2018 ASEE Annual Conference & Exposition
June 24-27, 2018
Salt Palace Convention Center
Salt Lake City, UT

Paper ID #23992

Transitioning a Manufacturing Systems Engineering Course to Student-Centered Learning

Dr. Jason M. Weaver, Brigham Young University

Dr. Weaver is an Assistant Professor in Manufacturing Engineering Technology at Brigham Young University. He has a PhD in Mechanical Engineering from The University of Texas at Austin. Jason's areas of expertise include additive manufacturing, data analysis, manufacturing system design, and product design.

©American Society for Engineering Education, 2018

Transitioning a Manufacturing Systems Engineering Course to Student-Centered Learning

Jason M. Weaver
Brigham Young University

Abstract

This evidence-based paper describes the transition of a senior-level manufacturing engineering course from a traditional lecture-focused curriculum to a more engaging curriculum based on the research in student-centered learning. Many college courses have a familiar format: students listen to lectures, read textbooks, complete assignments, and demonstrate their learning through exams. Often, the instructor will structure the course for convenience, perhaps creating highly structured PowerPoint presentations and using standardized multiple choice exams to easily grade performance. Students, on the other hand, then structure their learning practices to match—trying to determine exactly how much to come to class, read, and memorize, with the end goal of regurgitating information on the exam and getting a satisfactory grade in the course. These practices are not conducive to long-term retention and application by the students, nor to accurate assessment or facilitation of learning by the instructor. But unless both the instructor and the students in a course understand and are amenable to alternative techniques, the format is unlikely to change.

There has been extensive research on techniques aimed to increase student engagement in the classroom, such as "flipping the classroom" and identifying and overcoming the "illusion of learning." This paper describes the efforts of the author over three semesters to incorporate these tools into a senior-level course on manufacturing system design and lean manufacturing to help facilitate better learning and assess proficiency more effectively. Several techniques are used, including suggestions from the recent book Make It Stick by Brown, Roediger, and McDaniel. Student feedback and instructor observations are discussed, and future recommendations for the course are given.

Keywords

student-centered learning, illusion of learning, flipped classroom

Introduction

Many college courses have a familiar format: students listen to lectures, read textbooks, complete assignments, and demonstrate their learning through exams. Often, the instructor will structure the course for convenience, perhaps creating highly structured PowerPoint presentations and using standardized multiple choice exams to easily grade performance. Students, on the other hand, then structure their learning practices to match—trying to determine exactly how much to come to class, read, and memorize, with the end goal of regurgitating information on the exam and getting a satisfactory grade in the course.

These practices are not conducive to long-term retention and application by the students, nor to accurate assessment or facilitation of learning by the instructor[1]. Yet, changes to the curriculum to more student-led learning is often met with reservation and frustration from the students, instructors, or both[2,3]. Unless both the instructor and the students in a course understand and are amenable to alternative techniques, the format is unlikely to change.

One frequent problem in such classes is referred to as the illusion of learning. A student may read the textbook and listen to the professor's lecture, with a confidence that he or she understands the material. When asked to solve problems that stray away from the specific formats covered, however, the student discovers a lack of comprehension of the underlying principles. Too often, this happens at the moment when stakes are highest, during the midterm or final exam. The idea of the illusion of learning (alternatively "the illusion of knowing" or "the illusion of competence") has been recognized for many years[4,5]. The book *Make It Stick: The Science of Successful Learning*, by Brown, Roediger, and McDaniel[6], has recently made this idea popular as a guide in improving both teaching and learning practices. There are many tactics for shattering this illusion and enabling more permanent learning, many of which can be summed up by the three "big ideas" put forth by *Make It Stick*:

1. Learning works by getting it out, not getting it in.
2. Difficulty is desirable.
3. A growth mindset motivates.

In this paper, an engineering course is examined for symptoms of illusions of learning, and improvements to the curriculum and teaching methods are incorporated and reviewed. The course of interest is MFG 480: Manufacturing Process Planning and System Design, a 3-credit engineering course for seniors that has been taught for decades at Brigham Young University. Grades and student feedback (through online reviews, in class, and in offline discussions) are the primary means for judging shortcomings and improvements.

Common Illusions

Make It Stick is based on ongoing research of two of its authors[7-12], and many others in the fields of psychology and education[13-15]. A main focus of this research is the phenomenon where one tries to learn, has the illusion that they have learned it, and then finds out that their mastery is much less than assumed. Four common types of these illusions are described that can lead to unproductive learning practices[16]:

Illusion 1: Repeated exposure burns new knowledge into memory.
This illusion forms the foundation for many practices exhibited by both teachers and students. Teachers often format their curricula to focus on one subject at a time. They give their students a text or lecture slides, with the understanding that future homework and tests will be based on the information included. A single subject is repeatedly discussed in a variety of formats and examples, until the students appear to have mastered it. Homework assignments drill the subject repeatedly, with only small variations. There is some near-term assessment, like a quiz or test, and the class moves on to the next subject. Likewise, the students read and reread the same text, attempting to memorize as much as possible, and learn to complete the assignments by learning

the patterns and templates for the specific problems given. When studying for an exam or quiz, they will yet again reread the texts or lecture slides, focusing on placing the information in short-term memory for immediate recall. The result of these practices is often that the student goes into an exam feeling confident based on their memorization of the source material, only to find that they do not truly understand the concepts and cannot apply them to situations that differ significantly from the problem formats presented in class. Additionally, they often find that even this surface-level comprehension is fleeting – by the time they come back to the material for a final exam or in a subsequent class, their short-term memory has dumped all of their hard work, and they are unable to remember much about what they had learned.

Illusion 2: Single-focus, rapid-fire practice hones new skills
Similarly, course curricula are often formatted towards "massed practice" – skills and concepts are practiced repeatedly, with little variation, until mastered. Then a new skill or a variation on the first skill is introduced, and this second area is practiced until mastery is apparent. When practicing something over and over, students and teachers see rapid improvements in ability. But discouragingly, the ability somehow is lost when the skill is needed later. Despite the rapid growth often apparent during massed practice, this growth is often short-lived. In addition, the skills gained are often limited to the precise situation that has been practiced, without the ability to transfer the skills to new and different applications.

Illusion 3: If learning feels easy, it is a sign you are mastering it
If new content is presented in a way that is very familiar and clear, the learner will often feel a sense of "I already knew that" or "That's simple." The student is less likely to devote much effort to internalizing the concept, because they feel that the knowledge is already present. This can be a problem particularly when the instructor takes pains to simplify and streamline the curriculum – always using the same words to describe something, following the same structure of topics as in the textbook, basing homework problems and test questions strictly off of the information written on lecture slides. The student sees the same information presented the same way and feels a sense of familiarity that is mistaken for mastery, a notion that quickly evaporates when the student is asked to teach someone else or apply the content to a very different type of problem.

Illusion 4: We are good judges of what we know and don't know
There is a desire to make courses more student-directed in formatting what to cover and how much time to devote to each topic. Likewise, student learning practices are usually based on their own self-evaluation on how much they understand and how prepared they feel. But self-evaluation is not a trustworthy metric for how well we have mastered a concept. The phrase "I thought I understood it pretty well going in to the exam, but…" is well known in any professor's office. Learners in general will often take unconscious shortcuts when studying; for example, they may read a question, think "Well, I know the answer to that," and move on without actually going through the thought process to conceptualize how to state the answer. Then on the exam, they have the unpleasant experience of "knowing that they know it," but being unable to get it onto paper. Often, those with the lowest levels of mastery are the ones most likely to think they understand, leading to frustration and anger when they are surprised by their assessments.

Tools for Overcoming Illusions

To overcome these illusions, several changes must be made. Many of these changes can be enacted by the learner, but maximum benefit will occur when both the teacher and the students understand and agree on how to use the appropriate tools. As mentioned above, *Make It Stick* offers three "big ideas" that can help orient this change process.

Big Idea 1: Learning works by getting it out, not getting it in.
The first concept that must be internalized is the recognition that retrieval and practice, not study and memorization, are the most effective methods for internalizing, understanding and mastering an idea or skill. Common perception is often that we learn through reading, watching, or listening, and we demonstrate our learning through assessment and testing. However, after the initial exposure to knowledge, there is only limited gains in repeated readings and rote memorization. Instead, the learning occurs as we try (and usually fail, at least initially) to generate or retrieve the knowledge from our memory. For example, reviewing flash cards by reading them is far less effective than being quizzed on them by someone else. The earlier in the process the student can be led to "get it out," through quizzes, peer teaching, in-class activities, and experiential learning, the better. This also has the added benefit of still assessing the student's knowledge early in the learning process, long before any "high-stakes" exams.

Big Idea 2: Difficulty is desirable.
The second concept is that a certain level of controlled difficulty can aid the learning process. Often, teachers will try to make things as easy as possible for students – aligning lecture slides, textbook, and homework to follow similar format and order, avoiding vague or open-ended problems or test questions, and testing primarily on recently learned information. However, making the learning process "easy" actually works against long term retention[17]. For example, if the lecture slides, the textbook, and the instructor's verbal discussion all say the same thing in the same way, the student is just rereading the same information three times, which (per Big Idea 1 above) is not very effective. If instead, each of these teaching methods uses different words, different content order, even different ways of looking at a problem, now the student is learning three different sets of information and, most importantly, generating their own ideas about how the three sets relate to each other. Spacing practice out, such as cumulative testing and homework where different problems are intermingled and repeatedly visited throughout the class, likewise encourage repeated regeneration and reevaluation of knowledge, in contrast to the practice of doing the same problem over and over again, memorizing the template, using the template to work an exam problem, and then not revisiting the concept for the rest of the class.

Big Idea 3: A growth mindset motivates.
The third big idea is that how the student and the teacher view the student's learning potential has a substantial effect on the student's learning success. *Make It Stick* retells a study by Blackwell, et. al[15], where four years' worth of junior high students were tracked through two consecutive math classes. At the beginning of the first math class, each student took a workshop on the brain and effective study skills. Half of the students were also taught about the stages of memory (the control group), while the other half were taught that the brain grows and changes with learning, and that intelligence is not fixed, but can increase in anyone with hard work and effective practices. In all four sets of students, the grades of the control group remained essentially constant over the two years of math, while the "growth mindset" group improved

their grades consistently through each semester. By viewing their learning ability as in their control, not something thrust on them at birth, they were both willing and able to work hard, overcome failure, and seek out growth opportunities.

Similarly, Cutts, et. al[18], conducted a study in their introductory programming course at the University of Glasgow. Students in the course received one or more of three tools designed to be "mindset interventions," i.e., to help students shift from a fixed to a growth mindset. The first tool was a series of workshops taught by the tutors, guiding the students in reflecting on their experiences so far in the course and how they fit into a fixed or growth mindset. The second tool was a handout listing resources, tools, and tips successful computing students frequently use to get unstuck. This handout would be referenced by the tutors whenever they helped a student, guiding them towards a recognition that they have the resources available to figure out solutions and fix problems on their own. The third tool was incorporating notes on the grading rubrics given as feedback encouraging the students and telling them that though learning the material is difficult, almost all students that devote the time and effort needed will be successful. Cutts, et. al, determined that the tools were helpful by themselves in improving a growth mindset, but were not individually successful in improving grades. However, using both the training sessions and rubric feedback together did lead to significant increases in exam scores, especially later in the semester. Students seemed to benefit the most when they were both taught the theory behind fixed and growth mindset and consistently reminded and encouraged throughout the course.

To help support these three big ideas, the book also shares several tips for teachers:

Explain to students how learning works
Students are naturally concerned with grades; thus many of their learning practices develop as an effort to maximize their grades, not learning. They also dislike frustration and unnecessary difficulty, which can lead to resentment if something seems difficult without reason. Because of this, the teacher can help students understand how learning works and point to specific ways the class structure and their study habits can help the learning process. For example, the practice of "flipping the classroom," where students go learn on their own and then meet together with the teacher for additional discussion and activities, is an excellent way to encourage active generation and retrieval of ideas rather than passive listening and absorption. Explaining this to students will help them avoid wondering "Why am I asked to do this? We haven't even talked about it in class?"

Teach students how to study
Study habits such as repeated rereading, cramming, and massed practice are common, but relatively ineffective. By teaching students the benefit of spaced practice and retrieval and crafting the curriculum to encourage these practices, teachers can guide students to habits that support long-term retention and internalization.

Create desirable difficulties in the classroom
No student likes a curriculum that is needlessly disorienting or confusing, but introducing deliberate and controllable difficulties into the curriculum will help support more permanent retention and understanding. Learning works best as a slow burn, with repeated cycles of practice, partial forgetting, and retrieval. Frequent closed-book quizzes and activities that require

synthesis and elaboration of previously learned concepts help students practice active retrieval of the information over a long period of time.

Be transparent
Through all of this, be up front with the students about why the course is structured how it is. Many of these tools can seem counterintuitive, but will enable deeper, more permanent, and more internalized learning.

Many of these tools have been consciously applied to an undergraduate engineering course taught by the author. Below, the format of the class is described, along with some feedback from the students and the author's observations. Changes to the curriculum rooted in the tools described above are listed, and their initial success is considered.

Case Study: Implementing Changes in an Existing Course on Manufacturing System Design Over Three Semesters

MFG 480: Manufacturing Process Planning and System Design is a senior-level engineering class that has been taught for decades by several faculty members. The class is required for the Manufacturing Engineering Technology (MET) program. Prerequisites include introductory statistics and a course on quality improvement. It is typically taught once per year as a full-semester class with 30 to 70 students and once as a spring term accelerated class with five to fifteen students, with almost all the students coming from the MET program. Average grades in similar upper-level courses in the program are typically around 3.1 out of 4.0.

First Offering (Fall Semester 2016, 38 students)

The course's format at the beginning of this study can be summarized as the following:

- Lectures by the professor, supported by PowerPoint slides and occasional videos
- Few to no in-class activities
- Daily homework covering the most recent lecture, self-graded in the next class
- Lab assignments formatted similarly to the homework problems, but more in depth
- Two midterm exams and one final exam (in class, T/F, multiple choice, short answer)
- For convenience, all lecture slides and homework assignments are available online during the entire semester

Students were allowed to work on homework and lab assignments together, but would each turn in their own work.

The lecture topics were arranged in the following order:

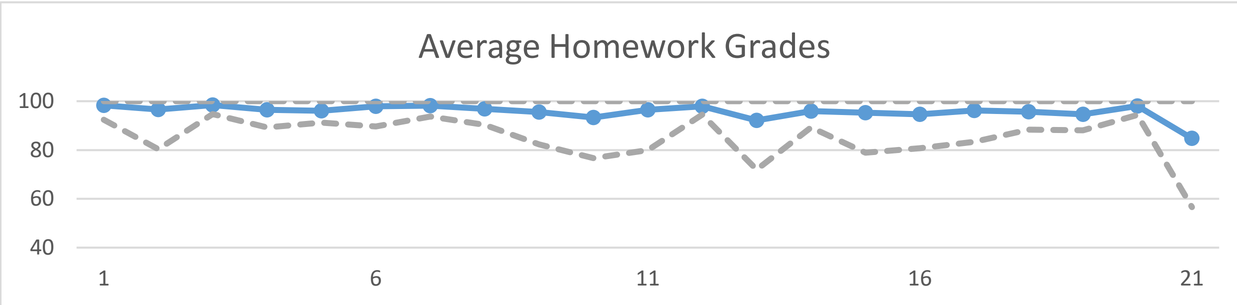
Table 1. MFG 480 Lecture Topics

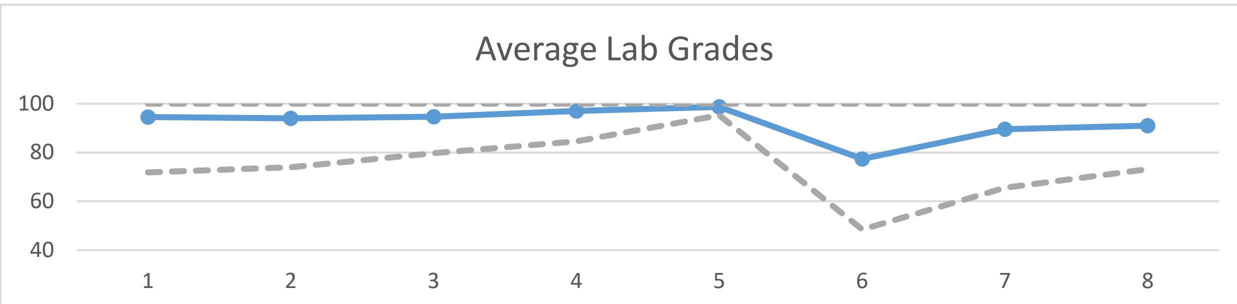
1. Introduction	2. Mfg. Engineering	3. Productivity
4. Mfg. Systems	5. System Types	6. Material Handling
7. Storage Systems	8. Information Sys.	9. Lean Mfg.
10. Theory of Constraints	11. Process Planning	12. Make/Buy & DFM
13. Process Sequencing	14. Equipment Selection	15. Plant Layout
16. Cellular Mfg.	17. Ergonomics	18. Inventory Control
19. Procurement	20. Project Management	21. Process Improvement

Before teaching the course for the first time, the author observed the previous instructor and team-taught several class periods. During the author's first time teaching the course (Fall Semester 2016), an effort was made to preserve the structure, content, and teaching style as much as possible. Towards the end of the course, the author gave an extra credit opportunity if students would come give feedback on the course. At the end of the course, students were also encouraged to give anonymous feedback through the university. Some of the comments received include:

- "The course was really easy with easily understood concepts, but the test had a lot of true false that were difficult. It seemed like the tests were designed to trick not test."
- "The course seems to be more of a survey of many concepts and ideas as opposed to a set of connected concepts that build on one another. This is okay, but I feel like some of the lectures could be reorganized for more flow."
- "I liked that Learning Suite (the online schedule and grading system) was very organized, and the course structure was the same all semester, but I didn't learn much…It would be more appropriate as a 400 level course to be less broad and delve more deeply into something."
- "Class involvement is at a minimal in lectures. More in-class activities would help spice up the slides"
- "Let us apply our own personal projects to what you teach in class. It would have been cool!"
- "Most of the homework in this class was just regurgitating information from the slides. I did almost all the homework during class, and I doubt I'll remember much of what I learned in this class after it's over."

The average grades throughout the course for homework, labs, and exams are shown below:





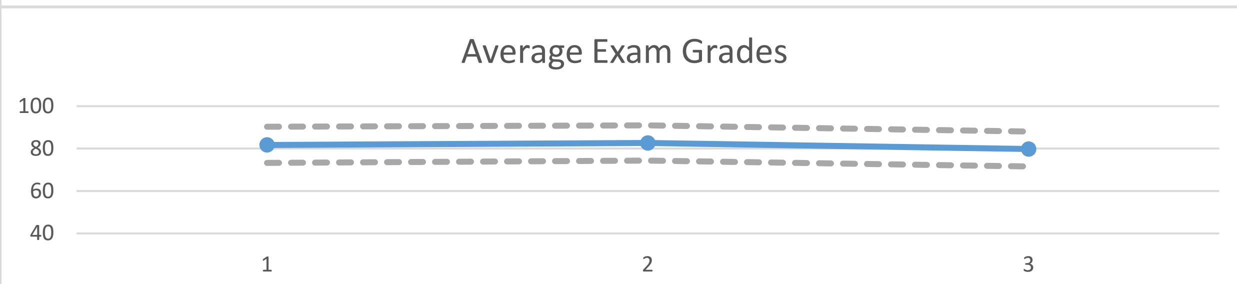


Figure 1. MFG 480 grades, Fall Semester 2016 (mean ± 1 standard deviation)

Grades in general for the course were typical for the department, with an average class GPA of 3.25 out of 4.0. Homework scores were consistently high among those that turned them in, as were lab scores (with the exception of Lab 6). However, exam grades were lower. This could be due only to a difference in grading practice between homework and exams, but the exams showed a large subgroup of the class that had significantly lower scores than the typical bell curve (See Figure 2). This seemed to indicate that, although the class was uniformly self-grading themselves well on the homeworks, a large subset was not retaining the concepts well enough to apply them in the exams.

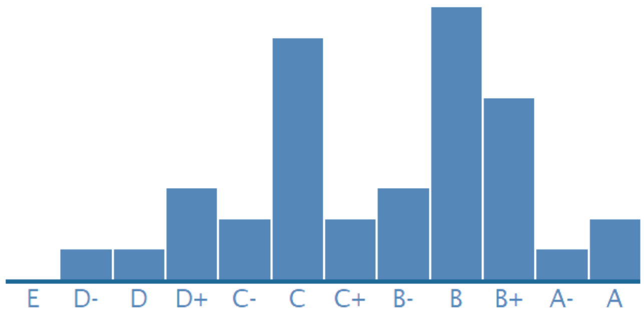


Figure 2. Final Exam grade distribution, Fall Semester 2016

Based on the students' grades and feedback, as well as the author's own observations, the following conclusions were made:

- Many of the students are listening to lectures and completing the homework while it is still fresh in their mind (or even during class) and then not attempting to retrieve the information again until the exam. Because the homework is based heavily on the lectures and is easy to complete, the students convince themselves that they have learned the material, but are unable to retrieve it later for the exam. Thus, the homework grades are consistently high, while the exam grades are significantly lower. Some students are unaware of this connection, and are surprised at their low scores on the exams, while many others recognize the connection and are asking for homework that is more challenging and better prepares them for the exams.

- Students are studying for the exams predominately by rereading the lecture slides and their completed homework and labs. They are seldom practicing active retrieval through quizzing each other or applying the concepts. Thus, again, they give themselves the illusion of understanding the concepts, but have not sufficiently practiced the skills.

- Because the class time is lecture-oriented, it is not engaging all the students. Considerable discussion between the instructor and the students does take place, but only a fraction of the class is actively answering questions, and the discussions typically do not deviate from the lecture topic or go very deep.

- Other than the homework and labs, the students have little opportunity to apply the skills taught in class. The students that are interested in the topics covered in the class would prefer to have more experience actually using the skills and concepts, particularly in real-world applications.

- The course syllabus covers a wide variety of topics. All of them are important and relate to the overall course description, but there is often little overlap between lectures, and it is difficult to spend enough time to go into detail on any of them.

Second Offering (Spring Term 2017, 5 students)

Following this analysis, the following changes were made to the course curriculum, in keeping with the big ideas and tips given in *Make It Stick*:

- At the beginning of the course, the concepts taught in *Make It Stick* would be explained to the students, and the underlying reasons for the curriculum structure would be discussed. The advantages of spaced practice, frequent retrieval, and desirable difficulties would be shared.

- To prevent the tendency to complete homework during the lecture, the homework would not be posted until several hours after class. This would ensure that the students would have at least a few hours between initial exposure and their first retrieval practice.

- Homework problems would be modified to rely less on regurgitating the lecture slides, and focus more on elaborating on concepts, applying them to new situations, and doing external research (for example, learning about a tool not discussed in class and comparing it to one that was discussed).

- Once a week, instead of a prepared lecture followed by homework, the class would be flipped: students would learn about a topic on their own, and then class time would be spent doing group activities together. The lab assignments would be rewritten to be "pre-labs" that would cover material not yet discussed, that lead directly into the in-class activities.

- On days where a traditional lecture is offered, at least one in-class activity would be included. This could be as simple as having a student come up and work through a problem with the other students' help, but would offer a chance for all students to become engaged and contribute to the discussion.

- To facilitate retrieval practice consistently throughout the course, an in-class quiz would be given once a week. These quizzes would be announced on the schedule, and could cover anything discussed so far in class. To encourage attendance, make-up quizzes would not be allowed, but the lowest one quiz grade would be dropped (to allow for unavoidable absences). These quizzes would focus on identifying problem areas early in the learning process, and revisiting these areas throughout the semester.

- Because of the extra class time used for quizzes, no in-class exams would be held. The quizzes would be the primary testing method for assessing the students' learning.

- In place of a comprehensive final exam, the students would complete a final project. This project would take several weeks and would apply the topics discussed in class to a real-world application. The project would be presented to the class in an oral presentation, and a written report would also be submitted, helping the student learn how to present their knowledge in a teaching atmosphere and in multiple formats.

- The content of the lectures would be rearranged to follow a cohesive theme of designing a lean factory. Some content would be dropped; other content would be presented to students offline as part of the pre-lab assignments. Lectures on the central topics, such as lean manufacturing, Theory of Constraints, discrete event simulation, ergonomics and motion studies, and cellular manufacturing, would be expanded, be more tightly interwoven into other lectures and activities, and would form the basis of the pre-labs and flipped classroom activities.

One example of these implementations is the treatment of lean thinking throughout the curriculum. In the original curriculum, the topic of lean manufacturing was first introduced during the ninth lecture, almost halfway through the course. This lecture was driven by a fairly long set of PowerPoint slides, covering a broad range of important topics (relationship to traditional manufacturing and Theory of Constraints, underlying philosophy, the five steps, the seven Muda wastes, tools such as value stream mapping, etc.). The end result was that students were introduced to an overabundance of ideas, without any additional application or in-depth discussion until later in the semester. Thus, although this lecture was one of the philosophical cores of the entire course, it was not immediately impactful.

Under the new curriculum, various facets of lean thinking were introduced beginning in the very first class period, where the main theme of productivity is developed, and the ideas of waste and non-value-added activities are explored. By the time the class period devoted to lean arrived (which was only moved up one day in the semester), most of the terms and ideas had already been lightly touched on. Then, instead of revisiting the same topics in an instructor-led lecture, the PowerPoint slides were given to the students ahead of class as part of a lab. In the lab, the students were to review the slides for any topics they were not already familiar with, and then watch several videos online about how lean was adopted by companies in varying industries. In class, time was devoted to an unhurried discussion of what the students learned from the videos, particularly looking for how the applications of lean in the different companies differed and what they had in common. The remainder of class was then spent on an activity where students formed a production line making and testing paper airplanes[19]. One group of students performed the simulation at the front of the class room, and then suggestions were taken from the remainder of the class on how to improve the process, using both common-sense and lean-oriented ideas. The students were able to immediately apply these improvements and see the effect it had on productivity and quality.

The class was taught a second time, with the changes above, during Spring Term 2017. Spring Term at BYU is a condensed schedule with smaller class sizes (five students in this instance), so the class experience is necessarily different and harder to directly compare. Feedback from the students, however, did indicate significant improvements in satisfaction, confidence in learned skills, and retention of concepts. The use of quizzes, in particular, was especially popular with the students, because the quizzes give them a low-stakes way to reevaluate their own understanding beyond their homework. The in-class activities have also had excellent feedback, as the students have a chance to apply their knowledge in open-ended process improvement scenarios, work together, and come up with their own solutions. Students found the final project to be useful for the class, but also confidence building – assuring them that they really could solve these types of problems in the real world – and professionally beneficial (many of their projects were for their jobs or internships).

Because of the small class size, formal student feedback at the end of the semester was limited. Comments included the following:

- “Great instructor and very willing to help.”
- “This course has been very informative and helpful in order to understand the needs of processes and production. Also Professor Weaver has done a great job with helping to understand concepts of the class.”
- “Great job working with a small class.”

The numeric student rating for the course from the students also rose from 4.0 to 4.6 (out of 5.0).

The average grades throughout the course for homework, labs, quizzes, and the final project are shown below:

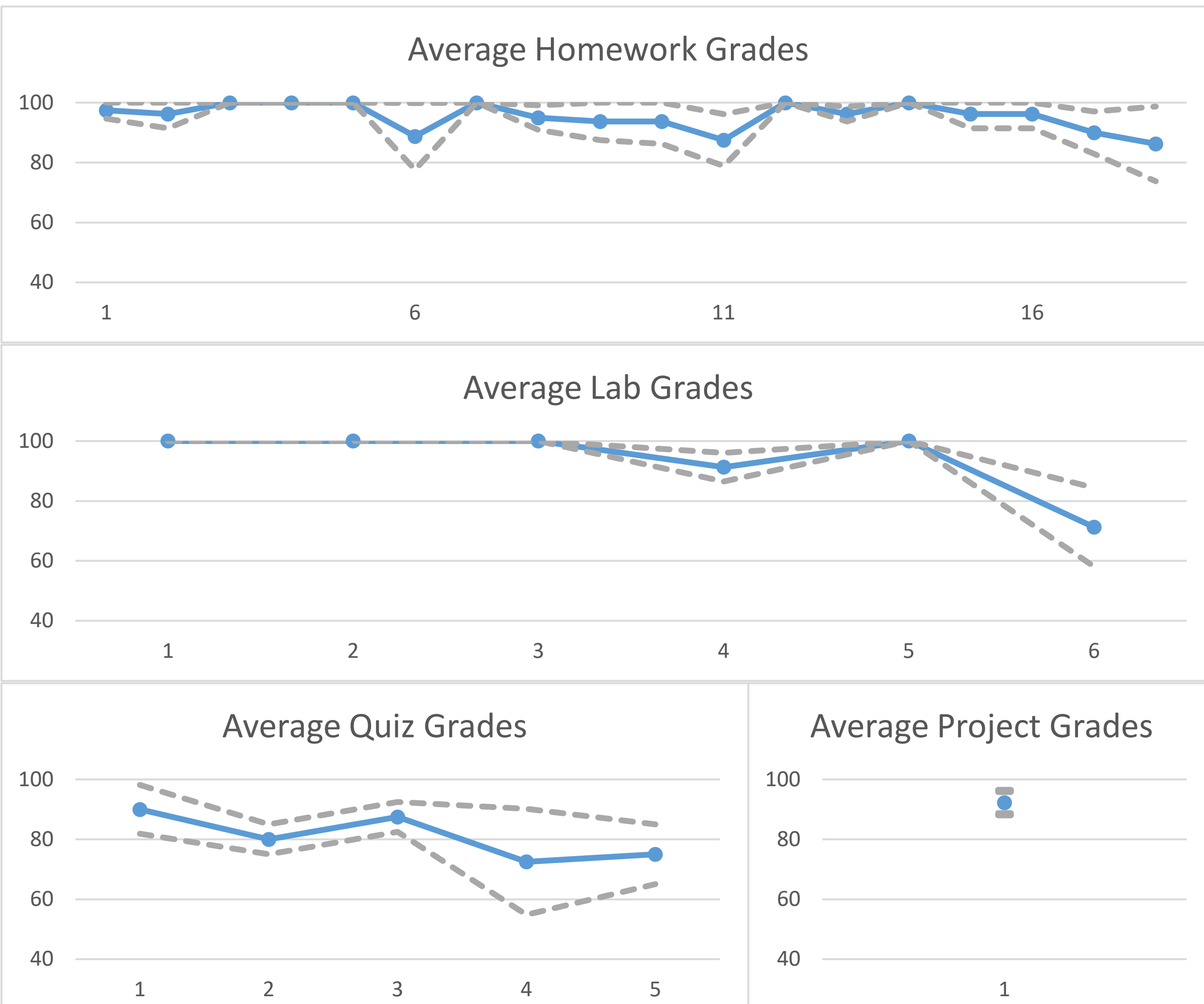


Figure 3. MFG 480 grades, Spring Term 2017 (mean ± 1 standard deviation)

Overall grades for this offering of the course were significantly higher than the previous semester, with an average class GPA of 3.8. Homework and lab grades were similar to the previous semester, with quiz grades lower, but not to the extent of the exams previously. Because the quiz questions were taken from the exams, the students were assessed on the same information, but the assessments occurred earlier, more frequently, and with lower stakes. In several instances where it was clear that students did not understand a concept, future quizzes and homework could be adjusted to allow additional practice and reassessment.

The labs included much the same content as before, but were offered in a different format. As described above, before completing the assignments as previously given, the students were also responsible for reading through the lecture slides that would normally be shared in class. Then in class, we would do open-ended group activities, including watching and analyzing videos of factories in action, conducting time motion or lean thinking exercises, or creating and optimizing activity diagrams for actual tasks the students did. These application-based exercises appeared to be much more effective than the lectures and homework used previously in guiding the students to a deep understanding and the self-confidence to correctly apply the concepts as needed.

The final project, which was much more enjoyable for both students and instructor than a final exam, proved to also be useful for the students, as each one was able to incorporate lean manufacturing concepts into their current job responsibilities. The presentations showed each student’s ability to not only answer questions about the material, but apply it to real life problems and communicate the results. Grades on the final projects were consistently high, ranging from B+ to A.

The changes implemented during Spring Term appear—from personal observation, student feedback, and overall grades—to be beneficial, though the difference in class size and schedule make it difficult to draw direct comparisons between semesters. Future offerings at the larger class size would make the effects of the changes more comparable. One observation that was made was that the limited number of quizzes given did not allow much opportunity for repeated retrieval and assessment of topics. Either reinstituting a comprehensive assessment of some sort at the end of the semester or increasing the length or frequency of the quizzes would be beneficial to support spaced retrieval and assessment. Finding additional lectures that would benefit from the “flipped classroom” model would also increase student engagement and allow additional time in class for group activities and discussions.

Third Offering (Winter Semester 2018, 64 students)

At the time this paper was submitted, the third offering of the course was still ongoing; thus, final grades and student evaluations were unavailable. Homework and lab grades (self-graded) remained high. The quiz scores through the first portion of the course are shown below. Note that, while the average grade is around 75-80, similar to the offering under the original curriculum, there is not a large secondary grouping of students that are struggling on quizzes.

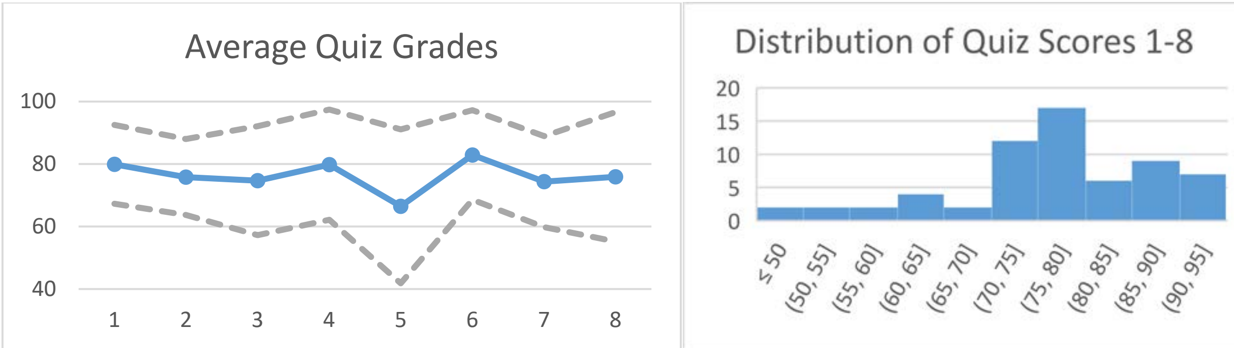


Figure 4. MFG 480 quiz grades, first half of Winter Semester 2018 (mean ± 1 standard deviation)

The following are some observations of the first offering in revised format to a large class size.

- During Spring Term, the accelerated schedule only allowed for 5 weekly quizzes. During the full-length Winter Semester, 12 quizzes are given, which works much better for sufficiently covering the topics throughout the semester and assessing for comprehension. Using weekly quizzes for assessment is more likely to be sufficient for the full-length semesters, but an alternate format, like daily quizzes, longer quizzes, or a comprehensive final, may still be needed for the accelerated term offerings.

- In a larger course with over 60 people, the flipped classroom days, in-class group activities, and group projects become even more beneficial. In the smaller Spring Term offering, it was possible to engage the entire class during lectures and discussions, but this is of course not feasible in the larger class size. The group activities and discussions allowed for more participation and discussion, particularly among students that are comfortable discussing topics with their friends but not in front of the class. In addition, the larger size also facilitated livelier discussions during the open-ended activities, with less lulls where no one is offering to contribute.

- The grades midway through the semester are similar to what was seen in Spring Term, and better than those seen under the original format, even not counting the final project. The main difference between the two later offerings and the original is that the exam/quiz scores now form

- The larger class size also appears to help facilitate larger, more meaningful final projects. During Spring Term, the students worked on individual projects, without much guidance or intervention from the instructor other than the written instructions. During Winter Semester, the students formed groups of 5-6 and worked through a project of their choice, but with more detailed guidelines on the process to follow throughout the semester, including several preliminary progress reports. The teams were able to contact companies in the area to work on real-world situations, measuring current productivity, making improvements, and quantifying their effects. Although the final reports had not been submitted at the time of this paper, through discussions with individual teams, it is apparent that with the additional guidance and the manpower available through multiple team members, their projects will be larger in scope and much more beneficial than the projects in the previous offering.

Conclusion

The concepts and tools presented in *Make It Stick* and the related research can form an excellent basis for modifying an existing curriculum. These changes can improve long-term internalization of concepts, enhance the ability to recall and apply the concepts in new situations, and build self-awareness in students of their own level of understanding. Many students do operate under an illusion of learning. They are often puzzled by how they can work so hard and still not gain lasting retention and understanding. Through conscious modification of curriculum and teacher behavior, and by helping the students understand how to change their own behavior, these illusions of learning can be shattered, and teacher and student can work together to build a strong foundation of learning.

The case study presented above demonstrates the success available through even a few simple and easy changes to how a course is presented. Through creating more frequent and lower-stakes opportunities for retrieval through quizzes instead of exams, the instructor was able to eliminate a sizeable subgroup that was performing well on homework, but struggling during assessment. Students were able to encounter desirable difficulties earlier and more frequently, resulting in more consistent step-by-step improvement. Through extensive opportunities to try out skills and principles in class, the students were more quickly able to try out new ideas, which allowed for more rapid and permanent internalization of not only what topics mean, but how and when to properly use them. Finally, incorporating a group final project provided an opportunity for students to apply their new knowledge in an open-ended environment, where they discovered for themselves that their skills and understanding could grow, and that they really did have the capacity to comprehend and apply the topics of the course to future problems.

References

1 Mohamed, Abdi-Rizak, “Effects of Active Learning Variants on Student Performance and Learning Perceptions,” International Journal of the Scholarship of Teaching and Learning, 2:2, 2008.

2 Felder, Ridhard M. and Rebecca Brent, “Navigating the Bumpy Road to Student-Centered Instruction,” College Teaching, Taylor & Francis, 44:2, Spring 1996, pg. 43-47.

3 Herreid, Clyde Freeman and Nancy A. Schiller, “Case Studies and the Flipped Classroom,” Journal of College Science Teaching, 42:5, 2013, pg. 62-66.

4 Begg, Ian, Susanna Duft Paul Lalonde, Richard Melnick, and Josephine Sanvito, “Memory Predictions are Based on Ease of Processing,” Journal of Memory and Language, Elsevier, 28:5, Oct. 1989, pg. 610-632.

5 King, Joseph F., Eugene B. Zechmeister, and John J. Shaughnessy, “Judgments of Knowing: The Influence of Retrieval Practice,” The American Journal of Psychology, University of Illinois Press, 93:2, Jun. 1980, pg. 329-343.

6 Brown, Peter C., Henry L. Roediger III, and Mark A. McDaniel, Make It Stick: The Science of Successful Learning, Harvard University Press, Cambridge, 2014.

7 McDaniel, M. A. and A. A. Callender, “Cognition, Memory, and Education,” Cognitive Psychology of Memory, Vol. 2 of Learning and Memory: A Comprehensive Reference, H. L. Roediger, ed., Elsevier, Cambridge, 2008, pg. 819-843.

8 Roediger, H. L. and M. A. Pyc, “Inexpensive Techniques to Improve Education: Applying Cognitive Psychology to Enhance Educational Practice,” Journal of Applied Research in Memory and Cognition, Elsevier, 1:4, 2012, pg. 242-248.

9 Castel, A. D., D. P. McCabe, and H. L. Roediger, “Illusions of Competence and Overestimation of Associative Memory for Identical Items: Evidence from Judgments of Learning,” Psychonomic Bulletin & Review, Springer, 14:1, 2007, pg. 107-111.

10 Karpicke, J. D., A. C. Butler, and H. L. Roediger III, "Metacognitive Strategies in Student Learning: Do Students Practise Retrieval When They Study On Their Own?" Memory, Psychology Press, 17:4, 2009, pg. 471-479.

11 Callender, A. A. and M. A. McDaniel, "The Limited Benefits of Rereading Educational Texts," Contemporary Education Psychology, Elsevier, 34:1, Jan. 2009, pg. 30-41.

12 Pashler, H., Patrice M. Bain, Brian A. Bottge, Arthur Graesser, Kenneth Koedinger, Mark McDaniel, and Janet Metcalfe, Organizing Instruction and Study to Improve Student Learning (NCER 2007-2004), National Center for Education Research, Washington, 2007, pg. 1-34.

13 Bjork, R. A., J. Dunlosky and N. Kornell, "Self-regulated Learning: Beliefs, Techniques and Illusions," Annual Review of Psychology, Annual Reviews, 64, 2013, pg. 417-444.

14 Moulton, Carol-Anne E., Adam Dubrowski, Helen MacRae, Brent Graham, Ethen Grober, and Richard Reznick, "Teaching Surgical Skills: What Kind of Practice Makes Perfect?" Annals of Surgery, Lippincott Williams & Wilkins, 244:3, Sep. 2006, pg. 400-409.

15 Blackwell, Lisa S., Kali H. Trzensniewski, and Carol S. Dweck, "Implicit Theories of Intelligence Predict Achievement Across an Adolescent Transition: A Longitudinal Study and an Intervention," Child Development, Society for Research in Child Development, 78:1, 2007, pg. 246-263.

16 Brown, Peter, Henry Roediger, and Mark McDaniel, "Classroom Practice – Effortless Learning is a Dangerous Illusion," TES Magazine, TSL Education, 17 Apr. 2014.

17 Bjork, E. L. and R. A. Bjork, "Creating Desirable Difficulties to Enhance Learning," Psychology and the Real World: Essays Illustrating Fundamental Contributions to Society, M. A. Gernsbacher, R. W. Pew, L. M. Hough, and J. R. Pomerantz, ed., Worth, New York, 2009, pg. 56-64.

18 Cutts, Quintin, Emily Cutts, Stephen Draper, Patrick O'Donnell, Peter Saffrey, "Manipulating Mindset to Positively Influence Introductory Programming Performance," Proceedings of the 41st ACM Technical Symposium on Computer Science Education, ACM, 2010, pg. 431-435.

19 Boersema, Martin, "Paper Airplane Lean Simulation," Lean Simulations, 13 December 2010, Available: http://www.leansimulations.org/2010/12/paper-airplane-lean-simulation-how-to.html