# 2006-2067: ASSESSMENT OF HANDS-ON INTRODUCTIONS TO INDUSTRIAL ENGINEERING

**Durward Sobek, Montana State University**

Durward Sobek is an Associate Professor in Industrial and Management Engineering. He holds an AB degree in Engineering Science from Dartmouth College, and MS and PhD degrees in Industrial and Operations Engineering from The University of Michigan.

**Susan Freeman, Northeastern University**

Susan Freeman is an Associate Academic Specialist in the College Of Engineering. She holds BS, MS and PhD degrees in Industrial Engineering from Northeastern University. Susan worked at Eastman Kodak Company for 9 years as an IE, and has been teaching in the Mechanical and Industrial Engineering Department for 15 years.

# Assessment of Hands-On Introductions to Industrial Engineering

## Abstract

This paper focuses on two Introduction to Industrial Engineering courses offered at different institutions. The instructors of these courses have independently developed and incorporated numerous hands-on and experiential learning exercises to convey core topics in the field of Industrial Engineering. While it is evident that the courses are more entertaining with these exercises, it is less clear that they affect student learning in positive ways. Thus, this paper describes similarities and differences between the approaches used to address the common topics covered in the two courses. We then present data from student surveys on what they perceive they have learned about major topics covered in the course, and their engagement level with the instruction used for the various topics. This assessment enables us to evaluate the efficacy of the hands-on, active learning approaches versus more traditional approaches.

## Introduction

Industrial Engineers do not build bridges, design devices, analyze chemicals, or test for earthquakes. Much of the engineering that Industrial Engineers accomplish is not as visible as in other engineering fields. Yet IE's are vital to many industries and have a variety of field concentrations with excellent career and job advancement opportunities. Introductory courses serve to expose student to the breadth of the field and help recruit students to a little known major. Ideally, these courses prepare students for follow-on courses and future Industrial Engineering (IE) jobs.

The IE programs at Northeastern University (NU) and Montana State University (MSU) have recently developed introductory courses to attract students to the IE major, expose them to the breadth of the field, and prepare them for future coursework. The instructors of these courses (and authors of this paper) independently developed hands-on and other interactive activities to introduce core IE topics. It is well documented that active learning techniques enhance learning and the student experience.[1-4] It is also apparent that not all active learning exercises are equally effective. Thus, while the anecdotal evidence strongly suggests that students enjoy the hands-on activities more than traditional classroom delivery (i.e., via lecture), we saw a need to confirm the pedagogical merit of the specific activities employed.

In this paper, after a brief description of the courses and institutions where they are taught, we provide descriptions of some of the exercises. We then present data and analysis from a survey of students regarding their engagement and level of learning across the spectrum of activities. We conclude with a summary of responses to open ended questions related to their overall perceptions of the field to which they've just been introduced.

## Course Descriptions and Background

The NU course is a required four-credit sophomore course for Industrial Engineering majors, with a few engineering students taking IE as a minor. The course covers core IE topics, about one topic per week, using selected chapters from Turner, et al.'s text[5] along with supplemental material. The class meets three times weekly: one class is generally an introductory lecture with problem-solving, the second includes more problem solving or further exploration of the topic, and the third is a laboratory or hands-on classroom activity. The students complete homework problems and an occasional lab or activity write-up, often in groups. There are also two projects and two exams in the course. When NU converted from quarters to semesters in 2003, the course was revamped from one focused on traditional work design topics to one covering a greater breadth of the field. Students taking the course have selected IE as their major (or minor), but have not yet taken any IE courses. Nearly 100% of the students will participate in Co-operative Education semesters, either in the immediately following semester or the subsequent summer. Northeastern University is a private institution located in Boston, Massachusetts. The College of Engineering has five majors, and the Department of Mechanical and Industrial Engineering has approximately 100 students majoring in IE.

MSU is a public, land-grant university of comparable size located in a small community in the Rocky Mountains. The College of Engineering offers eight degree programs in engineering and technology. The IE program, housed in the Department of Mechanical and Industrial Engineering, boasts approximately 120 students majoring in IE. Most of the students enrolled in MSU's one-credit required introductory IE course are freshman and sophomores who are "checking out" the major and have taken no other IE courses. Like the NU course, the MSU course covers a different IE topic each week of the 15-week semester. Classroom experiences include a mix of traditional lectures, demonstrations, small group work, and hands-on activities. Students complete weekly homework assignments, but do not complete a project or take exams. The course does not require a textbook.

The two courses cover many of the same topics, but do not completely overlap; although the NU course goes into greater depth being a four-credit offering versus one-credit. Table 1 summarizes and compares the topical coverage of the courses.

## Examples of Hands-On Activities

To portray the active learning elements of the courses with greater vibrancy, we describe a few of the hands-on activities developed and used.

| Topic | Montana State University | Northeastern University |
|---|---|---|
| *Introduction* | Lego motorcycle production | Cookie Treat production |
| *IE History* | Discussion of research on IE’s | Students present IE’s from research |
| *Work Design & Work Measurement* | Workstation design for Lego motorcycle | Time study lab – students perform time study at 6 stations |
| *Capacity Planning* | Small group productivity and capacity calculations | Not covered |
| *Layout & Production* | Layout of Lego airplane production | Layout of small playground in groups |
| *Production Systems* | Push versus pull production simulation using Lego airplanes | Line balancing versus bucket brigade approaches in order picking using straws and plastic cups |
| *Process Charting* | Analyze healthcare case in small groups using flow diagrams | Create process charts in small groups on given examples; projects on process charts |
| *Ergonomics* | Demonstration of grip force, lower back strain, anthropometry | In lab, compare auditory, pictorial and written instructions in groups |
| *Operations Research* | OR/MS video, work LP problem using data from earlier Lego production | In computer lab, solve LP problem using Excel Solver; what-if analysis |
| *CIM* | Tour CIM Lab | Not covered |
| *Queueing* | Not covered | Physical simulation of various arrival and service distributions |
| *Simulation* | Demonstration using examples in ARENA, | Perform simulation on paper to review the steps needed |
| *Quality Control* | Lecture on the effects of variability | In computer lab, review 8 SPC tools and use Excel to create charts |
| *Engineering Economy* | Not covered | Examples worked in small groups and homework |
| *Project Management* | Not covered | Class problem worked, guest lecture on scheduling |
| *Product Development* | Guest lecture: from concept to company startup to high volume production | Not covered |
| *IE Curriculum and Advising* | Lecture | Lecture |

Table 1: Comparison of Topical Coverage

First Day of Class – The instructors of both courses have chosen to introduce students to IE by having them experience it, rather than talk about it. At NU, the exercise emphasizes the principle, "Work Smarter, Not Harder" through process improvement on the manufacture of "cookie treats." Students are divided into groups of four or five. Each team is given about 40 small cookies, sprinkles, squirt frosting, plastic wrap and ribbon along with some production tools (foil and plastic knives). They are given specifications as to what a "completed" cookie treat is, and are instructed to make as many cookie treats as they can in 90 seconds. After a few minutes to discuss their method and set up, the groups conduct a 90-second run and count completed cookie treats. Before the next 90 second trial, the groups discuss how their assembly process worked, and what changes they will make in the method and process to improve the throughput. A second trial is done, with completed cookies counted. A handout is given out with questions to prompt the teams to reflect about what they learned, how they might apply what they learned to a manufacturing facility, what equipment would help, and any suggestions. This, then, provides the basis for a class discussion on what Industrial Engineering is, and what they have learned from this experiment.

At MSU, groups of three to four students are given an assembled Lego motorcycle with enough parts to make several more. They are given 10-15 minutes to plan out how they will make 10 motorcycles in the shortest possible time. When time is up, groups pair up so they can pool their parts, and take turns executing their production run while the other group times. Once all the data have been collected on the board, the instructor leads a discussion of "what kinds of questions did you ask" which results in a list on the board of such items as: material management, layout of work area, work load balancing, and sequencing. This discussion, then, is presented to the students as an introduction to the field of IE.

Assembly Line Balancing and Bucket Brigade – This simple experiment illustrates two approaches to process control, modeled after the work done at Georgia Tech.[6] Students pick orders using Zone Picking and Bucket Brigade strategies, then compare numerical results for the average time to complete an order, number of orders completed and the number of orders left in process, along with observations of the ongoing process. The materials used are plastic cups numbered from 1 to 15, straws, chopsticks, needle-nose pliers and a stack of orders. Three students pick orders, one student times each order as it goes through, one student records the times, and usually one student acts as material handler/supervisor to keep the system organized and running.

In the zone picking approach, students pick parts from their respective zones (a subset of the numbered cups) using their tools to complete the orders. In the bucket brigade approach, students pick up an order from the previous worker when their own is completed or picked up by a downstream worker. After running the two systems and collecting data, the students discuss the numerical results, observations of bottlenecks and idle workers, and where each type of system might be best suited and why. A follow-up assignment requires the students to find applications of these techniques.

Work Design – This exercise follows on the heels of the introductory Lego motorcycle exercise at MSU by walking the students through a more formal and systematic design of the motorcycle assembly task and associated work station. The students receive a written bill of materials. As a class, the students identify all the tasks required to assemble the motorcycle. In small groups, the students create a precedence diagram. The instructor then leads the class in creating a consensus diagram on a whiteboard. From the diagram, the class generates a work sequence and then a work station layout. A student volunteer then assembles 10-12 motorcycles to demonstrate the work design. Improvement suggestions are solicited as rarely does the design work flawlessly the first time. The improved work design is implemented and another trial run demonstrated. Some volunteers time the second run in order to estimate the cycle time of the assembly tasks.

In the next class period, the times from the optimized work station are used to calculate a productivity measure that is compared to the productivity of the best performing group from the first day of class, usually showing a 30-50% improvement. Later in the course, the times appear again in a linear programming formulation of production mix problem involving Lego motorcycle production.

**Pre-Course Feedback – Why Industrial Engineering? and Learning Mode preferences**

The students at Northeastern University were surveyed at the start of the Introduction to Industrial Engineering course. The purpose of the survey was to assess how the students came to the program and what they perceive are effective ways to learn. The survey is also being used as information for improving some aspects of the course. The questions that apply here are listed below with results from the 24 respondents summarized:

*"Why have you decided to major in or have an interest in Industrial Engineering?"*
- 9 indicate that it is the way their mind works, this is how they think, or how they are.
- 4 use the word efficiency, as in to study or improve efficiency
- 4 like the breadth, the systems approach, seeing and improving the big picture
- 2 mention IE's ties to the business side of engineering
- 5 indicated that they had heard about IE at an event designed to expose freshmen to the different majors, or by talking with someone

*"How do you prefer to be taught (lecture, hands on activity, both, etc.) Please describe and/or give an example."*
- 7 prefer hands-on activities
- 13 like both, mentioning how they work together to enhance learning
- 2 like lecture by good teachers

*"What helps you retain information that is taught in class (repetition, listening, watching, team work, individual work, problem solving, other activities)?"*
- All responders mention more than one, some choose them all
- Most mention problem solving, working with examples and working on problems both individually and as teams
- Repetition is mentioned as reinforcement, to help cement the knowledge
- Very little consistency, showing many learning styles

What do these results mean? The first question tells us that they have a genuine interest and some knowledge of IE as they enter. They do not mention very many specific IE topics, but seem to have a sense of what makes IE different from the other disciplines, and that they have an inclination towards and a proclivity for IE. At NU, the course can then confirm through learning what IE's really do, and if they have selected the correct major for themselves. Since it is the first semester, students can change majors, so the purpose of the introductory course is not to rope them in, but ensure a good fit.

The second question shows some insight about preferred learning modes. Doing fun activities is fine, but it is a combination of the material taught in a traditional manner with the addition of hands-on experiences that seems to enhance their learning and hopefully their retention of the material. The last question also confirms that they all learn differently, and the varied approaches we take in the classroom and in their homework have varying effects on what they learn, depending on their own style and motivation.

**End-of-Course Survey Results – Perceived Assessment of Learning and Efficacy of Hands-on Activities**

The instructors of each course listed the main activities used to teach the primary topics covered in their respective courses. The students rated the activities according to how much they thought they learned from the activity (from "0" for "learned nothing" to "4" for "learned a ton"), and how engaging they found the activity (from "0" for boring to "4" for very interesting). Figures 1 and 2 display the results graphically. Activities are ordered according to their sequence as presented in the course.

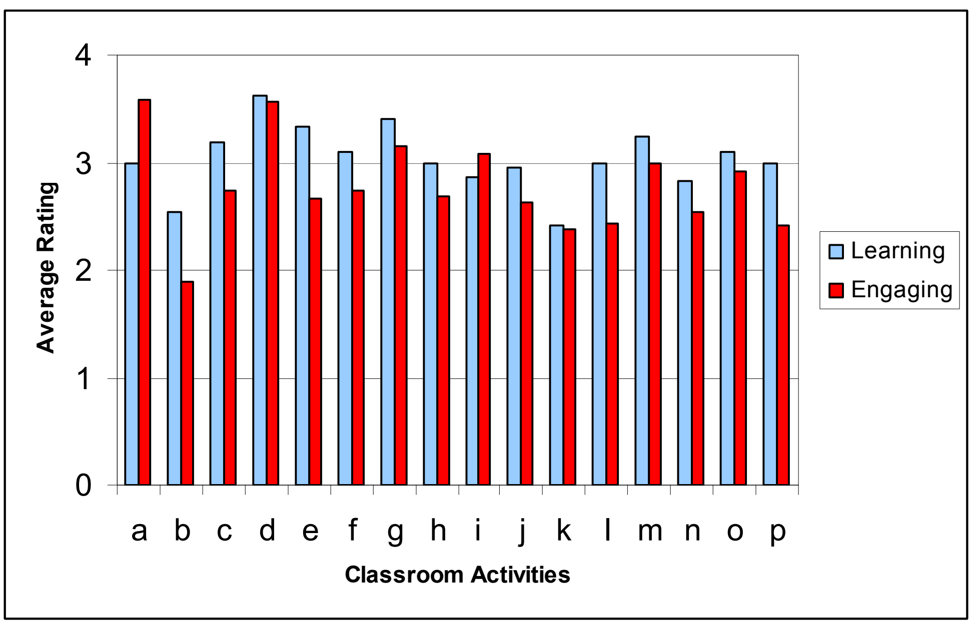


Figure 1: End-of-Course Survey Results from NU
(sample size = 28)

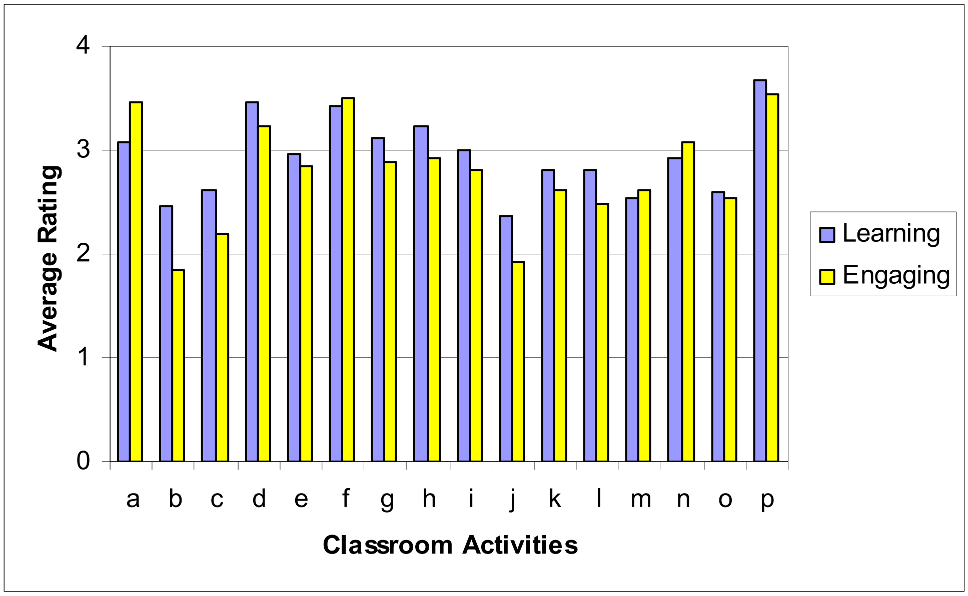


Figure 2: End-of-Course Survey Results from MSU
(sample size = 26)

One of the striking characteristics of these results is how the two ratings track one another. The NU data have a correlation coefficient of +0.66 while the MSU data has a correlation of +0.89. Thus, on average, students felt they learned more when teaching involved exercises they found more engaging.

When sorting the data, activities with the strongest hands-on elements (i.e., with students handling physical objects) dominated the upper quartile of the engagement ratings. A similar pattern can be seen with the learning ratings only not as strong. For example, in both courses, the introductory exercise on the first day of class received strong engagement ratings, but lesser learning ratings.

Teaching modes centered on lectures or discussion dominated the lower quartile of engagement ratings. Interestingly, though, they were more dispersed among the rankings of the learning scores. In both courses, the class on IE history scored very low on both measures, as did IE curriculum and advising, despite efforts to make the class participatory. In NU's case, students each research an important figure and present them. The instructor then leads the class in developing a table that highlights the key item to remember for each person. In MSU's case, students each research the definition of IE and Frederick Taylor, then in class compare notes with other students in a small group setting followed by instructor-lead class discussion to pull together the key learning points. Although the instructors feel IE history is important background for the students, they do not seem to find it as interesting as other topics.

Some of the responses surprised us. For example, the NU course instructor devised a Pictionary-like game to review principles of motion economy (versus the usually tedious task of going over a list of them). The class was lively and funny, and considering the routine ways it could have been done, appeared to be a success. Not so from the student point of view: they did not rate it engaging nor did they perceive that they learned a lot from the activity. Thus it appears that just making class fun does not translate to learning or even engagement on the part of the students.

At MSU, a guest speaker was brought in near the end of the semester. He presented a personal story of designing a product from very early concept stages to a saleable product and manufacturing processes to produce it, and from starting a small company with two other business partners to running a high-volume, automated production facility. Throughout, he emphasized how his IE education helped him in this endeavor. The guest speaker delivered a fairly standard lecture using an overhead projector and black-and-white transparencies for visual aids and a product sample. The course instructor left class feeling the lecture had been a bust; however, when the survey results were tallied, this class period received the highest average rating in both learning and engagement! Thus, it seems the well-designed and delivered lecture still has a place in engineering education. In addition, a topic that engages the students' minds, and maybe their dreams, can also hold their interest. Both instructors will use the feedback from the survey to modify future offerings in their respective courses.

In addition to asking students about their perception of various classroom activities, we also queried students about what kinds of homework they found most beneficial. Somewhat surprisingly, given the modern information age and student internet savvy, web research questions received the lowest marks. Redesign problems (i.e., "Here's a system—how would you improve it?"), interestingly enough, received the highest average rating. Conceptual questions, computational problems, and reflective questions scored in the middle.

**Qualitative Responses – What they really take from the course that matters**

In addition to rating class activities, students were queried using open-ended questions regarding various aspects and elements of the courses. Three questions in particular reveal that the students really take the right things from the course, from the instructors' perspectives. The questions and summary of responses for each follow:

*"If someone you meet on the street were to ask you, 'So, what's Industrial Engineering?' how would you answer?"*

- Nearly all answers mentioned improvement, efficiency, or productivity of processes or systems.
- Everyone answered, and seemed confident in their answer.
- Many mention examples, and many topics.
- None were limited to just one topic, such as time study.

*"True or False: Industrial Engineers only job opportunities are in manufacturing. Please explain."*

- All answered false.
- Most noted the field's broad applicability (e.g., "IE's are employed anywhere there are systems"), mentioning specific industries and examples.
- Many mentioned that IE's are needed everywhere improvements are needed, e.g., "Everyone needs IE's."

*"How has your perception of IE changed as a result of taking this course?"*

- Many said they feel they better understand the field and what an IE career entails.
- "I have a much better understanding of what IE really is. Coming in I only knew basics"
- "I have learned just how powerful it is, and that things are fairly limitless for an IE."
- "I came in knowing pretty much nothing about IE. I thought I liked it, now I know that I love IE."
- "IE is applied to a larger range of applications than I thought. More job opportunities and I know without a doubt that this is what I want to do."
- "I'm a lot more excited about IE now that I know what IE's do."
- "I have been opened to new possibilities and fields of study."

Students who stay in the major will learn the analytical techniques and theory they need to be skilled IE's in later courses. Thus, an extremely important outcome of introductory courses is that the students feel strongly that they have made the right choice. There is nothing greater than their being excited about their chosen field. They seem to be glad to be able to describe what IE is, proud of what they do, and like having a broad range of choices and skills that give them job opportunities in the future. We want to recruit students to IE, but only if the fit is good for each student. An equally good outcome is for a student to say at the end of the course, "I feel like I have a good grasp of what IE is all about, and I don't think it's for me."

**Concluding Remarks**

The experiences of these instructors concur with the survey results which indicate that, in short, hardware works. For students with an inclination toward IE, handling physical products and seeing how systems actually operate in real-time seems to engage the mind and reinforce the theory in ways more powerful than other modes of instruction. This seems to foster excitement among students about the possibilities an IE major holds. Hands-on experiences appear to be most effective when carefully designed to achieve specific learning outcomes, and when interwoven with lectures, discussions, and homework assignments that are designed to pull out and reinforce the basic concepts. Making activities fun or participatory, however, does not necessarily improve learning outcomes. At the same time, traditional lectures can be very effective. Finally, while these authors feel it would be desirable that students leave the course with some IE knowledge that they can put to use (e.g., ability to create process charts or do a simple economic analysis or calculate productivity), the most important outcome of an introductory course is to create excitement for the field. It seems that a course with a strong hands-on element and substantive learning does the job.

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