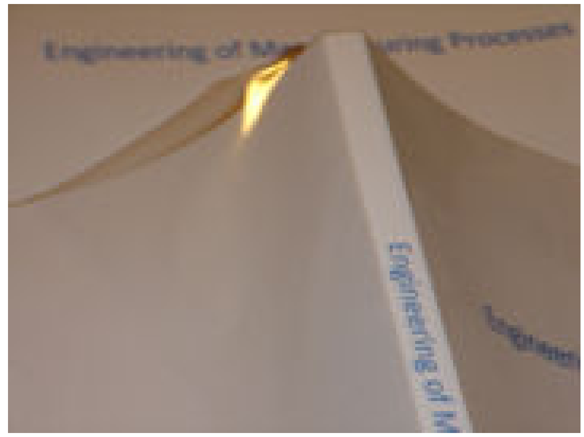

Figure 8. Cover defect

Having self-made books for the course, students were satisfied with their results. They were enthusiastic about the process as well. They learned to recognize and correct the flaws in the process and to adapt to the specific process parameters. Pre and posttests showed significant improvements in student understanding of the book-making process. Processes like printing, laminating, bending, binding, and cutting from this book-making exercise were used successfully in lectures as scaffolding examples for other typical manufacturing processes like sheet-metalworking processes.

To measure student conceptions and attitudes towards this lab, a survey was developed and administered to two groups of students. During the first year the lab was implemented, the survey was administered eight weeks after the experiment. During the second year, the survey was administered two days after the completion of the lab. The survey with average student responses for both groups is shown in Table 1. While the 5-point Likert scale was used for the survey, the results presented are normalized so that 1 on Likert scale corresponds to 0% and 5 on Likert scale corresponds to 100%. Then, the responses can be interpreted as:

0%: Not at All
25%: To a Limited Extent
50%: To a Moderate Extent
75%: To a Great Extent
100%: To a Very Great Extent

Table 1. Survey questions with average response scores

#	Question	Response Group 1 (%)	Response Group 2 (%)	Increase (%)
1	Did you understand the objectives of the book-making laboratory exercise?	75	77.9	2.9
2	Were you able to produce a book to your satisfaction?	69.9	83.8	13.9
3	Did you enjoy making your own book?	87.5	85.3	-2.2
4	Given the equipment could you make your own books?	65.6	94.1	28.5
5	Was the book-making lab relevant to your interests?	50	66.2	16.2
6	Did the lab stimulate your interest in other manufacturing processes?	56.3	60.3	4
7	Do you have a better understanding of manufacturing in general from this lab?	59.4	61.8	2.4
8	Do you feel that expectations of the lab were reasonable?	75	82.4	7.4

Please, add any other comment relevant to the book-making lab.

As mentioned previously, the survey involved two groups of students from two subsequent years. In the first year, eight surveys were analyzed. The results were positive with an overall normalized average of 67.3% and the standard deviation of 28.4. Student satisfaction with the lab was relatively high (87.5%) as well as the student confidence level (65.6%). However, students' perception of the relevance of the book-making experiment to students' interests was only 50%. In general, student comments were positive. They included statements like "*Overall, the concept this lab addressed was quite interesting and realistic to a manufacturing environment.*" or "*It was great to have a souvenir.*"

The second group consisted of 17 students who successfully finished the lab and provided responses to the surveys. All results for this group were positive with an overall normalized average of 76.5% and standard deviation of 24.5. Therefore, the improvement in the overall scores was 9.1%. While student satisfaction with the lab was somewhat lower than for the first group (85.3% for group 2 vs. 87.5% for group 1), the student confidence level showed a remarkable improvement of 28.5%, from 65.6% for group 1 to 94.1% for group 2. Again, all student comments were positive. They included statements like *"I enjoyed the book-making very much. If all texts could be done this way students could save a fortune."* or *"I think this was a very good exercise. Book manufacturing is a skill that can be used by many types of engineers. You might need a user's manual for a product you've made or maybe just a very professional looking presentation. I really enjoyed making my book."* The energy level and the enthusiasm of the second group were higher.

There were a few differences between the two sessions in the lecture presentation, lab preparation, and lab execution. The students in the first group used empty paper as a bookcase while the students in the second group used actual printed course notes looking as close as possible to a regularly published bookcase. In lecture, the first group was exposed to book-making as a separate set of manufacturing processes. For the second group, book-making steps were compared to other manufacturing processes. For example, printing was compared to stamping, laminating to painting and deposition processes, paper bending to sheet-metal bending, cutting to sheet-metal cutting, and gluing to other fastening processes. In the lab, the first group used the sheet metal bending machine exclusively while all the students in the second group bent their covers (after creasing) by hand. To probe further, an informal interview with students was conducted. One student that repeated the lab claimed that making a real book instead of an empty notebook made all the difference in enthusiasm.

The book-making lab required a purchase of few additional devices that are usually not a part of manufacturing laboratories. They were purchased on eBay. The laminator was purchased for about $180, paper cutter for about $220, GBC binder for about $200, and Xerox binder for about $30. Therefore, the price of the additional equipment for the book-making laboratory was about $630. The glue strips were purchased for about $1/strip in quantity of 50.

Conclusions

In this paper, a book-making laboratory exercise is described in sufficient detail for quick adoption. The laboratory exercise is developed (1) to introduce students early in the Engineering of Manufacturing Processes course to the broader concepts and complexities of modern production targeting intuitive learners, (2) to facilitate active learning of book-making processes targeting sensing learners, and (3) to provide scaffolding by building on the book-making processes when analyzing other manufacturing processes. Based on student responses, it is confirmed that the book-making laboratory is an effective active learning educational tool. Students were successful in producing their own books and they were satisfied with the laboratory experience. Furthermore, as indicated by students' survey results in two consecutive years, significant improvements in this laboratory were accomplished by introducing traditional manufacturing processes through the book-making processes. Finally, the laboratory equipment purchased to run the book-making experiment was inexpensive thus making it affordable for implementation in many other institutions.

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