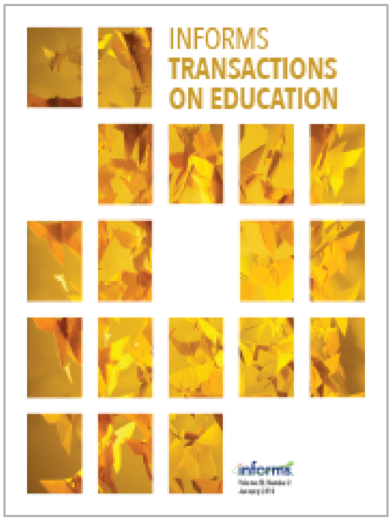

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Student Peer Evaluated Line Balancing Competition

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Abstract. The Student Peer Evaluated Line Balancing Competition is a 30-minute in-class problem-based learning experiential exercise that challenges student groups to design a feasible and efficient laptop computer assembly line. Each student group's proposed design is publicly peer-reviewed by the rest of the class, enabling students to evaluate various alternatives and realize the key requirements for optimally balancing an assembly line. Evidence of effectiveness is provided, including student survey results and a statistical analysis of exam question performance both before and after the exercise was incorporated into our business undergraduate operations management class. The survey revealed that 96% of students recommended continued usage and 92% believed the competition helped them to be able to determine a feasible solution for line balancing problems. Exam question performance analysis revealed that our initial instructions for the competition actually resulted in lower performance compared to traditional lecture. We subsequently improved the instructions and found that this change has resulted in similar exam question performance as traditional lecture. The result is an exercise that significantly improves student engagement while maintaining student performance previously achieved through traditional lecture.

Supplemental Material: Supplemental material is available at https://doi.org/10.1287/ited.2016.0164.

Keywords: classroom games • active learning • teaching production/operations management

1. Introduction and Innovation

1.1. Overview

Can students discover how to optimally balance an assembly line without any lecturing from their instructor? Is the resulting student learning equivalent to the historical lecture approach? This exercise uses student competition and public peer evaluation to enable student discovery of how to optimally balance an assembly line without any lecturing. The entire class becomes actively engaged as the students work in small groups to tackle the real-world-based problem.

After teaching assembly line balancing in the traditional "lecture followed by practice question" approach for years and getting the traditional results of an unengaged classroom, we hypothesized that with minor facilitation and a competitive environment, students could unearth the method for determining an optimal line balance themselves. We added a public peer evaluation where each group's proposed solution is reviewed by the entire class to determine a winner, which indirectly teases out how to optimally balance an assembly line. The competitive environment combined with the public peer evaluation incentivizes students to fully engage in the exercise. Figure 1 contrasts our student peer evaluated line balancing competition approach (A) with the historical lecture approach (B) for a 50-minute class session.

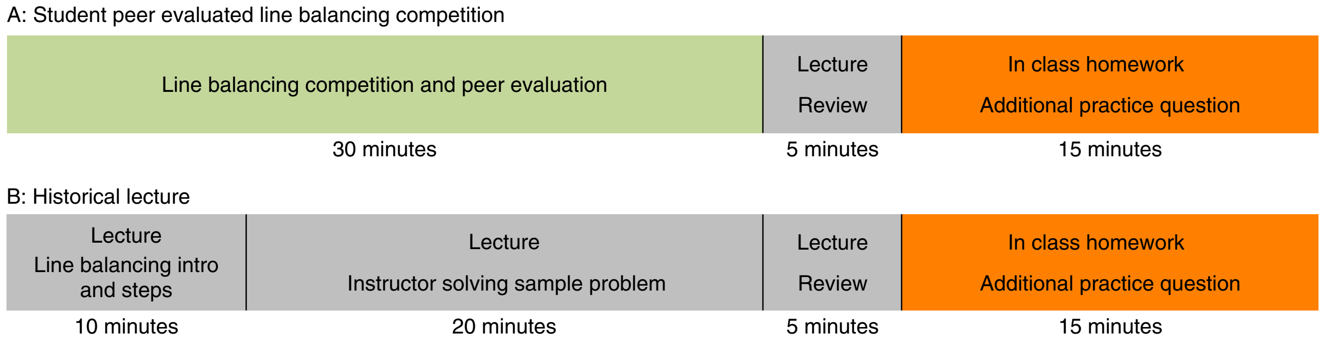
The exercise uses a problem-based learning (PBL) approach with students tackling an engaging real-world problem before lecture content is covered. For PBL to be highly effective, students need to self-reflect as well as critically appraise others' reasoning and conclusions. Our 30-minute in-class exercise incorporates this as students reflect when developing a solution in a small group and the public peer evaluation by the entire class provides the critical appraisal. The exercise is intended for an undergraduate introductory course of operations management or management science, though it could be used for graduate courses as well.

Our results show that this approach significantly increased student classroom engagement while also providing equivalent learning results to the historical lecture format.

1.2. Scenario Description

The competition challenges student groups to determine an assembly line design that could accurately assemble 100 laptops in an eight hour shift, while minimizing operating costs (employees). There are eight tasks in the assembly process and their durations range

Figure 1. Comparison of Approaches for 50-Minute Class Session



from one to four minutes. We have incorporated a real-world scenario where an electronics firm is hoping to improve their triple bottom line (economic, environmental, social) performance and we have found it connects to our current generation of students, increasing their motivation for the competition. Although we use the scenario described below, instructors could tailor the business scenario to their local business environment and current issues they deem relevant and interesting for their students.

In our scenario, an electronics firm is considering "on-shoring" a local assembly line for laptops rather than continuing their current approach of using a foreign supplier whose labor practices have been questioned in recent media reports. Assembling the laptops locally would improve their social responsibility by refusing to do business with the questionable foreign supplier while also providing local employment. In addition, producing their product in close proximity to their consumer demand would help reduce transportation related pollution, improving the organization's environmental performance. The organization hopes that an efficient local assembly line design, when combined with reduced transportation costs and potential increased sales from consumers who recognize their environmental and social performance, will also lead to improved financial performance.

2. Literature Review

2.1. Problem-Based Learning

In postsecondary education, PBL is an accepted instructional strategy that has been used as the basis for courses (Hendry et al. 1999, Desai et al. 2014, Nargundkar et al. 2014), programs (Stinson and Milter 1996), and entire schools (Barrows and Tamblyn 1980). PBL is based upon the philosophy of constructivism, which purports that new knowledge is constructed through interactions with the world and activation of students' prior knowledge. It is most often executed in a collaborative learning environment, implying that knowledge is coconstructed among peers based upon shared understandings and interpretations.

Our students have had limited formal exposure to problem-based learning, but for many years, we have used "Kristen's Cookie Co" (Bohn 1986), as the opening lecture to our introductory operations management course and asked students to work in groups to "discover" their own method to calculate capacity, throughput time, cycle times, and utilization. Students frequently mention the exercise as a highlight of the course and appreciate the opportunity it provides to meet and work with fellow classmates in the first lecture. Interestingly, Kirschener et al. (2006) found that discovery, problem-based, experiential, and inquiry-based learning are not only less efficient but also less effective than more traditional teacher-centric approaches. Carriger (2015) suggests that while PBL may result in improved problem-solving skills and a learning environment that students may prefer, it does not result in superior knowledge acquisition. While this contrarian view is not well supported empirically, it does raise concerns about the level of guidance provided to students during a PBL exercise. As the students in our classes have limited previous exposure to problem-based learning, we have chosen to provide structured guidance for this activity. In fact, based upon summative assessment results after the first iteration of this competition, we further increased the guidance students received during subsequent use of this PBL exercise by clarifying the instructions provided at the start.

Other educators with students new to this learning process have also found that learner characteristics, specifically their development of self-directed, self-regulated learning skills, impacted their success and disposition toward PBL (Kumar and Kogut 2006); however, students were able to adapt to the system after a sustained period of exposure and practice. Stinson and Milter (1996, p. 41) also encountered similar issues with student transition but found that with appropriate facilitating, "all but the most regimented of students make the transition and eventually thrive in the new learning environment." The skills of the instructor as facilitator/coach are critical to PBL and are well documented (Hendry et al. 1999, Kumar and Kogut

2006, Desai et al. 2014). To give students a feeling of greater ease and comfort when introduced to PBL, Nargundkar et al. (2014) created a reversed textbook that introduced the problems and guided student inquiry and problem analysis prior to the introduction of theory. The authors found that through the use of this reversed textbook, students' critical thinking scores increased significantly.

2.2. Competitions and Games

In-class competitions for business students have been used to overcome apathy toward complex lecture content such as inventory management (Robb et al. 2010) and forecasting (Gavirneni 2008). Snider and Eliasson (2013) describe a prelecture forecasting game where business students were able to compete effectively despite not yet having covered the topic, while also increasing their interest in learning the techniques covered in the subsequent lecture. There are several other experiential games to illustrate various aspects of line balancing, lean manufacturing, and capacity planning. Fish (2005) and Wright and Ammar (2014) use children's DUPLO and LEGO blocks to simulate assembly lines. Billington (2004) uses a simple paper airplane to explore the manufacturing process. In all three games, activity times are variable, which may lead students to focus on the individual's ability to complete the task quickly rather than on the design of the process. The games created by Fish (2005) and Billington (2004) allow students to derive an operational definition of throughput and cycle times while also exploring concepts such as bottleneck, quality, push systems, and inventory. Wright's (2014) game is explained briefly in his online blog and appears to have students focus on the judicious allocation of tasks to workstations in order to meet production requirements. Klotz (2011) has created a bicycle assembly line game that has predetermined task times and the requirement that each student group pick one of seven assembly line designs that they will "implement" to determine its ability to maximize revenue as compared to the other teams.

2.3. Student Peer Evaluated Line Balancing Competition as Experiential Learning

Experiential Learning has been defined by Itin (1999) as "the change in an individual that results from reflection on a direct experience and results in new abstractions and applications" (p. 92), while Kolb (1984) defined it as a "process whereby knowledge is created through the transformation of experience" (p. 38). Although there are many reasons why a professor might prefer to stick with a pure lecture format (Smith and Van Doren 2004), the benefits of experiential learning techniques within business education are extensively published (Daly 2001, Cotner et al. 2004, Paul and Mukhopadhyay 2004, Williams and Chinn 2009, Webb et al. 2014). McCarthy and McCarthy (2006) contend that although the case study teaching approach is very popular in business education, experiential learning techniques provide superior learning, and the authors even go so far as to advocate that experiential learning programs be mandatory in the major areas of a business curriculum. From the student perspective, Piercy et al. (2012) suggest experiential learning is valuable to support and encourage student learning, especially by those students with limited business experience. According to Snider and Balakrishnan's (2013) summary of experiential learning types, our exercise would be classified as a *semistructured* experiential learning activity because it is a short classroom activity where students learn from direct experience.

Our exercise differs from those included in the literature review, in numerous ways:

- It can be played immediately at the start of class before any lecture content on line balancing is delivered.
- Each group's proposal is shared with the entire class and jointly evaluated (public peer evaluation).
- Student groups are responsible for determining the number of workstations and also allocating tasks.
- It is very easy to administer in class as it does not require extensive setup or supplies since it does not physically simulate a manufacturing environment.
- Our scenario is based on a real-world situation that integrates triple bottom line (economic, environmental, social) considerations.

3. Evidence of Effectiveness

The line balancing competition has been conducted in our introductory operations management class for over three years and has become an integral component of the course. To evaluate the effectiveness of the exercise, we surveyed students immediately after the competition (Figure 2 provides the survey questions). Recognizing that self-assessment of knowledge may be biased, as described in Sitzmann et al. (2010), we also compared precompetition (traditional lecture format) and postcompetition student performance on the same exam question as a knowledge test. To isolate the potential influence of varying instructors, the following analysis of survey results and precompetition and postcompetition results were exclusive to a single instructor's classes. As described earlier, we improved our original instructions based on initial student feedback. These iterations have enabled us to compare the results based on the same instructor employing three different methods to teach assembling line balancing: (i) traditional lecture, (ii) PBL with minimal instruction, and (iii) PBL with enhanced instructions.

Figure 2. Student Survey Questions

1. Evaluating what the other groups proposed helped me learn how to determine a feasible soultion for line balancing problems. (*please circle your answer*)

Strongly disagree			Neutral			Strongly agree
−3	−2	−1	0	+1	+2	+3

2. After playing this game, I am confident that I can determine a feasible solution for an assembly line balancing problem. (*please circle your answer*)

Strongly disagree			Neutral			Strongly agree
−3	−2	−1	0	+1	+2	+3

3. I would have preferred more traditional lecture form of instruction on line balancing rather than the competition (*please circle your answer*)

Strongly disagree			Neutral			Strongly agree
−3	−2	−1	0	+1	+2	+3

4. Should we keep using the competition in the course? (*please circle your answer*)

Yes *No*

5. What is your overall satisfaction rating for the competition (*out of* 10)?

/10

6. Do you have any suggestions for improving the competition?

____

____

3.1. Survey Results

An anonymous survey of students who had just finished the competition with the initial instructions ($n = 189$, from five sections) yielded very positive results. Based on a yes/no question, 96% of the respondents recommended the continued usage of the competition to teach line balancing in the course. Further questions using a seven point (−3 to +3) Likert scale measured student perceptions of the learning experience and its efficacy. As detailed in Table 1, 92% of the survey respondents indicated that the competition helped them to learn line balancing concepts and steps and the mean score was +2.14. Interestingly, although 96% were confident in their understanding of line balancing after the competition, and the mean score was +2.28, 13% of the respondents still indicated that they would prefer to learn the concept in a standard lecture format. Question 3 was worded inversely to improve the reliability of the results. Seventy-five percent of students indicated they would prefer the competition over the lecture format while 12% of students were indifferent regarding their preferred instructional format. The mean score for preferring lecture was −1.43. Question 5 (overall satisfaction rating out of 10) produced a mean of 8.97 with 167 of 189 students (88%) rating the competition an 8 out of 10 or higher.

Student written comments reveal a strong preference by many students for interactive activities over traditional lecture formats:

> Hands on learning > lecture any day.
>
> Practice is the best way to solidify learning of the process.
>
> Good way to learn this topic. Better than a traditional lecture.
>
> Excellent game; good practice for exam.
>
> Great way to get students involved. The more you can move lectures away from the traditional form and get students thinking helps get us engaged and learn more by doing.
>
> Loved how there was a chocolate prize.

Table 1. Student Survey Results (Questions Provided in Figure 2)

	−3	−2	−1	0	+1	+2	+3	Total	*Mean*	% − (%)	% 0 (%)	% + (%)
Q1 *"Help Learn"*	1	3	4	7	18	69	87	189	**+2.14**	*4.2*	*3.7*	***92.1***
Q2 *"Confident"*	0	1	1	6	27	55	99	189	**+2.28**	*1.1*	*3.2*	***95.8***
Q3 *"Prefer Lecture"*	66	45	31	22	8	11	6	189	**−1.43**	***75.1***	*11.6*	*13.2*

Table 2. Student Exam Question Scores

Method	Term	Score 0/3	1/3	2/3	3/3	Total
Traditional lecture	Winter and Spring 2012	6	17	60	121	204
		2.9%	*8.3%*	*29.4%*	*59.3%*	*100.0%*
Game with initial instructions	Spring and Fall 2013, Winter 2014	11	33	67	94	205
		5.4%	*16.1%*	*32.7%*	*45.9%*	*100.0%*
Game with improved instructions	Spring and Fall 2014	11	19	65	162	257
		4.3%	7.4%	25.3%	63.0%	100.0%

The student comments also revealed some students felt some discomfort because of uncertainty resulting from our limited initial instructions:

> Explain cycle time a little more before game starts.
>
> More advice and hints before starting . . . once I had some guidance from my group mates, it made more sense.
>
> Maybe provide a bit more explanation on how to setup stations beforehand.

On the other hand, a number of students suggested making the activity more difficult to enhance their learning:

> Make it harder so there are not 2 winners. Otherwise great!
>
> Increase challenge, increase reward.
>
> Make it a little harder.
>
> Do a more complex example.

3.2. Exam Question Performance Results

The exam question that was used for this analysis is a short answer question that asks students to evaluate a proposed solution for a line balancing problem. The question is scored out of three marks: one for identifying that the proposed solution does not adhere to the required precedence steps, one mark for calculating the required cycle time, and one mark for identifying that the proposed solution would result in one workstation exceeding the required takt time. A total of 666 examination results were analyzed (204 students who were taught using standard lecture format, 205 who participated in the line balancing competition with the first set of instructions, and 257 who played with the improved instructions). A summary of the student scores is provided in Table 2. The results of a one-way ANOVA to determine the effect of teaching method and instruction type on examination scores are shown in Table 3. There was a significant effect of the teaching method on examination scores at the $p < 0.001$ level $F(2, 663) = 7.72$, $p = 0.000$. As detailed in Table 4, post-hoc comparisons using the Tukey HSD (honest significant difference) test indicate that the mean score for the traditional lecture method ($M = 2.45$, $SD = 0.77$) was significantly different from the mean score of students taught with the first set of instructions ($M = 2.19$, $SD = 0.90$) but was not significantly different from the mean score of students taught using the competition with improved instructions ($M = 2.48$, $SD = 0.81$). The mean score of students taught using the competition with initial instructions also differed significantly from the mean score of students taught with improved instructions. While the competition initially produced inferior learning results, improving the instructions led to student performance improving to the same level as the traditional lecture format. The end result is an exercise that significantly increases student classroom engagement while continuing to deliver similar learning results as a traditional lecture format.

Table 3. Anova of Exam Question Scores

	Sum of squares	df	Mean square	F	Sig.
Between groups	10.527	2	5.264	7.719	0.000
Within groups	452.121	663	0.682		
Total	462.649	665			

4. Summary

This 30 minute PBL experiential competition has proven to be a fun and engaging way to start the assembly line balancing topic in an undergraduate management science/operations management course. Very little preparation is required before class by the instructor and it is flexible for varying class sizes, with 10 being the ideal number of groups (four–six students per group works well). The exercise could be modified for larger classes by employing a real-time classroom polling system. Our experience has shown that through the use of this guided PBL exercise, summative assessment scores are maintained, while students' self-reported engagement is increased significantly. For those instructors developing these types of exercises, our results suggest caution as well. While the majority of students enjoy these types of in-class activities, problem-based learning is intended to teach specific concepts and skills. Our initial instructions did not result in improved or even similar evidence of learning as indicated by the test scores, necessitating a revision

Table 4. Tukey HSD Post-Hoc Test Results

Method	Mean difference $(I - J)$	Std. error	Sig.	95% confidence interval	
				Lower bound	Upper bound
Traditional lecture					
With initial instructions	0.2607*	0.0817	0.004	0.069	0.453
With improved instructions	−0.0198	0.0774	0.964	−0.202	0.162
Competition with initial instructions					
Traditional lecture	−0.2607*	0.0817	0.004	−0.453	−0.069
With improved instructions	−0.2806*	0.0773	0.001	−0.462	−0.099
Competition with improved instructions					
Traditional lecture	0.0198	0.0774	0.964	−0.162	0.202
Game with initial instructions	0.2806*	0.0773	0.001	0.099	0.462

*The mean difference is significant at the 0.05 level.

of the instructions. Exercise creators must be aware of the need to assess effectiveness and revise exercises in order to achieve the desired combination of engagement and learning. With this proven successful approach to instruct assembly line balancing, perhaps the combination of student competition with public peer evaluation of proposed solutions could be used to teach other operations concepts.

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