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Enhancing a Blended Learning Approach to CAD Instruction Using Lean Manufacturing Principles

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Lean Manufacturing principles have been applied to many service industries that do not manufacture physical goods. Blended Learning techniques have increasingly been utilized in university courses. This paper explores the parallels between the two in the context of an introductory CAD course, discovering a ”Lean Education” framework that uses Blended Learning techniques to serve Lean Manufacturing goals and philosophies.

Enhancing a Blended Learning Approach to CAD Instruction Using Lean Manufacturing Principles

The Department of Engineering and Design at Western Washington University has implemented a blended learning methodology in its introductory Computer-Aided Design course. This methodology improves learning using a combination of techniques which improve the efficiency of delivery of course content while maximizing value-added student activities where interactions with the instructor and TAs are prized. These techniques include a "flipped classroom" model, on-line video instructional materials, efficient content modularization and customizability, automated feedback, integrated assessment mechanisms and team-based in-class activities. A high proportion of class time is structured to support creative project work where students appropriate CAD skills by applying them to creative problem solving. It is the opinion of the authors that this blended learning methodology has the potential to provide a just-in-time delivery of instruction which can be customized to meet an individual student's need.

While traditional assessment techniques are designed to measure student course outcomes, they do little to measure the efficiency of instruction. Since there is an undeniable connection between the delivery mechanism and how well a student learns, it can be postulated that the ability to measure the performance of this mechanism and to adjust this in a systematic way, needs to be an integral part of any strategy for improving student learning. In this paper we present a perspective that looks to the body of work in *Lean Manufacturing* to provide a framework for better understanding the performance of the blended learning mechanism we have adopted.

The *Toyota Production System* (TPS) is one view of Lean Manufacturing. Amongst other concepts, it identifies *Muda* (unnecessary work), *Muri* (overburden) and *Mura* (unevenness) as the three contributors to waste in manufacturing. The goal of Lean Manufacturing is to control and ultimately eliminate these three sources of waste. This view of manufacturing can be applied to an instructional environment. For example, *Muda* can manifest itself in repetitive instruction needed to keep students with different learning abilities in step. *Muri* can result from increasing class sizes where the instructor and TA are spread thin in their coverage of student needs. And, *Mura* can be created by the traditional approach to instruction where it is available only at scheduled times and in a specific location. Mitigating these inefficiencies can be viewed as developing a *Lean Education* philosophy in the same way that lean principles have been applied to other disciplines outside of manufacturing such as in the health care, construction, distribution and service industries.

This paper will review the mechanisms of a blended learning approach developed for this introductory CAD course. Each activity performed and technique used by the instructor, TAs and students will be described and categorized in terms of lean principles such as the three discussed in the previous paragraph. This will show that new approaches to education such as blended learning have the potential to be organized and managed using a *Lean Education* framework that is analogous to the one for manufacturing. Further, the authors will present several ideas on how using this perspective on instruction can be used to benefit when developing and running a course adapted to the blended learning philosophy.

1.0 Introduction

The Department of Engineering and Design at Western Washington University was created recently by transitioning programs in Manufacturing, Plastics and Electrical Engineering technology to their engineering equivalents. Historically, Computer-Aided Design has been a major component of the curriculums of both the old and now the new programs. Over the past 10 years as these programs have evolved to their current status, the CAD curriculum has also undergone major transformation. In the early years, CAD instruction focused primarily on the mechanics of learning how to use these systems to create 2D drawings. The prominence of AutoCAD at this time featured in the instructional strategies. With the introduction of 3-D parametric modeling, the creation of drawings became less the primary focus and more a byproduct of the modeling activity. With this change, instruction became focused on the mechanics of creating 3-D models using state-of-the-art systems such as Pro-Engineer and CATIA. In addition to creating drawings, these CAD models were used to support Computer-Aided Manufacturing activities such as toolpath generation for CNC machining. The orientation of the programs towards hands-on lab-based activities, meant a heavy dependence upon CAD to support fabrication work.

Notwithstanding this change in emphasis, the instructional approaches to CAD remained somewhat stagnant. CAD instruction took the form of instructor led tutorial sessions, during which students would follow along on demonstrations of various CAD techniques. These would typically be followed with the students working independently on a series of exercises that help deepen their understanding of the topic in question. More open ended experiences would be obtained through homework exercises and term projects. Homework exercises would typically be given one per week on each major component covered in the modeler. Term projects would include both an individual and group oriented experience. The individual project would require students to complete a 3-D assembly model and drawings based on a design given to them by the instructor. The group project on the other hand, would require students to apply their modeling skills within the context of the design process. Groups were given a general theme to base their design upon, and would then have to follow the sequence of steps in the design process to go from a specification of the problem to a final detailed design that included a 3-D parameter model, properly dimensioned drawings, and a physical prototype. This prototype required the use of rapid prototyping to create components that were part of the final assembly. A full description of this approach to CAD instruction including examples of homework and of projects is included in the references[16].

2.0 Observations on this Approach to Instruction

Over the years, several key observations have been made by instructors of the CAD curriculum using this approach to instruction:

- Large class sizes (40 students) are difficult to lead through demonstrations. Inevitably a sizeable portion of the class falls behind. The better students become frustrated as the instructor waits or repeats instructions.

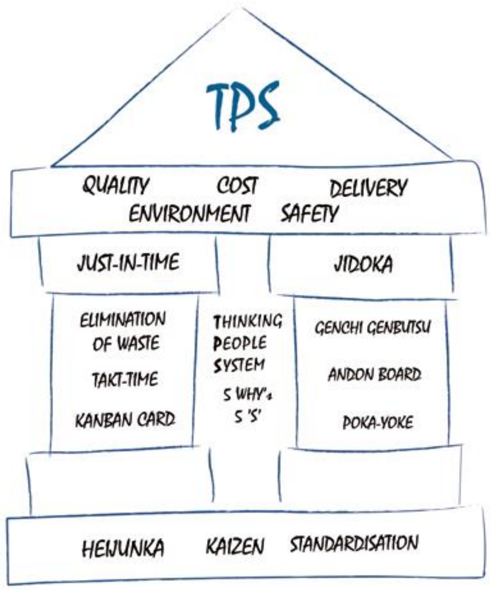
- Step-by-step instructions that accompany most examples in CAD training manuals often limit the depth of understanding obtained by students. Many follow the instructions blindly and in haste to complete the exercises.
- The clarity of text-based exercises can often be an issue. Not every student interprets instructions in the same way.
- Students read and interpret instructions at different speeds. This results in challenges keeping the class moving through material together. This can exacerbate a weaker student's understanding of critical concepts as they rush in an attempt to keep pace with their peers.
- Instructors and TAs are often by-standers when students are working on these exercises. In many cases they are relegated to assisting students understand the instructions rather than engaging them in deepening their understanding of the concepts. This is not the best use of their time and skill.
- Feedback is most effective on more open-ended problems (e.g. homework and project work) and needs to be provided as soon as possible after an exercise has been completed so that a student has the question fresh in their mind.
- Students must complete a significant amount of coursework outside of the formally scheduled class time. Often the instructor and teaching assistants are not available when students encounter problems during these times. In many cases, students spend a significant amount of time on an issue that is easily resolvable with the right guidance.

In general, curriculum development is driven by identifying a set of value-added activities that ensure course outcomes are being met. These are usually easy to identify because they effect one or more outcomes: lecturing on a topic, conducting a demonstration, running a lab, tutoring a student, coaching a group, leading a discussion group, developing a better lesson, doing research, or solving student problems. Alternatively, non-value adding work wraps itself around these: repeating ourselves to students who have not heard us, collecting and grading exercises and exams, printing out lesson materials, lecturing to a class where some students cannot keep up yet others are bored. Many of these observations are indicative of a problem of non-value added time being incurred by the students and the instructors of a course.

The remainder of this paper will look at a strategy for teaching this introductory CAD course through the lens of Lean Manufacturing. Lean Manufacturing focuses on the elimination of work that is not value added for the customer. Viewing courses in this manner provides opportunities to address the observations made above and to create better courses and outcomes for students. The focus will be on identifying wasted time and will explore some of the approaches integrated into a *Blended Learning* environment for reducing non-value adding work.

3.0 Lean Manufacturing

There are many permutations of lean manufacturing, so for clarity of discussion we have outlined some key concepts of the *Toyota Production System* (TPS) in Figure 1. The Toyota Production System is usually described as consisting of two production process pillars. More recently, a third pillar is sometimes added to reflect the people-related processes. The three pillars are (1) *Just in Time* - optimizing the workflow to respond to customer demand, (2) *Thinking People System* - developing and utilizing each employee's entire potential, and (3) *Jidoka* - delivering high quality goods and services.



1. **Just in Time - Smooth, continuous, optimized workflows**
   Heijunka - Minimizing inventory, Producing goods according to demand. Leveling processes.
   Mura - Unevenness in workload
      Takt - The rate of customer demand
      Takt Time - The work-cycle to produce an item for 1 customer
      SMED - The ability to change product tooling quickly
      Kanban - Supermarket-inspired, pull-based inventory system
   Muri - Overburden of workers that reduces safety & quality
   Muda - Waste. Work that does not create customer value. e.g. Over-processing, Excess Inventory, Conveyance, Overproduction, Motion, Waiting, Defects

2. **Thinking People System - Use everyone's brainpower**
   Kaizen - A culture of continuous improvement
   Asa-ichi Meeting - a daily meeting to discuss quality issues and eliminate their causes
   5 Why's - Justify improvements by asking 'why' 5 times
   5 S's - Cleaning and organizing for better morale & quality

3. **Build in Quality**
   Jidoka - Automation with a human touch (Autonomation)
   Quality - Each team member checks their own work
   Genchi Genbutsu - Assessing the source of a problem directly
   Andon Board - A way to help workers communicate production line state or stop the process.
   Standardization - Reduces errors & sets standards
   Poka Yoke - Mistake-proofing devices & labelling

Figure 1. The Toyota Production System[1]

In addition, we will be discussing several educational psychology concepts as defined below:

The spacing effect - Spaced study (especially with sleep consolidation between recall-based reviews) leads to longer recall times for the same amount of study time and effort.[2, 3]

The testing effect - Being asked to recall a fact leads to longer term retention than simply reviewing the fact.[4, 5]

The interleaving effect - Interleaving different concepts leads to greater ability to select a problem solving strategy[6]. This technique has been effectively used in teaching mathematics.[7]

The context effect - Learning a concept in multiple contexts strengthens the ability to recall and apply the information.[8, 13]

Chunking - Grouping information improves a student's ability to process more information at once and understand higher level information.[9]

4.0 Blended Learning as a Solution

In order to create a leaner classroom, we implemented the learning mechanisms listed in the table below. These mechanisms can be grouped into the 3 pillars of the TPS described previously. "Just in Time" mechanisms relate to making the classroom more flexible and adaptable by using shorter video lectures in a flipped classroom format. "Thinking People System" mechanisms relate to increasing the students' responsibility for and ability to continuously improve the classroom. Finally, "Build in Quality" mechanisms focus on improving the quality of instruction and student work.

4.1 "Just In Time" Learning Mechanisms	
Learning Mechanism	**Related Lean Manufacturing Concepts**
"Flipped Classroom" with Video Lectures	Heijunka, Mura, Waste: Over-processing, Waste: Excess Inventory, Waste: Conveyance
Alternating Short Lectures with Practice	Heijunka, Mura, Takt Time, SMED, Kanban
Timing all lectures and activities	Waste: Overproduction
In-Person Grading & Feedback	Waste: Motion
Answer Chain	Waste: Waiting

4.2 "Thinking People System" Learning Mechanisms	
Learning Mechanism	**Related Lean Manufacturing Concepts**
Daily Class Meeting	Asa-ichi meeting
Peer Exploration	Respect for People
Peer Instruction	Quality at every step. Letting any employee stop the line.
Peer Grading	Muri, Waste: Waiting
Discussion boards for all lectures and activities	Andon Board, Worker Input, Kaizen
Copying courses and lessons. Focusing improvement on the weakest lessons.	Worker Input, Kaizen

4.3 "Build-in Quality" Learning Mechanisms	
Learning Mechanism	**Related Lean Manufacturing Concepts**
Video Based Lectures	Jidoka (Autonomation)
Self-grading	Each member checks their own work, production cell, single-piece flow

In-person Grading	Genchi Genbutsu
Standardized lessons and drawings. Standardized lesson creation technique	Standardization
Exploring errors in lesson discussion boards	Poka Yoke

In the following sections, examples will be given to illustrate how key learning mechanisms can be viewed from the perspective of a lean manufacturing concept. For brevity, additional examples have been placed in appendix A at the end of the paper.

4.1 Just in Time - Smooth, continuous, optimized workflows

In a lean manufacturing context the term Heijunka translates to “production levelling”. Many lean practitioners attempt to achieve Heijunka by reducing the Mura (uneveness in workload), Muri (overburden of workers), and Muda (Waste) that results from Mura and Muri.

Another way to view Heijunka is as the attempt to couple production with demand as tightly as possible. From this viewpoint, batching is considered to be counterproductive because of the potential to mass produce mistakes. Production flexibility is a highly valued way to reduce Mura and can be expressed through the practices of volume and type leveling, shorter production cycles (Takt Time), Small Tooling Changeover Times (SMED), and small inventories (Kanban). The goal of all these practices is to reduce waste that comes from large batches.

Mura - Unevenness in workload (Related Concepts: Takt, Takt Time, SMED, Kanban)

A common trend in blended courses is that as lectures are transferred to online formats, teachers have found it more effective to break the lectures into smaller chunks that are alternated with retrieval-based exercises.[10] When we transferred all of the course lectures to web-based video tutorials, we implemented this technique, placing a 15 minute maximum on video tutorials and alternating each video tutorial with an exercise as shown in Figure 2.

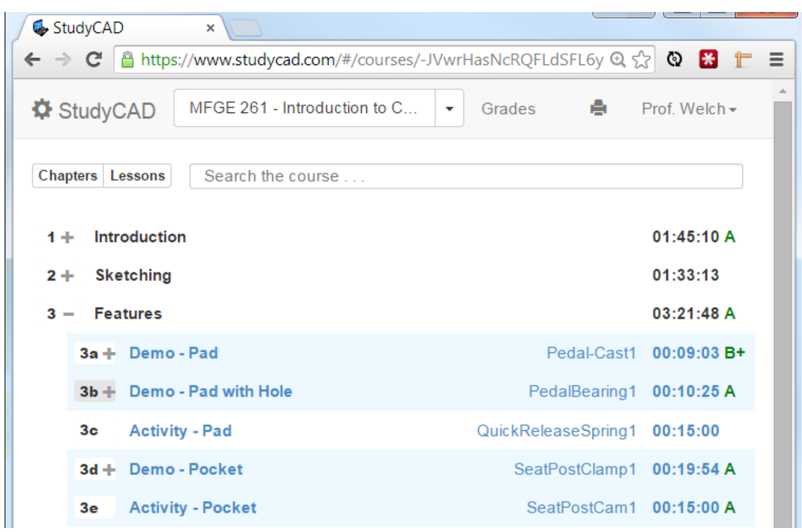


Figure 2. Interleaving short web video lectures with retrieval-based activities

From a lean manufacturing perspective, we reduced our production cycle (Takt Time) from 1 hour to 15 minutes. The web-based video delivery mechanism is analogous to SMED (Single Minute Exchange of Dies) because students can switch from viewing a lecture to applying knowledge quickly. Finally, as the reproduction cost of a digital lecture is extremely low, digital lectures are essentially available on-demand everywhere.

Viewed from a leveling perspective, there are a few advantages to this technique. First, because the availability of lectures is no longer restricted to scheduled times and locations, our students can access the material whenever they have time or feel most effective, and wherever they have access to a computer. Second, since students are self-pacing their own lectures they do not need to either wait for other students or worry about falling behind the class. They can rewind when they miss an important step and stop the lecture to research a supporting concept they may have forgotten. After we implemented this technique were surprised to see that lab sessions regularly achieved a level of quiet intensity as 40 students were continuously focused on one lesson after another, only being disturbed by an individual or group feedback session. Third, this style of lecture provides the ability to spread learning into smaller doses over more days of the week, allowing time for the spacing effect and sleep consolidation to take effect between learning sessions.

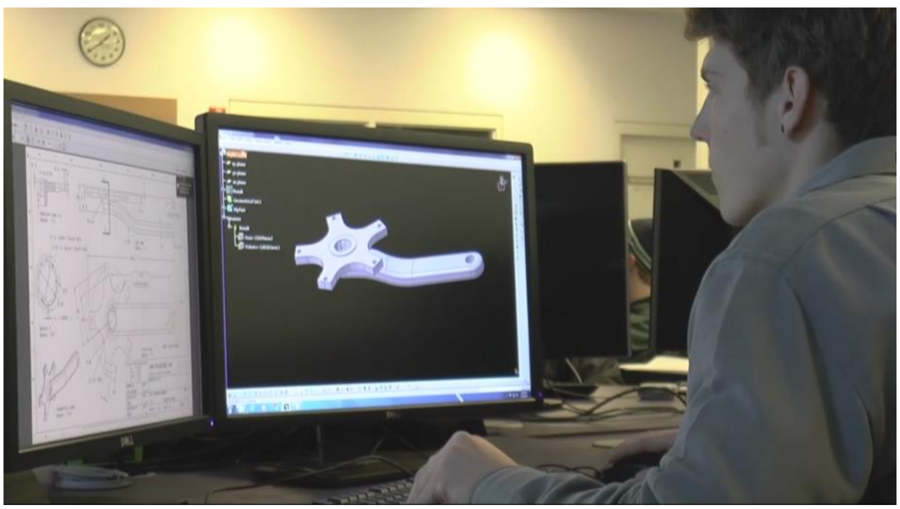


Figure 3: A student creates a part immediately after watching a short video tutorial

From an instructor's standpoint, shorter lectures and exercises were also easier to produce and manage. The shorter format was more amenable to greater focus and standardization. Given the ability to do so, students proved very good at optimizing their own time. Digital lectures turned out to be a very pull-based, just-in-time product, enabling students to create their own custom learning flow whenever and wherever they want.

Muri - Overburden of workers that reduces safety & quality

With 40 students in our lab class, the Instructor and the two TAs were spread thin. We implemented blended learning as a way to give students personal attention in a class of that size.

To reduce the burden on instructors and TAs we relied on four types of techniques. First, technology-based tools like video tutorials repeated themselves indefinitely so that instructors and TAs didn't have to. Secondly, process-based techniques like in-person grading eliminated grading paperwork and allowed us to tailor feedback to root causes via discussion. Third, we used underutilized student capabilities to reduce pressure on the instructor by implementing peer exploration, peer instruction, and peer review. Fourth, we used quality enhancing techniques like automated grading and lesson-based discussion boards.

With the time savings from moving the lecture outside of class and implementing the time-saving techniques listed above, we were able to increase instructor time per student from 8 minutes to 13 minutes for each class session. (170 min x (1 Instructor + 2 TA)) / 40 students. The additional time reduced the pressure to hurry from student to student, enhancing the quality of the instructor-student interaction.

Waste: Motion

In Lean Manufacturing, "Muda" (Waste) is defined as any work that does not create value for the customer. There are several wastes related to manufacturing, as an example, we will look at the waste of motion.

With 40 students, submitting and grading files took a lot of IT overhead and student & instructor time. Our initial process involved several steps: setting up a network file structure with custom permissions, having the student submit the files, having the instructor open up the work, grade the file, fill out a grade worksheet, send the worksheet to the student, and close the file before moving on to the next one. With 40 students, each additional minute spent grading cost 40 minutes of instructor time.

By moving the lecture outside of the scheduled meeting times through the use of videos, additional contact time was created for instructors and TAs to grade during each class and so reduce a lot of that "motion". Instead of bringing the work to the instructor, the instructor went to each student and critiqued their work verbally using a rubric. This eliminated many of the motion steps listed above: no file systems were managed, no files were transferred, and no forms were filled out. With the time saved through in-person grading, the instructor was able to spend the extra time improving lectures or interacting with students.

This process also created a chance for the instructor to personally check in with the student and determine the source of any misconceptions or gaps in knowledge. Lean manufacturing practitioners teach that the most effective way to solve a problem is to go to its source, a practice known as "Genchi Genbutsu".

Finally, we found in-person grading to be more motivating than remote grading. Students were far more likely to do their work when they had the accountability of showing it to the instructor directly.[15]

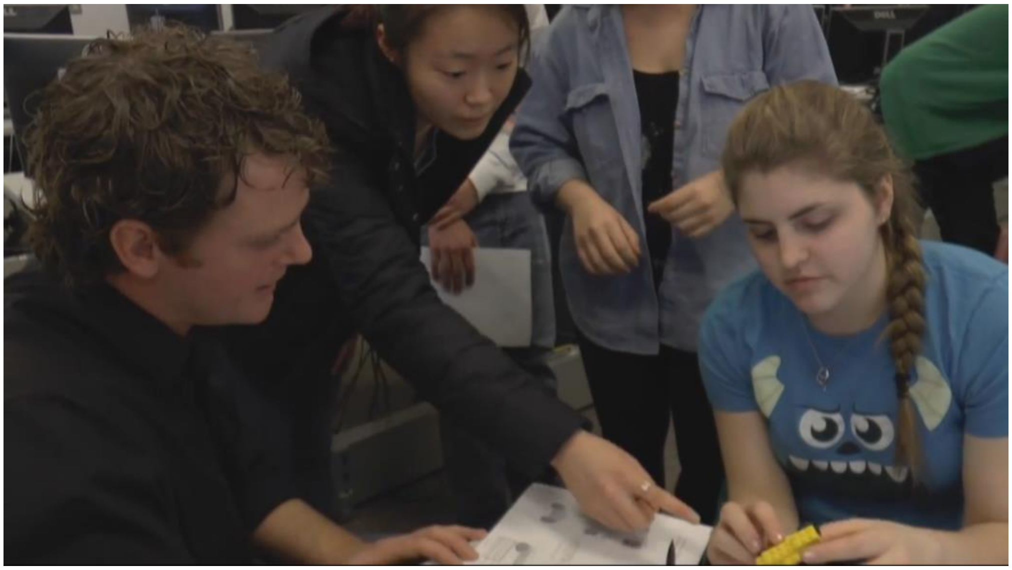


Figure 4. In-person grading of a group project

4.2 Thinking People System - Use everyone's brainpower

One of the most effective Lean Manufacturing values that a company can cultivate is to actively engage everyone in the company to look for ways to improve. When companies tap into underutilized talent by respecting, cultivating, and utilizing the capabilities of their workers, they are often shocked at the increase in novel ideas and subsequent productivity. Viewing the worker as a problem solver and engendering trust, respect, and teamwork are key values of TPS.

In academic environments, no matter how brilliant a professor may be, forty students will always have significantly more mental bandwidth than a single professor. The question is how to structure time and activities to utilize that untrained mental power. In our course we used three primary techniques: Peer exploration, peer instruction, and peer review. We will discuss peer review here.

Peer Review

In the conventional version of the course, Instructors were spending a significant percentage of their time redlining and grading student drawings. Additionally, students had to wait up to a week for feedback on their projects.

To address this feedback delay we implemented online peer-review of drawing PDFs. Beyond improving student's red-lining skills, this process reduced instructor time spent grading. Using a structured, completion-based rubric, we had each student redline two other student's work and assign a grade in several categories. In the interest of fairness, the instructor reviewed the final result. Surprisingly, we found that the instructor's review was usually redundant. In almost every case, the instructor agreed with an average of the two reviewer's scores.

There are two benefits to this approach: students get a chance to apply review skills that they will use in industry, and students know how they did in 40 minutes instead of 4 days.

4.3 Build in Quality

Jidoka - Automation with a human touch (Autonomation)

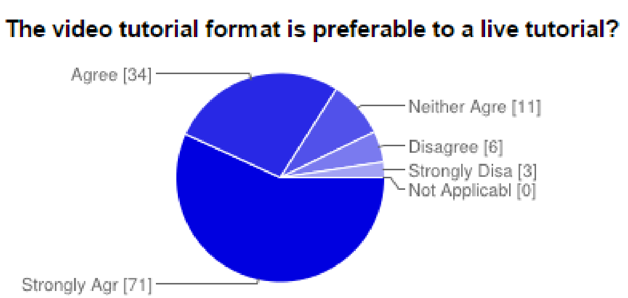
Separating human supervision from automated production was one of the first principles of TPS. Toyota's founder Sakichi Toyoda created automated looms that allowed one operator to manage several automated looms at once. Similarly, flipped classrooms can be a vehicle for separating the thinking work involved in teaching from the repetitive work involved.

In a live demo the Instructor may have to repeat prior material to achieve an outcome or the Instructor can make a mistake and need to backtrack in the lecture. These factors can lead to long or meandering lectures, which waste both time and potential. There is evidence that switching between lecture and activities improves student attention and engagement, especially for lectures longer than a half hour.[12]

In order to address the problem of the meandering lecture, we recorded video lectures as a focused "greatest hits" video that contains just the essentials from the lecture. While recording, instructors would pause the recording and skip over previously covered material in a demo before restarting the recording. This leaves a gap in the video during which students are asked to recall and implement previously taught material on their own.

These gaps, besides creating an opportunity for students to self-test previous material, also interleave old material with new material to make use of the Interleaving effect. Most importantly, these gaps require a mental change from absorbing information to implementing the information, which has been shown to increase student attention and engagement for the next section of the lecture.[12]

In our surveys of student feedback, students have consistently indicated that these activity intervals have been very effective in developing their CAD skills (figure 5). This rhythm of rapidly alternating lecture with student activities makes effective use of both the instructor's skills as a lecturer and the computer's customizable pace as the delivery mechanism.



Strongly Agree	71	53%
Agree	34	26%
Neither Agree or Disagree	11	8%
Disagree	6	5%
Strongly Disagree	3	2%
Not Applicable	0	0%

Figure 5. After taking the blended course, the majority of students we surveyed preferred the video tutorial format

Quality - Each team member checks their own work

A common approach to improving quality in Lean Manufacturing is the production cell, in which a worker will take responsibility for taking a part through several stages of a production process and then do a quality check on the part before handing it on to the next phase. This increases the worker's ownership of the part and reduces quality problems.

Waiting for an instructor to grade a part increases the amount of time between a student's efforts and feedback. It also offloads responsibility for quality from the student to the instructor. In industry this would be analogous to having large amounts of work in progress sent to a quality assurance department.

To achieve an education process more similar to single-piece flow in a production cell, we developed an Automated Grader. This grader catches errors and gives feedback in real time, allowing the student to get feedback immediately and complete the learning cycle themselves. Using this tool, the workflow looks like this: the student gathers the files, creates the part, inspects the part themselves, and then uploads the grades directly to the server. For more complicated parts that cannot be graded with the automated grader, we have the in-person grading mentioned before.

We discovered a few benefits from this single piece flow. First, the student gets immediate feedback. If they are a little bit off, the grading software will let them know how much their part differs from the sample solution. The student can use this information to motivate finding their own mistakes and correct them. Secondly, this rhythm of producing and checking one's own work is standard practice in industry, and this self-grading process begins to initiate the student into that process. Third, from a waste perspective, there is no conveyance, inventory, waiting, and motion. Simply put, there is no moving, sorting, storing, opening, and closing of files.

5.0 Utilizing this Lean Manufacturing Framework

The next step in this study is to utilize this lean manufacturing framework for the blended learning CAD instructional mechanism to improve the learning of students. The observations made to date strongly suggest that the new mechanisms are making it easier for students to study CAD. However, this would have been the case without the perspective presented in this paper. The authors believe that benefit can be found in the following areas:

1. *Lean Manufacturing is a well-established framework that provides tools and techniques that allow practitioners to systematically improve operations by removing waste:* Our experiences show that this is often an overlooked aspect of curriculum development. The primary performance measures used in courses are designed to assess student learning outcomes. It is typically left to the instructor to determine what student experiences should be assessed and the mechanisms for doing this. The choices can lead to widely varying effort and effectiveness across a cadre of instructions teaching the same material. This is particularly true for lab intensive experiences such as CAD instruction. For example, as mentioned earlier, the traditional approach to grading can be an extremely wasteful process where a significant amount of time is spent just getting to the information. A variety of techniques have been tried over the years each having a different efficiency and level of waste. Using Lean Manufacturing principles can assist curriculum developers and instructors in evaluating

learning mechanisms for waste and give guidance to the choices they make when selecting them.

2. *Motivates and guides continuous improvement:* Feedback from students based on course evaluations, teaching peer reviews and the instructors own personal observations during a course offering, are important sources of data for identifying areas for improvement. When several options present themselves, time constraints forces a choice, and it is not always an easy matter to decide which. The Lean Manufacturing framework presented here can be used to develop a mechanism for instructors to use to weigh options and point them towards the ones that have the highest potential to positively impact Just-In-Time delivery, use of available brainpower and building-in quality. This can be motivational for the instructor by giving them a priori a degree of confidence that the changes they are considering will have benefit, as opposed to just hoping for the best.

3. *Promotes collaboration, ownership and teamwork:* Teamwork and collaboration are key experiential outcomes expected of engineering programs. The TPS concept broadens the notion of teamwork beyond the final deliverable of a particular assignment or project to one that is concerned with the learning environment as a whole. So a "good" team player is not just someone who completes their assigned task, or who provides assistance to their teammates in completing theirs. It also has the dimension of assisting in the development of an efficient and effective learning environment. Our experience is that students are eager "to play the instructor" when given the opportunity. By presenting them with the overarching framework of the Thinking People System and its success in manufacturing, students can more fully appreciate the value of this approach to teamwork and will be even more enthusiastic in their desire to participate.

4. *Positively impacts achieving student learning outcome*: At the end of the day quantified assessment of student learning outcomes is the measure of the quality of a curriculum. But this cannot be divorced from the efficiency of the instructional environment and the goal of utilizing all available resources to add value to the experience. Though the precise relationship is likely unknowable, students undoubtedly learn better in a lean educational setting in the same way that the quality and throughput of manufactured goods are better from a factory practicing lean manufacturing principles. The Just-In-Time concept implemented in an educational setting has the added advantage of being able to utilize Mass Customization, which is much more complicated to achieve in a manufacturing environment. Many of the learning mechanisms described (e.g. use of videos, discussion boards, help chains) allow students to engage to material in a manner that best suits their learning style.

5. *Raising awareness of Lean Manufacturing amongst students*: This can be very beneficial to a department with programs in Manufacturing and Plastics and Composites Engineering. Students in these programs are required to take courses in Quality Assurance and the MFGE majors, Lean Manufacturing. As mentioned earlier, the terminology and concepts that this framework would introduce are the same that graduates of these programs would encounter on the job, on a daily basis. By exposing students to these concepts within the context of CAD instruction, they will be seeing a practical example of Lean Manufacturing at work. They will be receiving advanced preparation for the classes where they will be studying this topic in depth, and will begin appropriating Lean Manufacturing concepts as a way of looking at the world.

6.0 Conclusion

Blended learning is changing the mode of instruction and learning in classrooms and laboratories. For a subject like CAD, that is centered around the availability and use of the computer, the options of techniques and technologies to adopt are numerous. This paper has summarized these for an introduction to CAD course taught at WWU. It has also presented a framework for organizing these course components that utilizes concepts from the well-established field of Lean Manufacturing. The authors believe that developing and using this framework has the potential to improve value and efficiency of instruction and learning as part of a *Lean Education* paradigm, in the same way that they improve quality and productivity in a Lean Manufacturing setting. It can also expose students to lean principles and help them become aware of their value in the engineering profession, particularly in manufacturing.

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Appendix of Learning Mechanisms (optional exploration for ambitious readers)

A.1 Just in Time - Smooth, continuous, optimized workflows

Muda - Waste

From a student perspective, there are two primary types of waste in a teaching environment: wasted student time and wasted student potential.

To get an idea of how much wasting student time costs, let us review the money spent during one hour of our CAD class. At Western Washington University, the average annual cost of full-time (45 credit), in-state attendance for the 2014 school year is $23,222, or $516 per credit.[14] Our 4 credit class consists of 6 hours of lecture/lab per week over 10 weeks, with an enrollment of 40 students. Calculations show that each student is paying roughly $34 per hour of instruction, and that the 40 student class as a whole is directly paying $1,376 per hour of class, or $22 per minute.

Consequently, the per-student cost of a wasted minute is $0.50. The per-class cost of a wasted minute is $22. You could make this number smaller by using direct tuition, fee, and book costs instead of cost of attendance ($0.28/minute per student), or you could make it larger by considering that state funding contributes an additional 60% for in-state students (out of state students pay $0.53/minute just for tuition, fees, and books). Either way, shared time in a large classroom is expensive.

Wasted student potential is harder to measure, but cognitive psychology studies have measured some qualitative improvements in retention using the educational effects defined above. The spacing effect has shown longer retention times for the same amount of study time. Self-testing in particular has been shown to improve recall up to 10% more than passively reviewing information.[13] Interleaving improves the ability to choose a problem solving strategy. Ignoring benefits like 10% more retention is akin to wasting 10% of a student’s potential.

Type of Waste	Class Example(s)	Adopted Solution	Observations
Over-Processing	Instructors and TA's would often repeat themselves to students who forgot a concept or didn't hear it the first time.	• Rewindable and searchable video tutorials that allow students search for an answer to their question and review it.	• If a student has simply missed or forgotten a lecture, now the instructor can direct the student to a particular lesson to refresh their knowledge • Instructor time is spent answering more challenging questions
Excess Inventory	Students who take our class have a large variety of backgrounds. Some are more prepared than others.	• The creation of smaller and modular lectures, aided by video media. • Lectures tailored to specific deficiencies have been created e.g. an optional tutorial on file management	• Students who had already taken a CAD class were able to skip exercises and move at a faster pace.

		was created for students with limited computer experience.	• Students could customize the instruction to fit their own experience and skills.
Overproduction	The nature of CAD work and the range of abilities makes it challenging for the instructor to accurately gage the time to complete an assignment. Can result in the "Course and a half" syndrome.	• Demos and assignments are given an estimated time. StudyCAD adds up these times for the entire course to guide the instructor. • Mechanisms have been created to measure how often and how much time a student spends with a video on a particular topic.	• Assignments that take a long time on average are identified. The cause can be investigated. • The instructor simplifies an assignment. • More instruction is provided to increase skill and knowledge of a particular technique or concept.
Conveyance	The primary source of conveyance in the classroom environment is the movement of the students themselves. While students are encouraged to work in the lab for the supportive environment, even in the best case scenario where the student lives on campus, simply walking to the lab makes a 15 minute lesson take 30 minutes.	• We identified two ways that a blended format helps minimize conveyance: organizing group work and enabling short, intense bursts of work from any computer location. • The use of a web-based blended curriculum to make a 15 minute lesson feasible anywhere at any time. • With reduced lecturing during class time, an increased use of check-ins by instructors and TAs with individual students and groups was adopted.	• Each group spent the quarter designing a LEGO car. It was found that the quality of this project increased as more and more time for guided group work was created. • Since many students had difficulty getting to the lab outside of class times, coupled with limited lab hours, we saw students taking advantage of the availability of the 15 minutes on-line lessons from remote locations.
Waiting	A characteristic of CAD system usage is that unexpected errors (to the novice) happen frequently. While they are trying to overcome the error, the lecture marches on and they typically fall further behind. This is a very visible source of wasted time as students wait for the instructor or TA to become available to help explain how to deal with the error. Faster students also waste time as they wait for their class mates to catch up. Everyone suffers.	• An *Answer Chain* was created which guided students to where they could get the quickest response. The answer chain listed in order of the quickest reply to longest reply: Search Google > Lesson Discussion Board > Search Course > Support Group > TA > Instructor • Searchable discussion boards on the same web-page as every tutorial and assignment. In addition, the entire course site is searchable. • Small project support groups were set up so that each student has 3 other students they can call for help (or preferably co-study with).	• Reduced Time to Answer (TTA). • The self-paced nature of web-based lectures eliminated much of this type of waiting. When a student encountered an error, they put the lecture on pause, dealt with it using the answer chain, and then resumed learning new material. • Students were able to see from the discussion boards if their problem had already been solved. • Instructors and TAs were able to post replies to common problems quickly on the discussion board.
Defects	See appendix on *Jikoda*.		

A.2 Thinking People System - Use everyone's brainpower

Technique	Description	Observations
Peer Exploration	In an effort to distribute the teaching load, we created groups for a group project. The primary goal of the group was to learn how to work together to design, build, and 3D print a multi-part CAD assembly of a LEGO car. The group process was an opportunity for students to be actively engaged in the process of creating something with others.	• Coordinating and negotiating a design provided a context for students to help each other explore the engineering design process. • A side benefit of this process was that the groups became informal support networks. Seeing this, we strengthened these connections by letting students choose their own groups, creating a seating layout that puts groups together, making sure everyone had each other's contact information, and making asking your group for help an official step in the answer chain mentioned earlier.
Peer Instruction	Use of a technique of alternating live lecture with peer instruction: • The lecturer will demonstrate a single step or concept on a screen. • Students are instructed to make sure that their neighbors have completed or understood the step before moving on. • Instructor walks the lab making sure that everyone has completed the step. • If a student is having trouble, the instructor will ask a neighboring student to help them.	• The interpersonal interaction of explaining something to another person sharply focuses your understanding of the material. • Encourages shy students who would not usually seek help from a classmate. • Gives faster students the incentive to help the slower students, creating an automatic mentor/mentee relationships among the students. • When lecturing using this style, the process does sacrifice some pace. For example, it might take 1 hour to cover the same amount of material that a focused lecture would cover in 30 minutes. • For students who are teaching their peers, the experience is one of switching between absorbing new information and then teaching that

<table>
<tr><td></td><td>Once the introduction is made, the students usually engage in the next step of the lecture.
The instructor does not proceed to the next step until everyone in the class has completed the step.
Teaching in this manner is analogous to letting any employee in a production line stop the entire production line. It is a zero-defect policy that makes quality problems in teaching styles or student preparation very visible in the amount of time it takes for all the students to complete each step.</td><td>same information. Because of this, student engagement appears to remain high during that hour.
Instructors must give students time to absorb the information, and it does not leave anyone behind.
Tracking the difference between the demonstration time for a step and when all the students in a class comprehend it is a valuable form of feedback for an instructor in preparing online versions of the lecture. The instructor gets a direct feeling for which concepts take the longest for students to absorb and which explanations worked best.
It is very helpful to go through the live lecture process with at least one student before recording a video version. The authors personally found it easier to record an online version of a lecture if they recorded it after presenting a live version first.</td></tr>
<tr><td>Kaizen – A culture of continuous improvement.</td><td>One approach used to encourage continuous improvement was to attach a discussion board to every video lecture and exercise. Comments are linked to the moment of the video when they were made. Students can point out unexpected CAD problems they encounter or drafting errors as they are discovered.
The nature of recurring courses is that they are continuously iterated, and not necessarily by the same instructor. At the end of a quarter, individual lessons or an entire course can be imported into a new course, complete with the discussions of each lesson.
Use of an In-class grading approach where the instructor and TAs directly evaluate a student’s work in their presence.
The use of automated grading allows students to check their work against the expected result and obtain a rough measure of the difference.</td><td>Everyone in the class can see that there was a problem and the discussion on how to address it.
In this environment, shy students have as much voice as loud students, and students can help as much as instructors.
These discussion boards serve as a type of andon board. If there is a lot of discussion, this is a signal to the instructor that there is likely a root problem to be addressed. Instructors can focus additional instruction to clarify points in the video using these time-based comments.
New instructors have a vetted course structure to start from. Returning instructors have the opportunity to identify the weakest lessons and assignments and revise them for the next offering.
Beyond direct student feedback, instructors can review the discussion boards and average grades to identify where to improve.
Since the lessons are video recorded, the instructor is free from preparing and presenting every lecture in the upcoming quarter. They can better focus their effort.
Because most of the grading is either done in-class or automated, much of an instructor’s out of class time can be dedicated to creating better explanations and exercises. This approach to keeping the greatest hits and improving the weak spots will provide for more rapid improvement of the course.
In-class grading provides closer to real-time feedback for students. Explanations or mistakes are clearer and students can ask clarifying questions.
Automated grading tells student that there is a mistake, but not what it is. This motivates students to reassess their work and seek help to improve their grade on the assignment.</td></tr>
<tr><td>Asa-ichi meeting - a daily meeting to discuss quality issues and eliminate their causes</td><td>In a flipped classroom, class time is very much like an asa-ichi meeting. In the beginning of class, we have a brief meeting to review common problems encountered during the homework. We also discuss upcoming events and deadlines. As the class progresses and common difficulties are discovered, the entire class can be addressed for a few minutes to resolve the misunderstanding.</td><td>During class the instructor spends a lot of time meeting with student groups of 3-4 students about their group projects. Feedback takes the form of a verbal response, which is immediate, involves no paperwork, and increases student accountability. Being told how you can improve in front of a small group of your peers turns out to be very motivating.</td></tr>
<tr><td>5 S’s - Cleaning and organizing for better morale & quality</td><td>The table of contents shown in figure 2 lets students know their current status on completion of material. Items marked blue indicate completed assignments and items with a grade have been either auto-graded or graded in-person.</td><td>As students complete demos and activities, they can see their progress in real time.</td></tr>
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A.3 Jidoka - Build in Quality

Technique	Description	Observations
Genchi Genbutsu	• The ability to assess the source of a problem directly. • Use of the “flipped” classroom concept brings the skills and knowledge of the	• The primary benefit of the flipped classroom is that class time is essentially entirely Genchi Genbutsu. Activities like in-person grading, individual coaching, and group progress updates all connect the instructor with the students directly.

	instructor and TAs more directly to bear on solving the problem of learning CAD. • Students are also directly assisting each other with learning through mechanisms mentioned under peer exploration and review.	
Andon Board	• A way to help workers communicate the production line state and to stop the process if needed to solve a problem. • Student’s grades are displayed on the blended learning site as shown in Figure 2.	• An instructor can glance at the gradebook to see how the class is doing as a whole in real time. • The discussion boards on each lecture and assignment help make problems visible.
Standardization	• This seeks to reduce errors & sets standards • In an effort to focus our teaching and reduce errors, we approach each lesson via the same process. We write lesson outcomes first, the lesson exercise second, and finally record a related video demo.[11] Tutorial videos are sandwiched between an introduction to topics covered and a review of the tutorial. Additionally, to encourage the ability to read drawings, almost every project is based off the same style of drawing.	
Poka Yoke	• This is the use of mistake-proofing devices & labelling • Poka Yoke is the process of making it difficult to inadvertently make a mistake in a production process. One way to attempt this is through labeling an item, but more effective ways to prevent mistakes usually address the root causes of a mistake. An example would be creating an asymmetric plug to prevent inserting a plug backwards. Since mistakes are often hard to predict, the process of Poka Yoking a process usually includes: 1. Making or anticipating the mistake. 2. Discovering the Root Cause. 3. Making it difficult to make the mistake again.	• A key skill in using CAD systems is determining what the source of an error is and how to deal with it. CAD systems error dialogs can be incomprehensible to a novice. But once they have been explained they are easier to predict, prevent and trouble shoot when they occur. • While it may be convenient to prevent the student from making an error in the first place, the ability to understand and overcome them is a valuable skill to develop. • For important types of error that occur frequently, the instructors will often deliberately create conditions for the error and include an explanation of its meaning and how to overcome it. • In order to document errors and their fixes we encourage use of the discussion boards. This provides a searchable tool to let everyone know that there is a problem and what the immediate fix is. • In the long term, the instructor can use this to identify the more commonly occurring errors and add a section to the tutorial video or discussion board to explain more fully its cause and how to deal with it.