Keep Them on the Edge of Their Seats: Bringing Drama into the Engineering Classroom

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Introduction

The role of the teacher in the classroom is often likened to the actor engaging an audience in the theatre. Joseph Lowman\(^1\) states that, “College classrooms are fundamentally dramatic arenas in which the teacher is the focal point, like the actor or orator on stage.” Wankat and Oreowicz\(^2\) further state, “All lectures are performances.” A teacher can be competent without performing, but “the ability to stimulate strong positive emotions in students separates the competent from the outstanding teacher”\(^1\). Humor, spontaneity, variety of activity, animated delivery, enthusiasm for the subject matter, and the presence of drama in the classroom can help foster such emotions. It may appear difficult upon first glance to imagine how one brings drama and flair into the engineering world of derivations, complex equations, and code requirements. It takes more imagination than a class on law or history, which seem to lend themselves better to dramatic effect. Wankat and Oreowicz\(^2\) contend that dramatic effect in the realm of engineering is natural because “there is an inherent drama and majesty in the ability of theory to predict and occasionally miss the behavior of the real world.” The Statics and Dynamics course at the United States Military Academy (USMA) at West Point, New York, has made drama an integral part of the course and the cornerstone for several lessons. This paper presents three specific lessons that effectively use drama to excite students and enhance their learning. Several key components are identified for each lesson that were critical to developing the desired drama effect during the lesson. These components could be used in any course to develop drama in the classroom to equally develop a stimulating learning environment.

Statics and Dynamics Course Background

Statics and Dynamics, course number EM302 at USMA, is a three credit-hour engineering mechanics course that is offered both fall and spring semesters in the Civil and Mechanical Engineering Department. The course encompasses traditional rigid body mechanics: Statics, Kinematics and Kinetics. The course is required for all civil, mechanical and electrical engineering majors. It is an elective for several other engineering programs, to include systems and environmental engineering. Also, unique to the West Point academic system, non-engineering students may be required to take the course. All USMA students, regardless of their major, are required to complete a five-course sequence in an engineering field. EM302 is the first course in the majority of the engineering field sequences. As a result of this unique situation, EM302 has been carefully designed to appeal to a broad base of learning styles for engineering and non-engineering majors. Drama is a key to the success of engaging this broad student base and plays a critical role in the three specific lessons outlined in this paper.
Lesson Example #1: The Free Body Diagram Demonstrator

One of the most critical skills in engineering mechanics is the ability to draw effective free body diagrams (FBD). Because of the importance of this skill, most courses devote an entire lesson to the development and discussion of the FBD as the key component in solving mechanics problems. At the basic lesson level, the instructor probably uses a set of figures from a textbook or other source to introduce the FBD. Following a preliminary discussion of various types of supports and associated reactions, the instructor may do an example problem. An intermediate lesson level makes use of physical models of the supports to get the students to “feel” the reactions. Drama takes it a step further by bringing the physical models alive and turning the lesson into an unforgettable learning experience.

Norman Schwartzkopf led the Allied Coalition Forces to victory in Desert Shield/Desert Storm and became an American Hero. However, his dramatic conclusion to the FBD demonstration lesson as a mechanics instructor at West Point has been source of inspiration for cadets and instructors for decades. The FBD demonstration lesson unfolds as follows:

a. The FBD concept is introduced and its importance is stressed along with a simple set of rules and development guidelines.

b. A model for a demonstration is unveiled that consists of a wooden member (2 in. x 2 in. x 24 in.) with an applied load and a variety of supports. Additionally, a partially complete FBD is posted behind the model, Figure 1.

c. The instructor takes elaborate safety measures, to include posting yellow caution tape, issuing safety glasses and hard hats, much to the curiosity and amusement of the students.

d. The demonstration begins with a discussion and removal of the applied load. However, rather than simply removing the weight by hand, the instructor uses large pliers to meticulously remove the weight with excessive caution. The instructor then marks the associated applied load on FBD.

e. The instructor continues the demonstration for each of the supports by discussing how motion is prevented, posting the associated reactions on the FBD drawing and removing the support from the model. Similar to the applied load, the instructor selects a progressively more ridiculous tool for removing each support. The specific tools used to remove the supports vary among instructors, but the author’s favorite selections for each support are:
   - Roller, use a hammer to knock it across the room,
   - Cable, use a blow torch to cut it,
   - Pins, use a grinder to cut them off, Figure 2,
   - Dowel (fixed support at the end), chainsaw or an axe (as immortalized by Norman Schwartzkopf as his personal favorite) to conclude the demonstration.

Regardless of the sequence of “equipment” used in the demonstration, the student will enjoy the excitement and drama the instructor has brought to the lesson. The drama in this lesson results from the instructor slowly building from what appears to be a “mundane” demonstration into a sequence of unexpected events, which can startle and amaze the students. There are several key components to building drama in this lesson example:
• The instructor is overly concerned about safety at the beginning of the demonstration. The students expect a safe environment in the classroom, but will become interested if the instructor is obviously going out his way to be safe, i.e. a roll of caution tape and hard hats.

• The use of increasing levels of excess equipment for simple actions. The demonstration should not start with a chainsaw. Build the students’ anticipation with increasing greater overkill and they are soon asking, “What could possibly be next?”

• The instructor guides the demonstration through a series of “up and down” events. An effective building of drama in the classroom can use this roller coaster-like ride of learning: excitement followed by serious discussion, followed by more excitement, followed by more discussion, etc. The students will be amazed with each sequence of events as the instructor returns to “earth” after each wild event. The whole demonstration is delivered very “matter-of-fact” as it is the standard business for learning engineering mechanics.

• As with a good joke, the overall pace and timing in a demonstration of this magnitude are critical. Some actions require a slow and deliberate motion: placing the caution tape, using pliers to remove the applied load, using the blow torch on the cable and using the grinding wheel on the pins. Other actions require a quick motion: using a hammer to remove the roller and an ax or chainsaw for the fixed support dowel. Ideally, it is an alternating sequence of slow and fast events that keeps the lesson alive.

At the end of the lesson, the instructor should be winded and the students’ mouths agape. The students will leave with a visual memory of the free body demonstration, the belief that their instructor “lives, breaths, and loves” the material, and an understanding of the FBD shown in Figure 3. They will never enter the classroom again without asking, “Hmmm, I wonder what will happen today?”

Lesson Example #2: The Mass Moment of Inertia Race

There are many opportunities in a mechanics course to challenge the student’s perception about the physics of the real world. The physical property of mass moment of inertia is one of these opportunities. This property can be introduced at the basic lesson level through mathematical derivations and textbook figures. As with the FBD demonstration lesson, physical models bring the lesson to the intermediate level of excitement and drama takes it one more level to the target learning environment.

A simple race is used to demonstrate the effect of the mass moment of inertia (MMI) on moving bodies. But the sequence of events preparing for the MMI race builds the drama in the lesson and keeps the students on the edge of their seats. The lesson unfolds as follows:

a. The MMI race begins with the instructor ringing a bell and announcing, “Place your bets, place your bets. Welcome to the EM302 Racetrack. Today we have Rolling Timber versus Steel Wheel. Who will be the big winner?”
b. Two composite cylinders are displayed with roughly the same total mass, Figure 4. *Rolling Timber* has a wooden shell with steel core and *Steel Wheel* has a steel shell with wooden core.

c. The instructor surveys the students for their “bets,” ensuring that every student commits to a prediction, and asks for a volunteer to assist in the race. He carefully positions the volunteer at the end of an inclined plane, Figure 5, and slowly moves to the top to start the race.

d. The instructor meticulously places the two composite cylinders on the top of the ramp and says, “Ready, set, oh wait a second here – hold one!” The instructor postpones the race and questions the students about the composite cylinders. Are they the same? What does it matter? What property will determine who wins the race? What are we talking about? The goal is to begin a formal discussion of the course’s base equation, $F = ma$. Eventually, the instructor claims, “The composite cylinders have roughly the same total mass, so their acceleration should be the same and there should be a tie.” The instructor again surveys the classroom for “bets” and the big race continues. Only to be stopped again!

e. The sequence, “ready, set, wait a second!” is repeated several times as the instructor postpones the race to continue a developing discussion about how the students could predict the winner. The students are lead to the conclusion that the composite cylinders are in general plane motion and, although their total masses are roughly equal, their mass moments of inertia are not equal. Therefore, the mass moment of inertia of the composite cylinders will determine the winner and this property is calculated for each composite cylinder:

1. Weigh and calculate the mass of each component of the composite cylinders,
2. Calculate each component’s mass moment of inertia,
   - Solid core, $I_{\text{core}} = \frac{1}{2} m_{\text{core}} r_{\text{core}}$  \hspace{1cm} (1)
   - Shell, $I_{\text{shell}} = m_{\text{shell}} r_{\text{shell}}$  \hspace{1cm} (2)
3. Calculate the composite cylinders total mass moment of inertia,
   - $I_{\text{total}} = I_{\text{cylinder}} + I_{\text{shell}}$  \hspace{1cm} (3)

f. The instructor surveys the class once more, sets up the race and yells, “Go” as he finally releases the composite cylinders. As predicted, the composite cylinder with the lower mass moment of inertia wins the race.

The drama built in this lesson example is different than the first lesson example. The students are asked to participate with a prediction about a physical test based on physical body properties. Some of the students will hesitate due to their lack of knowledge, confidence and/or experience. Other students will jump to a conclusion and take a chance with their prediction. However, both groups of students will have a strong desire to see what happens and eventually learn why what they observed happened. This active participation by the students is what sets this lesson example apart from the first lesson example. There are several key components to building drama in this lesson example:

- Student participation in the prediction of the demonstration outcome. As previously discussed, this component gets the students to invest in the lesson.
• The instructor guides the demonstration through a series of “up and down” events. Similar to the first lesson example, the roller coaster-like ride of learning continues: excitement followed by serious discussion followed by more excitement followed by more discussion, and continued till the demonstration is complete.

• The overall pace and timing of the demonstration events is again critical to this lesson example. The speed at which the instructor sets up for each race should quicken with each iteration. This pace will complement the student’s growing desire to see the outcome of the race.

At the end of this lesson, the instructor and students are enjoying the joke. However, the students will have committed to the race and are satisfied to finally see and understand the outcome.

**Lesson Example #3: Flaming Golf Ball Catapult**

Rigid body kinetics is the concluding block of material in EM302, Statics and Dynamics. This material provides a review of everything in the course and the opportunity to really investigate some real-world dynamic systems. At the United States Military Academy the students are obviously interested in weapon systems. Weapon systems provide a great opportunity to link their military and engineering disciplines. A basic lesson level for kinetics could discuss how various methods could be used to solve problems involving weapon systems. As seen with the previous two lesson examples, including physical models for these discussions would enhance the learning experience. However, this lesson takes the drama in the classroom to the next level with the opportunity to actually demonstrate kinetics in action.

This lesson example begins with the opening battle scene from the movie *Gladiator* where siege engine catapults are used to fire flaming pots of oil on the Germanic Barbarian warriors. This leads to a discussion about siege engines. Eventually the instructor proposes calculating the range of a model siege engine catapult firing a golf ball, Figure 6. The calculations on the model (which comprise the remainder of the lesson) are conducted as follows:

a. Instructor disassembles the catapult and guides the students through the required weight measurements and mass calculations:
   • Weight of ball, cup (holds the ball) and throwing arm: \( w_{ball}, w_{cup}, w_{arm} \)
   • Convert weights to mass: \( m_{ball}, m_{cup}, m_{arm} \)

b. Various lengths are measured on the throwing arm, Figure 7:
   • Total length, \( L_{arm} \)
   • Length, center of gravity to pin of rotation, \( L_{G/O} \)
   • Length, cup to pin location, \( L_{ball/O} \)

c. Calculate the composite Mass Moment of Inertia (MMI) for the throwing arm, ball and cup, about the pin of rotation using the Parallel Axis Theorem:
   • \( I_O = \Sigma (I_G + m d^2) \) (4)
   where:
   \( I_G \) is the MMI of each individual body about its center of gravity,
   \( m \) is the mass of each individual body in the system,
   \( d \) is the distance from each individual body to the pin of rotation.
d. Measure the throwing arm’s release angle, $\theta$, and the associated ball’s release angle, $\phi$, Figure 8.

e. Calculate the vertical displacements of the masses from state 1 where the arm is prepared to fire to state 2 where the arm has rotated about the pin and fired the golf ball at the arm’s release angle, $\theta$, Figure 8:

- $\Delta y_{ball} = L_{ball}/O \sin (\theta)$  
  \hspace{1cm} (5)
- $\Delta y_{G-arm} = L_{G}/O \sin (\theta)$  
  \hspace{1cm} (6)

f. The rubber band provides the energy to the system. Measure the required lengths for the rubber band:

- Unstretched length, $l_o$,
- Stretched length in state 1 (cocked), $l_1$,
- Stretched length in state 2 (missile release), $l_2$.

g. Measure the spring constant for the rubber band by hanging a known weight and measuring the elongation due to that weight:

- $k_{rubber\ band} = \text{weight (force)} / \text{elongation (displacement)}$  
  \hspace{1cm} (7)

h. Establish the work-energy kinetic equation: $T_1 + U_{1\ to\ 2} = T_2$  

where:

- $T_1$ is zero because the system starts from rest,
- $U_{1\ to\ 2}$ is the total work from state 1 (cocked) to state 2 (missile release):

  where:
  
  $U_{wt-arm} = - w_{arm} \Delta y_{G-arm}$  
  \hspace{1cm} (9)
  $U_{wt-ball} = - w_{ball} \Delta y_{ball}$  
  \hspace{1cm} (10)
  $U_{wt-cup} = - w_{cup} \Delta y_{ball}$  
  \hspace{1cm} (11)
  $U_{rubber\ band} = - \frac{1}{2} k_{rubber\ band} (s_2^2 - s_1^2)$  
  \hspace{1cm} (12)

  where:
  
  $s_2 = l_2 - l_o$  
  \hspace{1cm} (13)
  $s_1 = l_1 - l_o$  
  \hspace{1cm} (14)

- $T_2 = \frac{1}{2} I_o \omega_{arm}^2$  
  \hspace{1cm} (15)

  where:

  - $I_o$ is the MMI of the system about the pin of rotation
  - $\omega_{arm}$ is the angular velocity of the throwing arm
  - $\omega_{arm} = v_{ball} / L_{ball}/O$ due to kinematics

i. Solve for the final velocity of the ball from the work-energy equation above.

j. Calculate the predicated range from a simplified ballistic equation that ignores drag and assumes the same elevation for firing and landing of the ball:

- Range = $v_{ball}^2 \sin (2 \phi) / a_{gravity}$  
  \hspace{1cm} (17)

k. The whole process of calculating a predicted range for the golf ball will take the majority of the lesson period (55 minutes at USMA). Students are chosen to make specific measurements as time permits. Eventually the moment of truth arrives and the instructor reassembles the catapult and prepares it for launching.

l. An empty garbage can is positioned at the calculated range. Then the instructor, with a devilish grin, pulls out a can of lighter fluid, coats the golf ball and lights it, Figure 9.

The golf ball is released, flies through the air with a trail of flames and lands squarely in the garbage can. (hopefully!)
This lesson has been very popular among the students and the instructors. As shown in Eqns. (4) through (17), it reviews a multitude of previously learned key concepts. The lighter fluid provides great excitement in the launching position, but the fire will extinguish during the flight and land safely in the garbage can target. The bottom line with this demonstration is that the golf ball must land at least close to the garbage can target. It has taken several semesters of adjustments to hit the garbage can consistently.

There were three areas of concern that had to be accounted for to ensure consistent launches. First, the model catapult had to be modified with a collar to account for some belt friction across a support pin for the rubber band, Figure 10. Second, the rubber bands could not be left in the cocked position for long periods of time because they would develop permanent deformations and cause a miscalculation in the range. Third, although the instructor leads the students through the measuring of the model catapult components, he must stick to a set of predetermined calculations. The system is highly sensitive to the rubber band measurements and the angle of release. Hence, these measurements must be carefully taken and accounted for to ensure the predicted range.

This third lesson example provides another form of building drama in the classroom. The other two lesson examples do not fill the entire lesson period and are not essential to a successful class. The students and the instructor spend the entire lesson solving the catapult problem together. The class is only successful if the problem is solved and the golf ball gets fired before the class period ends. Rehearsal and time management are critical. There are several key components to building drama in this lesson example:

- Instructor and student participation in the outcome. This component was observed partially in the mass moment of inertia races, but as previously discussed the instructor and students are now a team in their investigation of the catapult.
- The instructor guides the class through the investigation. Initially this does not seem to be a component of building drama in the lesson. However, the instructor carefully asks questions throughout the lesson to keep the students curious how the calculations are completed and whether the outcome will be successful.
- The overall pace and timing of the lesson. The two previous lessons relied on an “up and down” roller coaster-like learning experience. This lesson is more like the initial climb for the first hill on the roller coaster ride. The “click-clack, click-clack, click-clack” is essentially heard throughout the lesson. However, ideally the pace quickens as the end of the lesson approaches. The students want to see what happens and if their efforts are rewarded.

At the end of the lesson, after hitting the garbage can target, the students will be amazed and truly appreciative of the instructor’s efforts to bring the classroom alive. They also see how seemingly disparate computations can all come together in a single problem. And when the ball hits the garbage can, the equations actually work in real life. If time allows, this lesson should be followed up with another catapult lesson where the students can repeat some of the calculations by investigating other system settings. Additionally, they are well prepared to investigate other siege engines or further investigate the catapult on a graded homework assignment or test problem.
Conclusions

The three lessons presented above represent a range of examples that use drama to reach an optimal excitement level and enhance the learning experience. The key components to building drama in the classroom were identified in each example. These are just several examples used by the instructors in EM302 at USMA. How other instructors build drama in their classroom for a particular lesson is limited only by their imagination and willingness to make the additional effort. In addition to these observations, the drama in the lessons can be categorized as follows:

1. **Pure Entertainment Demonstration.** The Free Body Diagram Demonstration lesson essentially is a dramatic presentation by the instructor. The use of outrageous tools to dismantle the FBD demonstrator adds nothing to course content, but helped hold student interest. It requires extensive preparation/practice, but the execution is low risk because there is minimal student interaction.

2. **Physical Property Prediction/Demonstration.** The Mass Moment of Inertia race also requires extensive preparation/practice by the instructor. The execution is riskier because of the student interaction and involvement. This exercise enhanced physical understanding and was entertaining to the students.

3. **Physical System Prediction/Demonstration.** The Flaming Golf Ball Catapult requires maximum preparation/practice and is obviously the most risky because of the mandatory requirement to hit the target. The entire lesson is built around the demonstration. Time management is absolutely critical because the class is a failure and the drama is totally lost if the computations are not completed and the flaming catapult is not fired by the end of the class period.

The three categories of drama shown above are essentially in order of increasing complexity, but represent associated greater payoffs in lesson excitement and student learning. The extensive preparation and additional rehearsal by the instructor are common to all three lessons. Drama in the classroom is not cheap, but well worth the cost when it is done well – and it’s fun!

Bibliography

3. The catapult used is called the *Statapult* and is manufactured by Air Academy Press.

Biography

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Joseph P. Hanus is an Assistant Professor and Course Director for EM302, Statics and Dynamics, at the United States Military Academy (USMA). He is registered Professional Engineer in Wisconsin. MAJ Hanus received a B.S. degree from University of Wisconsin at Platteville in 1990 and an M.S. in Civil Engineering from University of Minnesota at the Twin Cities in 1998. jj1977@usma.edu.

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Figure 1, Free Body Demonstrator

Figure 2, Grinder to Remove Pins
Figure 3, Completed FBD

Figure 4, Steel Wheel and Rolling Timber for the MMI Race
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Figure 5, Inclined Plane for the Mass Moment of Inertia Race

Figure 6, Model Catapult
Figure 7, Throwing Arm Measurements

Figure 8, Firing Angle and Vertical Displacements
Figure 9, “Loose” the Catapult!

Figure 10, Catapult Modification

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