Interactive video-enhanced tutorials (IVETs) involve web-based activities which lead students through a solution using expert-like problem-solving approaches, such as those needed for solving problems using Newton’s Second Law. The IVETs, which are based in part on the tutorials created at the University of Pittsburgh, are designed using multimedia principles of learning and research on human learning and memory. The tutorials are adaptive and provide different levels of scaffolding depending on students’ needs. They are also affect-adaptive, such that additional guidance is provided to students who indicate they are confused, frustrated, or bored while completing the IVET. This presentation will showcase one of the IVETs and its various design features. Research results regarding students’ behaviors as they engage with the IVET, as well as the impact of the IVET on student problem-solving ability, will also be presented.

*Work supported by the NSF IUSE Program (DUE #1821396)
Promoting Problem-Solving Abilities through Web-based Interactive Video-Enhanced Tutorials

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ROBERT TEESE & MICHELLE CHABOT, ROCHESTER INSTITUTE OF TECHNOLOGY

NSF IUSE DUE 1821396
Where do your students go for help with homework?
When stuck on homework problems, which **ONE** did you use most?

<table>
<thead>
<tr>
<th>Resource</th>
<th>Spring 2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>Google (ex. Chegg.com)</td>
<td>47%</td>
</tr>
<tr>
<td>Other students</td>
<td>23%</td>
</tr>
<tr>
<td>Khan or other online videos</td>
<td>15%</td>
</tr>
<tr>
<td>Textbook</td>
<td>8%</td>
</tr>
<tr>
<td>Physics Learning Center</td>
<td>2%</td>
</tr>
<tr>
<td>Office hours</td>
<td>1%</td>
</tr>
<tr>
<td>Supplemental Instruction Sessions</td>
<td>1%</td>
</tr>
<tr>
<td>Didn’t seek help or other</td>
<td>3%</td>
</tr>
</tbody>
</table>

85% of students

See low correlation between student HW scores and exam scores.
DeVore and Singh developed ~20 tutorials introductory physics. Implemented through Powerpoint and designed to carefully guide students to a solution through the use of branching questions.

A large wooden wheel of radius $R$ and moment of inertia $I_w$ about its axis of symmetry is mounted on an axle so as to rotate freely. A bullet of mass $m_b$ and speed $v_b$ is shot and moves in a straight line (neglect gravity) tangential to the wheel and strikes its edge, lodging in it at the rim. If the wheel was originally at rest, what would its angular speed be after the collision between the bullet and the wheel?
Effectiveness of Tutorials

Interactive Video Vignettes (IVVs)

Designed to teach concepts for which students are known to struggle.

www.compadre.org/ivv or WebAssign (Cengage)
Project Goals

- Create and evaluate a set of 30 IVETs

- Conduct research on
  - impact of IVETs on student problem solving abilities
  - techniques that motivate appropriate student behavior when using IVETs

- Disseminate through ComPADRE, publisher, etc.
Features of Design of IVETs

- Developed based on multimedia learning principles (Richard Mayer) and research on human learning and memory (Bransford)
- Problems challenge students while providing support designed to stretch students’ zone of proximal development
- Student support delivered through mini-lectures, hints, or encouragement (affect) by a tutor (a real person in a video)
Features of Design of IVETs

- Multiple-choice questions guide students through an *effective problem-solving approach* (e.g., define a coordinate system, draw a force diagram, etc.)
- Questions branch based on student responses, providing relevant feedback for incorrect (and correct) answers
- Self-paced such that students who need less support can navigate through it quickly and vice versa
- 5-10 minutes to complete
Example IVET – Linear Momentum and Energy
Two small spheres of putty, A and B, of equal mass \( m \), hang from the ceiling on massless strings of equal length. Sphere A is raised to a height \( h_0 \) as shown below and released. It collides with sphere B (which is initially at rest). The two spheres stick and swing together to a maximum height \( h_f \). (Assume a completely inelastic collision with the two spheres sticking together after the collision.)

Find the height \( h_f \) in terms of \( h_0 \).

Assume that the lowest point in the path is the point of zero gravitational potential energy.
Video option: Narrator presents problem to be solved.

\[ m_A = m_B = m \]

Find \( h_f \) in terms of \( h_0 \).
Keep good notes as you go through this tutorial. You will need them. Briefly summarize your plan for solving the problem in the box below:

Solution Plan
Before starting any physics problem, you should always decide which principles will be needed. If you want to see the problem statement again, click the **Problem Statement** button at the bottom of this window.

**Q1:** Choose all of the following physics principles we should use to solve this problem:

- A. Conservation of Total Mechanical Energy
- B. Conservation of Momentum
- C. Newton's 2nd Law
Feedback is provided for all incorrect as well as correct responses.

Newton's 2nd Law:
Remember initial and final accelerations.
Feedback is provided for all incorrect as well as correct responses.

Correct. Click the Next Page button to continue.
Multiple select questions used to engage students and reduce guessing.

Q2: What type(s) of initial mechanical energy does ball A have when it is released? What type(s) of final mechanical energy does ball A have just before it strikes ball B? Choose all that are not zero:

- A. Initial Kinetic Energy
- B. Initial Gravitational Potential Energy
- C. Final Kinetic Energy
- D. Final Gravitational Potential Energy

Feedback is aligned to choices made.
Students are expected to work problem out on paper along with IVET.

Q3: Which one of the following expressions for the speed $v_A$ of ball A right before it collides with ball B is correct?

- A. $v_A = \sqrt{2gh_0}$
- B. $v_A = \sqrt{gh_0}$
- C. $v_A = \sqrt{\frac{gh_0}{2}}$

Incorrect answer selected.
Feedback is provided to get student started in addressing this part of problem.

Incorrect. Click Next Page to go back and try again.

$$mg \Delta h = \frac{1}{2} \text{mv}_A^2$$
Students get brief summary even when correct.

**Reasoning:**

\[
m_A g h_0 = \frac{1}{2} m_A v_A^2
\]

\[
gh_0 = \frac{1}{2} v_A^2
\]

\[
2 gh_0 = v_A^2
\]

\[
v_A = \sqrt{2 gh_0}
\]
Throughout the IVET, emphasis is placed on solving the problem in parts. Here, the student is moved into the 2\textsuperscript{nd} part of the problem.

Q4: Which of the following principles is most convenient to find an expression for the speed of the merged balls ($v_{AB}$), in terms of the speed that ball A had immediately before the collision ($v_A$)?

- A. Conservation of Linear Momentum
- B. Newton’s Second Law
- C. Conservation of Total Mechanical Energy
Students are led to an equation which wraps up the collision part of the problem.

Q5. Which one of the following is true for a collision where two objects are moving together before the collision and separate after the collision?

\[ v_{AB} = \frac{v_A + v_B}{2} \]

- A. \[ \sum p_i = \sum p_f \]
- B. \[ m_A v_A = (m_A + m_B) v_{AB} \]
- C. \[ m_A v_A = 2m_B v_{AB} \]
- D. \[ v_{AB} = v_A \]
### How are you feeling right now?

<table>
<thead>
<tr>
<th>Feeling</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine</td>
<td>Your instructor will NOT see your answer to this question.</td>
</tr>
<tr>
<td>Confused</td>
<td>There are two reasons for answering the question.</td>
</tr>
<tr>
<td>Frustrated</td>
<td>1. You may find the response helpful.</td>
</tr>
<tr>
<td>Bored</td>
<td>2. The answer will be sent anonymously to the authors of the tutorial, and they will use the class-averaged data to improve the tutorial. If you do not wish to let the authors know how you are feeling, you can choose not to answer this question.</td>
</tr>
<tr>
<td>Worried</td>
<td>I worry that I will not do well in this course.</td>
</tr>
<tr>
<td>Other</td>
<td>None of the choices applies to me. Continue with the tutorial.</td>
</tr>
<tr>
<td>I Prefer Not To Answer</td>
<td>Continue with the tutorial.</td>
</tr>
</tbody>
</table>
Do you want to see a video summary of what we have done so far, or would you rather continue with the tutorial?

- Watch a video summary.
- Continue with the tutorial.

**Before:**
\[
\Sigma E_i = \Sigma E_f
\]
\[
M_A g h_0 = \frac{1}{2} M_A V_A^2
\]
\[
V_A = \sqrt{2 g h_0}
\]

**Collision:**
\[
\Sigma p_i = \Sigma p_f
\]
\[
M_A V_A = (M_A + M_B) V_{AB}
\]
\[
V_{AB} = \frac{V_A}{2}
\]
Throughout the IVET, emphasis is placed on solving the problem in parts. Here, the student is moved into the 3\(^{rd}\) (last) part of the problem.

Now that we have found the speed of the two balls stuck together, once again, use the law of conservation of mechanical energy assuming the initial point is right after the collision and the final point is when balls that are stuck together reach the maximum height \(h_f\).

Q6. Which one of the following expressions is correct for \(h_f\)?

\[
\begin{align*}
    h_f &= \frac{v_{AB}^2}{4g} \\
    h_f &= \frac{2v_{AB}^2}{g} \\
    h_f &= \frac{v_{AB}^2}{2g}
\end{align*}
\]

- A.
- B.
- C.
This step is the end of the problem.

Use the relations we found in previous questions to find an expression for the maximum height of the two balls together \( h_f \) in terms of the initial height of ball A \( h_0 \).

Q7. Which of the following expressions is correct for the maximum height \( h_f \) of the two balls together?

\[ h_f = 2h_0 \quad \quad \quad h_f = \frac{h_0}{4} \quad \quad \quad h_f = \frac{h_0}{2} \]
Do you want to see a video summary of what we have done, or would you rather continue with the tutorial?

- Watch a video summary.
- Continue with the tutorial.
Video summary is ~5 minutes long.

This same video summary is shown to a control group when we evaluated impact of IVET.
Reflection

To test your understanding of this type of problem, try solving it again using $m_B = \frac{1}{2} m_A$.

The result you should get is $h_f = (4/9) h_0$. 
List what things you learned from this tutorial.

Also, the developers would appreciate any feedback about how well the activity worked (technical problems, for example).

Then click the Next Page button in the lower right corner to finish.
Does IVET impact student problem solving ability?

Two sections of algebra-based physics included in study
- One section given the Linear Momentum IVET to complete at home
- One section asked to watch the same ~5 minute solution showcased in the IVET

Both groups given a paired problem to complete in class on the day the assignment was due.

The assignments were flipped between sections when subsequent IVETs were tested.
A 2000 kg truck starts at rest 15 m above the bottom of a hill. It rolls down the hill and at the bottom the truck collides and locks bumpers with (sticks to) a 1500 kg car which is at rest at the bottom of the hill in a completely inelastic collision. The two vehicles then roll together up a second hill. Assuming that both vehicles are in neutral and roll without energy loss due to friction or air resistance, how high up the second hill will the two vehicles travel before stopping?
Paired Problem – post-assessment

A 2000 kg truck starts at rest 15 m above the bottom of a hill. It rolls down the hill and at the bottom the truck collides and locks bumpers with (sticks to) a 1500 kg car which is at rest at the bottom of the hill in a completely inelastic collision. The two vehicles then roll together up a second hill. Assuming that both vehicles are in neutral and roll without energy loss due to friction or air resistance, how high up the second hill will the two vehicles travel before stopping?

1. Conservation of Energy

\[(m_{\text{truck}} \cdot gh)_{\text{top}} = \left(\frac{1}{2} m_{\text{truck}} v^2\right)_{\text{bottom}}\]
Paired Problem – post-assessment

A 2000 kg truck starts at rest 15 m above the bottom of a hill. It rolls down the hill and at the bottom the truck collides and locks bumpers with (sticks to) a 1500 kg car which is at rest at the bottom of the hill in a completely inelastic collision. The two vehicles then roll together up a second hill. Assuming that both vehicles are in neutral and roll without energy loss due to friction or air resistance, how high up the second hill will the two vehicles travel before stopping?

2 Conservation of Linear Momentum (collision)

\[(m_{\text{truck}}v)_{\text{before}} = (m_{\text{truck+car}}v)_{\text{after}}\]
Paired Problem – post-assessment

A 2000 kg truck starts at rest 15 m above the bottom of a hill. It rolls down the hill and at the bottom the truck collides and locks bumpers with (sticks to) a 1500 kg car which is at rest at the bottom of the hill in a completely inelastic collision. The two vehicles then roll together up a second hill. Assuming that both vehicles are in neutral and roll without energy loss due to friction or air resistance, how high up the second hill will the two vehicles travel before stopping?

\[
\text{Conservation of Energy (up the hill)}
\]
\[
\left( \frac{1}{2} m_{\text{truck+car}} v^2 \right)_{\text{bottom}} = (m_{\text{truck+car}} gh)_{\text{top}}
\]
Correct Solution

\[ PE_i = mgH \quad K = 0 \]

\[ m_1 = 2000 \text{ kg} \]

\[ H = 15 \text{ m} \]

\[ +3 \]

\[ PE_i + K_i = PE_f + K_f \]

\[ mgH + 0 = 0 + \frac{1}{2}m_1u_1^2 \]

\[ mh = \frac{1}{2}m_1u_1^2 \]

\[ u_1 = (2gH)^{1/2} \]

\[ +3 \]

\[ m_1u_1 + m_2u_2 = V \sqrt{(m_1+m_2)} \]

\[ 2000 \text{ kg} (2gH)^{1/2} = V \sqrt{(2000 \text{ kg} + 1500 \text{ kg})} \]

\[ 2000 (2 \times 9.8 \times 15)^{1/2} = 3500 \text{ V} \]

\[ 34292.056399 \times 3500 = 3500 \text{ V} \]

\[ V = 9.79796 \text{ m/s} \]

\[ +4 \]

\[ \frac{1}{2} (m_1+m_2)V^2 = (m_1+m_2)gH' \]

\[ \frac{1}{2} (2000 \text{ kg} + 1500 \text{ kg})(9.79796)^2 = (3500 \text{ kg})(9.8 \text{ m/s}^2)H' \]

\[ 1750 (9.80003) \approx 34300 \text{ H'} \]

\[ 1698000.58397 = 34300 \text{ H'} \]

\[ H' = 49.79796 \text{ m} \]

The 2 vehicles will travel \[4.90 \text{ m}\] up the hill before coming to a stop.
Results of Scoring Paired Problem

- Watched Video Solution (n=124)
  - Avg: 6.33
- Completed IVET (n=105)
  - Avg: 8.83

$p < 0.001$
Eff Size = 0.91
Results of Scoring Paired Problem

Correct (or with simple math error):
- 43%
- 77%
p < 0.001
Range of solutions presented

<table>
<thead>
<tr>
<th>Video</th>
<th>IVET</th>
<th>Code Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>43%</td>
<td>77%</td>
<td>Correct (includes minor math errors or unit omission)</td>
</tr>
<tr>
<td>5%</td>
<td>0%</td>
<td>Correct but conserved KE for collision instead of momentum</td>
</tr>
<tr>
<td>8%</td>
<td>11%</td>
<td>“Correct” idea, incorrectly transferred from Video/IVET</td>
</tr>
<tr>
<td>30%</td>
<td>12%</td>
<td>Used conservation of energy only; few mentioned LM</td>
</tr>
<tr>
<td>4%</td>
<td>0%</td>
<td>Used conservation of momentum only (collision)</td>
</tr>
<tr>
<td>5%</td>
<td>0%</td>
<td>Applied incorrect concepts in solution (Work-KE Thm, etc)</td>
</tr>
<tr>
<td>6%</td>
<td>1%</td>
<td>Appeared to have no idea</td>
</tr>
</tbody>
</table>
Applied Conservation of Energy Only (one step solution)

\[ \sum E_i = \sum E_f \]

\[ m_c g h_0 + M + g h_0 = (M + M_c) \cdot g h_f \]

\[ (1500)(9.8)(10) + (2000)(9.8)(15) = (2000 + 1500) \cdot (9.8) \cdot h_f \]

\[ 294000 = 34300 \text{J} \]

\[ h_f = 0.57 \text{m} \]

18% Video
4% IVET

A few students indicated momentum was conserved but didn’t include idea in solution
Applied Conservation of Energy Only
(two step solution)

1. \( U_g = KE_f \)
   
   \[ mgh_1 = \frac{1}{2}(m_1 + m_2)V^2 \]
   
   \[ (2000)(9.8)(15) = \frac{1}{2}(2000 + 1500)V^2 \]
   
   \[ V = 12.96 \text{ m/s} \]

2. \( KE_i = U_g \)
   
   \[ \frac{1}{2}(m_1 + m_2)V^2 = (m_1 + m_2)gh_2 \]
   
   \[ \frac{1}{2}(2000 + 1500)(12.96)^2(2000 + 1500)(9.8)h_2 \]
   
   \[ 294000 = 34300h_2 \]
   
   \[ h_2 = 8.57 \text{ m} \]

11% Video Only
8% IVET

A few of these indicated momentum was conserved but didn’t include idea in solution.
Incorrectly transferred ideas from Video/IVET

**Linear Momentum**

**Interactive Video Vignettes**

**BEFORE:**
\[
\Sigma E_i = \Sigma E_f
\]

\[
M_A g h_0 = \frac{1}{2} M_A V_A^2
\]

\[
V_A = \sqrt{2 g h_0}
\]

**COLLISION**

\[
\Sigma p_i = \Sigma p_f
\]

\[
M_A V_A = (M_A + M_B) V_{AB}
\]

\[
V_{AB} = \frac{V_A}{2}
\]

**AFTER**

\[
\Sigma E_i = \Sigma E_f
\]

\[
\frac{1}{2} (2m) V_{AB}^2 = (2m) g h_f
\]

\[
h_f = \frac{V_{AB}^2}{2g}
\]
Incorrectly transferred ideas from Video/IVET

1. $V_a = \sqrt{2gh_0}$
   
   $V_a = \sqrt{2 \times 9.8 \times 15}$
   
   $V_a = 17.15 \text{ m/s}$

2. $V_{AB} = \frac{V_A}{2} = 8.58 \text{ m/s}$

3. $h_f = \frac{(V_{AB})^2}{2g}$
   
   $h_f = \frac{(8.58)^2}{2 \times 9.8}$
   
   $h_f = 3.76 \text{ m}$

Memorized eqns used in video/IVET:

5% Video
6% IVET
Incorrectly Transferred Ideas from Video/IVET

\[ h = 15 \]
\[ m = 2000 \]

\[ V_a = \sqrt{2gh} \]
\[ = \sqrt{2(9.8)(15)} \]
\[ = 17.146 \text{ m/s} \]

Collision

\[ m_1v_1 + m_2v_2 = (m_1 + m_2)v_{12} \]

\[ V_{12} = \frac{V_a}{2} \]

\[ V_{12} = \frac{17.146}{2} \]
\[ = 8.573 \text{ m/s} \]

Considered truck and car as same mass

3% Video
5% IVET
Video vs Text Option

Did you use the video or text option for the online video tutorial?

<table>
<thead>
<tr>
<th>Option</th>
<th>Linear Momentum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mainly Video</td>
<td>47%</td>
</tr>
<tr>
<td>Mainly Text</td>
<td>24%</td>
</tr>
<tr>
<td>Same of each</td>
<td>12%</td>
</tr>
<tr>
<td>Didn’t realize an option</td>
<td>10%</td>
</tr>
<tr>
<td>Didn’t do tutorial</td>
<td>7%</td>
</tr>
</tbody>
</table>

Starting in Spring 2020 we can track this behavior.
### Video vs Text Option

Did you use the video or text option for the online video tutorial?

<table>
<thead>
<tr>
<th></th>
<th>Linear Momentum</th>
<th>Conservation of Energy</th>
<th>Newton’s 2(^{nd}) Law</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mainly Video</strong></td>
<td>47%</td>
<td>38%</td>
<td>54%</td>
</tr>
<tr>
<td><strong>Mainly Text</strong></td>
<td>24%</td>
<td>46%</td>
<td>30%</td>
</tr>
<tr>
<td><strong>Same of each</strong></td>
<td>12%</td>
<td>14%</td>
<td>9%</td>
</tr>
<tr>
<td><strong>Didn’t realize an option</strong></td>
<td>10%</td>
<td>2%</td>
<td>4%</td>
</tr>
<tr>
<td><strong>Didn’t do tutorial</strong></td>
<td>7%</td>
<td>0%</td>
<td>2%</td>
</tr>
</tbody>
</table>

Each survey above is from a different section; students not necessarily similar.
Thoughts about guidance in IVET

What did you think of the guidance in the tutorial (such as hints when you got a question wrong)?

<table>
<thead>
<tr>
<th>Opinion</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Helpful</td>
<td>25%</td>
</tr>
<tr>
<td>Mostly Helpful</td>
<td>39%</td>
</tr>
<tr>
<td>Helpful Half the Time</td>
<td>18%</td>
</tr>
<tr>
<td>Rarely Helpful</td>
<td>5%</td>
</tr>
<tr>
<td>Didn’t look at hints</td>
<td>14%</td>
</tr>
</tbody>
</table>
Thoughts about guidance in IVET

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</tr>
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<td>5%</td>
<td>5%</td>
<td>3%</td>
</tr>
<tr>
<td>Didn’t look at hints</td>
<td>14%</td>
<td>5%</td>
<td>9%</td>
</tr>
</tbody>
</table>

Each survey above is from a different section; students not necessarily similar.
Rate IVET

Overall, how would you rate the tutorial with regards to helping you learn how to apply the (problem solving strategy)?

<table>
<thead>
<tr>
<th>Rating</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>5%</td>
</tr>
<tr>
<td>Pretty good</td>
<td>34%</td>
</tr>
<tr>
<td>Average</td>
<td>50%</td>
</tr>
<tr>
<td>Below average</td>
<td>10%</td>
</tr>
<tr>
<td>Terrible</td>
<td>2%</td>
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<th>Conservation of Energy</th>
<th>Newton’s 2\textsuperscript{nd} Law</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>5%</td>
<td>22%</td>
<td>10%</td>
</tr>
<tr>
<td>Pretty good</td>
<td>34%</td>
<td>40%</td>
<td>52%</td>
</tr>
<tr>
<td>Average</td>
<td>50%</td>
<td>32%</td>
<td>32%</td>
</tr>
<tr>
<td>Below average</td>
<td>10%</td>
<td>6%</td>
<td>6%</td>
</tr>
<tr>
<td>Terrible</td>
<td>2%</td>
<td>0%</td>
<td>1%</td>
</tr>
</tbody>
</table>

Each survey above is from a different section; students not necessarily similar.
Student comments about IVET logistics

The activity worked well, and I liked how you could access the problem statement whenever you needed to.

I liked how it gave feedback to correct or incorrect answers.

The only technical problem was it taking a little longer than I expected to load each page. (7 of 120 mentioned loading time)
Student comments about IVETs

I learned to separate into sections and work on each one, one by one. This allows for a more clear way to set up problems.

I learned how to integrate different formulas together to solve 1 problem.
Student comments about IVETs

I learned to separate into sections and work on each one, one by one. This allows for a more clear way to set up problems.

I learned how to integrate different formulas together to solve 1 problem.

This activity was extremely easy to follow and I finally followed a physics problem all the way through.

Very good at explaining how to obtain equations. Related concepts to solving the problem.
Student comments about IVETs

I learned to separate into sections and work on each one, one by one. This allows for a more clear way to set up problems.

I learned how to integrate different formulas together to solve 1 problem.

This activity was extremely easy to follow and I finally followed a physics problem all the way through.

Very good at explaining how to obtain equations. Related concepts to solving the problem.

I really enjoyed the tutorial. Very well made and easy to follow.
Future Work

Identify techniques that motivate appropriate student behavior when using IVETs
  ◦ How do we get them to slow down? Mentally engage?
  ◦ How do we address boredom, confusion, frustration?

Ask a direct question: *How are you feeling right now?*
Have a pop-up with some feedback (text or real person)
Fall 2019, we evaluated 5 IVETs with videos:

- Newton’s 2\textsuperscript{nd} Law (force on two blocks)
- Static Equilibrium (person on ladder leaning against wall)
- Conservation of Energy (will string break on tire swing?)
- Linear Momentum and Energy (pendulum balls collide)
- Angular Momentum (bullet shot into wheel)

New for spring 2020

- Torque and rotation

Questions?

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