Applying Lean Thinking to the Structure and Delivery of a Kinematics Course

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Abstract

The proper application of lean management techniques to manufacturing processes typically results in process improvements. Many of the principles of lean thinking can also be applied to the educational process. This paper examines the implementation of lean management principles in the design and delivery of a traditional lecture-based engineering course – Kinematics of Machines.

The format of a typical kinematics course relies on lectures, homework, exams, and perhaps a design project as a means for transferring knowledge from the instructor to the students. In this paper, lean thinking principles are applied to redesign the kinematics course format to increase the effectiveness and efficiency of the knowledge transfer process. Because kinematics is taught in a common engineering course format, the model presented in this paper is transferrable to a number of other engineering courses.

This paper demonstrates that the implementation of lean thinking at the course level does not require the development of new pedagogical techniques, but rather the proper use and arrangement of existing methods. The first step in modifying the structure of the kinematics course is to build the course around course outcomes rather than course topics. Five outcomes were identified for the kinematics course. A corresponding outcomes-based grading format (specifications grading) was then applied as a means for measuring the student progress through the course. Exams and partial credit grading were eliminated from the course format to remove interruptions and defects from the course flow. Course content was flipped with notes and mini-lectures placed on the learning management system for the course. This made the course content continuously available to students, allowing them to move at their own pace. Classroom meetings focused on active student engagement with students working on assignments and projects, maximizing their ability to interact with one another and the professor.

Student response to the course, obtained via an end of the course survey, indicates a positive reaction to the course that is consistent with the observed behavior of the students during the course. Students favored the mini-lecture videos over live presentation of course material, with many students viewing any given video multiple times. Students took advantage of the outcome based assignments to progress at their chosen rate, with several students finishing the course one or two weeks prior to the end of the term.

Introduction

If one is seeking information on the best teaching practices in higher education, or engineering education, you do not need to go far to find a vast library of resources. Terms such as “active learning”, “flipped classrooms”, “hybrid courses”, “reflective thinking”, “standards-based grading”, and others run through the literature (for examples see Felder et. al, 2011[1]). As an engineering professor, I find the number of options and recommendations to be somewhat daunting. My needs are not for more methods by which to improve learning, but rather for a means to systematically organize and implement the practices that exist. The field of Lean Management provides a framework for the implementation of more effective and efficient instruction.
Lean thinking traces its source to the field of manufacturing. Lean principles work in manufacturing because they eliminate waste while improving the effectiveness and efficiency of the manufacturing process. The basic idea of Lean is to identify the value being produced (in the case of education: knowledge) and then fully examine the value stream to reduce and eliminate waste. Lean thinking methods have traditionally been applied to create improvements in the manufacturing of goods\textsuperscript{[2]}. The methods used in manufacturing, however, have been found to be transferable to a number of different fields, including government\textsuperscript{[3]}, finance\textsuperscript{[4]}, construction\textsuperscript{[5]}, healthcare\textsuperscript{[6]}, public services\textsuperscript{[7]} and education\textsuperscript{[8]}. Several authors\textsuperscript{[9, 10]} have examined the application of lean thinking to the design of non-engineering courses. The purpose of this paper is to provide a specific example of lean design for engineering courses by examining the use of lean principles to redesign a standard “Kinematics” course.

As we proceed through this paper, it will be important to remember that Lean is not, in and of itself, a best practice in engineering education. Rather, it provides a framework for organizing and implementing existing best practices. This will be developed in the paper sections that follow. The basic ideas of Lean Thinking are first introduced. This is followed by an examination of the engineering education practices that were implemented in the course being examined, along with the Lean rationale for choosing these practices. A third section looks at the student response to the Lean course structure. The paper concludes with a consideration of some of the cultural challenges that accompany the implementation of a lean course structure.

**Basics of Lean**

Lean manufacturing is a field with great depth that cannot be fully explored in this paper. The basic ideas of lean, however, revolve around five key themes. This section introduces those themes along with an overview of lean philosophy.

The foundation of lean thinking is based on the concepts of: Value, Value Stream, Flow, Pull, and Perfection. The important consideration for these in an educational setting might be defined by the following set of questions:

1. **Value** – What is the product being produced and how is value added to the product?
2. **Value Stream** – What are the steps used to create the value?
3. **Flow** – How does the production process move smoothly, without interruption or waste?
4. **Pull** – Does the customer dictate the pace at which the product is produced?
5. **Perfection** – Can we continue to make the system better?

For the purpose of this paper, we will consider “knowledge” to be the product produced by the educational system. In terms of course design and delivery, the value stream is the way knowledge is delivered to the student. The most important aspect of the value stream is the elimination of waste, allowing for a free flow of knowledge at a student-dictated pace (pull). The means by which all this happens is an ongoing study in continuous improvement (perfection). The objective of Lean thinking is to implement changes that produce “win-win” scenarios, rather than making trade-offs.

A close examination of the typical engineering course reveals a significant amount of waste in the knowledge transfer process, making such courses prime candidates for the application of lean thinking. Fortunately, a number of best practices in education fold nicely into a lean framework, so one does not need to reinvent the wheel to implement lean thinking into course design. The
The biggest need is to identify the wastes, identify a corresponding best practice that will eliminate that waste, and then adapt the process to the course being taught.

**Lean Principles Applied in Course Planning**

This paper focuses on the application of Lean principles to identify obstacles to effective knowledge transfer in a standard kinematics course. This section discusses the lean principles applied to the course, and the educational practices that were implemented as a result. The primary topics to be examined are: defining course outcomes; implementing an appropriate grading system; and making effective use of classroom meeting time.

**Course Outcomes**

The first step in applying Lean principles to course design is to examine what is being taught in a course and why. Engineering courses have traditionally been built around a set of topics. The focus on topics as a foundation for a course tends to result in an “overproduction” of technical knowledge at the expense of developing the professional side of engineering practice. A better practice is to use outcomes to define a course. This lean practice helps focus the course and allows for a balance between technical information and training in professional practices. The Kinematics course outcomes and the rationale for choosing each outcome are listed in Table 1.

A primary benefit of using outcomes is that it provides a structure for the knowledge transfer within a course. In terms of a Lean structure, the course outcomes define the specific value that we are trying to produce in the course and we can then create a set of student experiences to achieve the specified value. This focus helps eliminate waste in the course by allowing the removal of any instruction that does not support the course outcomes. Once the course outcomes are define, the next step is to determine how to assess students’ achievement in these outcomes.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Rationale</th>
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<tbody>
<tr>
<td>1. To be able to identify and classify mechanisms and examine their basic performance parameters including mobility, Grashof type, circuits, branches, transmission angles, and range of motion.</td>
<td>These are the basic ideas and definitions that define the performance of kinematic systems. This is foundational knowledge for the course.</td>
</tr>
<tr>
<td>2. To be able to design 4-bar linkages to perform a prescribed task. This includes the ability to verify the performance of solution mechanisms, identify defects that may arise in the design methods used and design defect-free linkages.</td>
<td>Students apply the foundational knowledge in a creative manner. Problems are open-ended with unique solutions. As such, students must learn multiple ways to verify performance. This is seen as preparation for professional practice where engineers must know how to assess their solutions.</td>
</tr>
<tr>
<td>3. To be able to analyze mechanism motion and include motion parameters such as velocity into the design process.</td>
<td>Basic kinematic analysis. Connecting the analysis to the design process allows students to explore the relationship between design and analysis.</td>
</tr>
<tr>
<td>4. To be able to design complex linkages to perform specialized and general tasks.</td>
<td>Once students understand the basics of kinematics, this outcome allows them to examine how to extend the knowledge to more complex problems.</td>
</tr>
<tr>
<td>5. To be able to create, design, optimize and verify solutions for the development of mechanisms that can be used to solve unique problems.</td>
<td>The “capstone” outcome of the course where students apply what they have learned to generate and analyze designs of their own creation.</td>
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Table 1: Course Outcomes and Rationale
**Grading and Assessment**

Several ideas from lean thinking come into play when considering the design of a method to assess students within a course. Two interrupters of “flow” in a production system include “defects”, and “batch-and-queue” processes. As an example, partial credit grading represents a grading system that accepts defects, and is therefore not compatible with a lean course structure. Similarly, exams and homework sets are batch-and-queue processes which cause students to have severe fluctuations in their daily efforts in any given course. A lean assessment system replaces these traditional practices with ones that allow for a better course flow.

The system adapted in the kinematics course was based on “Specifications Grading”[11], a grading method which fits well with a lean course philosophy. In specifications grading, students are given a set of assignments to complete under each course outcome. Credit is only given for assignments that meet a minimum quality standard – thus eliminating partial credit grading. A student’s grade in the course is determined by a combination of the distribution of assignments completed, and the total number of assignments completed. Table 2 summarizes the grading structure for the kinematics course.

The course contained no exams, thus eliminating the batch-and-queue defect associated with this form of assessment. To minimize batch-and-queue in the submission of assignments, each assignment in the course was a single problem, rather than a set of problems. Problems ranged from relatively simple “homework style” problems, to larger problems that were more comprehensive design or analysis projects. Each assignment had a specified due date with problems due each week of the course. Because assignments were not contained in sets, students were free to submit assignments at any time prior to the due date. Feedback was provided to students within 24 hours after submission. This encouraged students to submit assignments as they completed them rather than waiting until the due date. The feedback let students know if their assignments met the standards for the submission and allowed students to improve their solution (remove defects) if it was not up to the required standard. This process enhanced the flow of both student work, and faculty work by distributing the assignment submissions and the associated grading. Also of note is that the “acceptable/unacceptable” nature of specifications grading minimizes faculty grading while placing the process of “defect detection and elimination” on the student, which is where it belongs.

<table>
<thead>
<tr>
<th>GRADE</th>
<th>REQUIREMENTS</th>
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<tbody>
<tr>
<td>C</td>
<td>Complete 3 assignments each from outcomes 1-4 and one assignment from outcome 5. Must complete assignments 2a and 2b as part of the assignments from outcome 2. [13 assignments total]</td>
</tr>
<tr>
<td>C+</td>
<td>Complete the “C” requirements plus two additional assignments that include at least one additional assignment from outcome 5 [15 assignments total]</td>
</tr>
<tr>
<td>B</td>
<td>Complete four assignments from outcomes 1, and 2; three assignments from outcomes 3, 4, and 5. Complete one additional assignment of your choosing. [18 assignments total]</td>
</tr>
<tr>
<td>B+</td>
<td>Complete the “B” requirements plus three additional assignments [21 assignments total]</td>
</tr>
<tr>
<td>A</td>
<td>Complete 24 assignments. <strong>These must include 2a, 2b, and 5d.</strong> [24 assignments total]</td>
</tr>
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Note: The course includes a total of 26 assignments.
The Use of Classroom Time
From a lean perspective, the standard classroom structure of universities represents a major obstacle to effective knowledge transfer. First, the lecture is a “batch-and-queue” process where information is only available at certain times on certain days. This is a major obstacle to “pull” in which the customer dictates the pace of production. Secondly, the lecture allows for the introduction of a number of defects as students often fail to fully and properly record all information presented within a lecture. Lectures also provide an “unreasonable” demand on knowledge flow by the expectation that students will document and be able to recall any and all information presented within a lecture. Given these lean obstacles, it was quickly apparent that the classroom time in the kinematics course needed to be repurposed if the course was going to be built around lean principles.

As in the previous sections on course outcomes and grading, lean is used to identify the problem, and then also used to choose a solution from best educational practices that most completely solves this problem. In the case of the kinematics course, the solution was to use a flipped classroom. Course information was moved to an on-line format. The on-line resources included course notes, and short (5-15 minute) video presentations associated with the course notes.

The flipped course structure satisfies lean principles in a number of ways. The first is that the flipped course enables “pull”. Students can access any and all course information at any time they wish. Secondly, students can revisit any presentation multiple times to fill in gaps in their understanding that they may have missed the first time through. The online information also provides a “reasonable” resource where students have a complete set of the knowledge they need to navigate the course requirements.

With the flipped lectures, the reserved class time was used to allow students time to work on their assignments. Most classes began with an approximately 10 minute “mini-lecture” to remind students of the current topics and to provide strategies on how to approach the assignments. After this, the professor simply circulated among the students to assist and answer questions as they arose. From a lean perspective, this provides students with a work period where they can minimize the waste of “waiting” when they have a question on an assignment, and also helps improve flow during the faculty member’s office hours by reducing the number of students that need to visit during these hours (thus reducing lines and student waiting).

The above areas represent a first effort at moving the Kinematics course to a lean structure. Redefining the course content (topics to outcomes), changing the grading system, and repurposing class meeting times were seen as the highest impact items for an initial implementation of lean principles. The next section examines student response to these changes.

Student Response to the Lean Principles
While the initiatives taken in the above section are drawn from best practices in education, their implementation was done with some degree of fear and trepidation. From an early age, students are programmed to accept the traditional classroom structure and all of its trappings. Perhaps a faculty member can “get away” with any one of the above items and persuade students of its benefit. To simultaneously implement the set of changes described above poses greater risk. Not only do the students have to learn the course material, they must also “learn” a new course structure and grading system. This can potentially tax students learning capacity and increase
their frustration. In this section, we examine how the students did respond to the challenge of a new course format.

Student response to the course was measured in two different ways. The first was through a survey administered to students regarding the course structure. The second was via the standard course evaluations.

The survey given to the students asked them for their preferences on how to best use their time, and course time. Results from the survey are shown in Fig. 1. The students were asked to rank their preferences from first through sixth. The results in Fig. 1 are the weighted averages (6 points for most preferred, 5 points for second most, etc.).

From a lean perspective, the best course structure is the first one listed in Fig. 1 where students can attend an open “learning lab” to supplement on-line course information. This was the least favored structure as indicated by the student choices, with part of the possible reason being that students have never experienced that format. Items 2 and 4 are identical except for attendance being required or flexible. Students indicate a choice for flexible attendance when course information is posted on-line. This is consistent with a lean model. Items 2 and 3 compare flexible attendance policies with the difference between the two being that item 2 uses class time for work time, while item 3 supplements the work time with a highlighting of current topics. Method 3 is the most preferred of the methods presented. This result may be biased by the fact that this was the format of the course, so students had a better understanding of this course setup. Items 4 and 6 compare methods of delivery with all information either on-line vs. all information in class. Students prefer to get all their information in class if they have to pick one or the other. This is in contrast to a lean system which would prefer continuous access to information.

![Figure 1: Student preferences for course format.](image-url)
In all, the results shown in Fig. 1 seem to indicate students prefer course formats that are not based on a lean model. This may be due to the fact that the students have never experienced a truly lean course. The closest they have come is the course in which they were enrolled, and this was their most preferred model in spite of the other tendencies against lean formats.

Additional student response comes from the standard course evaluations. These evaluations are common to all courses on campus and contain standard questions about the course and the instructor. As such, no questions asked specifically about the course structure. A set of sample comments from student course evaluations is given below. These comments support a number of the lean characteristics of the course, including:

- Continuous access to information (comments 1, 2, 3, 4, 6).
- Clearly defined grading and feedback (comments 5, 6).
- Class time well used to support the course rather than as the centerpiece of the course (comments 3, 4).

1. One strength of this course is that all of the material was online, so it was easy to go back and look up past topics. Another strength was the video lectures allowed us to watch them multiple times if need.
2. The assignments helped me to understand what was being taught through the video lectures and the notes. The video lectures were very helpful and addressed many of the questions students might have if there weren't video lectures.
3. I liked the flipped classroom. The videos were much better than a traditional class lecture would be.
4. Can’t say enough good things about this course. I love the structure of the course. In my opinion, all classes should be taught this way. The video lectures were extremely helpful and also very clear, concise, and to the point. I also liked how the in-class time is a short lecture and spent working on assignment.
5. Liked the format of many assignments with no partial credit but could decide what grade I wanted to get based off of how much work I wanted to put in.
6. Course was very flexible -- students could choose what level of difficulty they wanted to attempt and knew what grade that would correlate to. Students willing to put in more work were essentially guaranteed an A in the class. Students also had flexibility to work on their own schedule.

One additional point of support for the lean format was the ability for students to work at their own pace. Of the 28 students in the course, 8 of them finished their desired set of assignments with more than one week remaining in the course.

Even given the vastly different format of the course, the student response was overwhelmingly positive. One challenge of lean is the push for continuous improvement, which means making things more lean. I am sure this would be possible given the same set of students working in a subsequent course. In an academic setting, however, each time a course is taught we start with a new group of students. If the course were to be pushed to an even more lean format, would students still respond positively, or would they start to feel too far out of their comfort zone? Part of the challenge of introducing lean to course design is to be able to define the edge of that comfort zone. This idea is briefly considered in the next section.
Cultural Challenges and Final Notes

The use of lean methods to reformat a kinematics course proved to be highly successful. The lean initiative improved information flow, reduced the amount of defective work produced by the students, and increased the opportunity for student-faculty interactions. While lean methods seem to be taking the presentation of this course in a good direction, the question arises as to how far the methods can go. Is it possible to make this course even more lean, or does the academic environment pose limits on how far one can go? Here are some challenges that were encountered with the course offering:

1) Imposing deadlines on student work. In a truly lean system, the students would access course information and complete assignments at their learning pace, rather than on an imposed pace dictated by assignment due dates. Due dates, however, were found to be necessary to keep students on task and ensure a smooth work load. As such, the concept of “pull” in the system is somewhat contrived by forcing students to pull their workload at an even rate rather than allowing them to execute standard student practice of applying “batch and queue” techniques to complete work.

2) Providing content during class meeting times. Classes began with a short lecture. The purpose of the lecture was twofold, neither of which was consistent with a fully lean course. As an instructor, I felt uncomfortable having students assembling in class without some kind of formal address from me. I have been trained to address students during class time, and this is a difficult practice to remove. Similarly, students expect formal instruction during class time. A fully lean structure should be able to remove this in-class instruction in favor of “just-in-time” interactions with students on an individual or small group basis.

3) Learning responsibility. A lean structure shifts the learning responsibility to the student. This can introduce some resistance to the lean structure as students are accustomed to having the instructor provide the learning impetus. This pressure is part of the reason why the short lectures noted above were maintained – to give some sense that the instructor was directing the learning. A fully lean system would not require this.

4) Making the shift. As noted in Fig. 1, students do not naturally prefer a lean structure. Unless a number of courses in a curriculum are built upon a lean format, the extent to which a fully lean course can be realized may be dependent upon the maximum amount of “culture shock” that students can withstand.

Overall, the adaptation of lean management techniques to a kinematics course produced excellent results. The challenge of lean, however, is to keep improving the system. Some possible improvements for the kinematics course include the removal of even the small lectures from class meeting times, restructuring the course into larger meeting time blocks to provide longer work periods, and placing more responsibility on students to define their own uniform set of due dates for their assignments.

References


