Teaching Problem Solving in Introductory Physics Using Interactive Video-Enhanced Tutorials

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Addressing a Need: Developing students' problem-solving skills can be challenging, particularly in large courses. This project involves the development and evaluation of 30 web-based Interactive Video-Enhanced Tutorials (IVETs) to promote effective problem-solving strategies in Introductory Physics.[1-3] Each focuses on important problem-solving approaches (e.g., conservation of energy) by guiding students through the solution of a challenging and complex problem. IVETs include short expositions by a narrator interspersed with branching multiple-choice questions that include feedback, allowing students who require less guidance to navigate quickly, while students who struggle receive additional support and encouragement (affect), offering more personalized instruction similar in certain respects to a live tutor.

The need for this new approach comes from previous research in developing problem-solving materials. Many were found to be effective when used under the supervision of a researcher but were much less effective when completed at home.[4,5] This suggests that students working on their own do not mentally engage at the level necessary for learning. Also, although online homework systems are widely available, with some offering tailored support, many game the system, resulting in little learning. Self-paced learning tools that motivate students to remain mentally engaged, while guiding them through complex problem-solving tasks, are not common. IVETs address this need.

Research questions:

The research agenda provides formative evaluation for improvement while contributing to the research literature.

1. What patterns of behavior do students engage in when completing IVETs in remote settings?
2. What mechanisms encourage productive patterns of student behavior during IVET completion?
3. To what extent do IVETs support student learning, as measured by performance on a transfer problem?

General Structure of IVETs

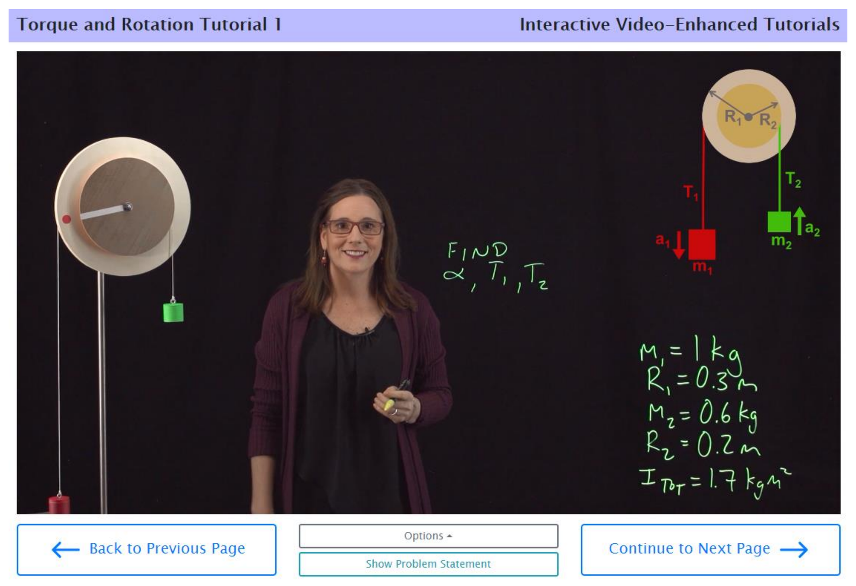
1. Developed based on multimedia learning principles (Mayer) and research on human learning and memory (Bransford).
2. Web-based, self-paced, short (5-15 minutes to complete)
3. Guides students through an expert-like problem-solving approach for given topic (ex. Newton's 2nd Law), using:
   a. Mini-lectures by a real person in a video
   b. Guiding, branching multiple-choice questions (e.g., decide on applicable principles, define coordinate system, etc), with relevant feedback
   c. Encouragement (affect) by a live person
   d. Students choose video or text throughout IVET.

References

1. Project information and a collection of freely available IVETs can be found at the project website: https://ivet.rit.edu/IVET/.
2. Koenig, K., Maries, A., and Teese, R. (2022). Promoting Problem Solving through Interactive Video-Enhanced Tutorials, *The Physics Teacher*, 60, 331-334.
3. Koenig, K., Sunny, C., Maries, A., and Teese, R. (2021). Interactive video enhanced tutorials: A tool for promoting self-paced learning and engagement for future engineers. *Proceedings of the Frontiers in Education (FIE) Annual conference*, University of Nebraska, Lincoln, Nebraska.
4. DeVore, S., Marshman, E., & Singh, C. (2017). Challenge of engaging all students via self-paced interactive electronic learning tutorials for introductory physics. *Phys Rev PER*, *13*(1), 010127.
5. DeVore, S., Using the tutorial approach to improve physics learning from introductory to graduate level, PhD dissertation (University of Pittsburgh, 2013).

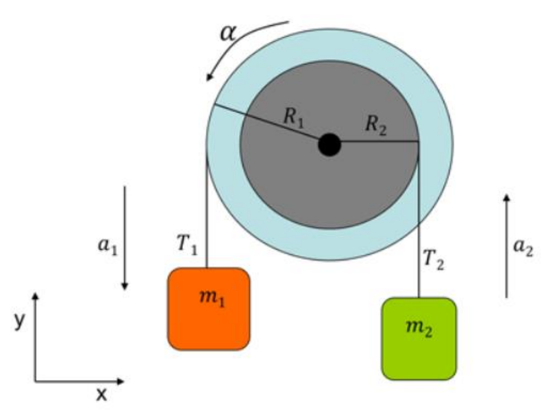
Flow of IVET: Torque and Rotation IVET used here as an example

Each IVET begins with a **description of the problem** by a narrator (below left). Students can also choose to see the problem in text form (below right) and return to it at any time using a button on the bottom of each screen. Before continuing, students are asked to sketch out how they might approach or start solving the problem, and then summarize their ideas in a text box.



Problem Statement

Two blocks ($m_1 = 1.0\,kg, m_2 = 0.6\,kg$) are hanging from a pulley as shown in the figure below. The moment of inertia through the axis of rotation passing through the center of the pulley is $I = 1.70\,kgm^2$. The ropes are attached at two different distances from the center of the pulley ($R_1 = 30cm$ and $R_2 = 20cm$).
Find the angular acceleration α of the pulley system and the tensions T_1 and T_2.



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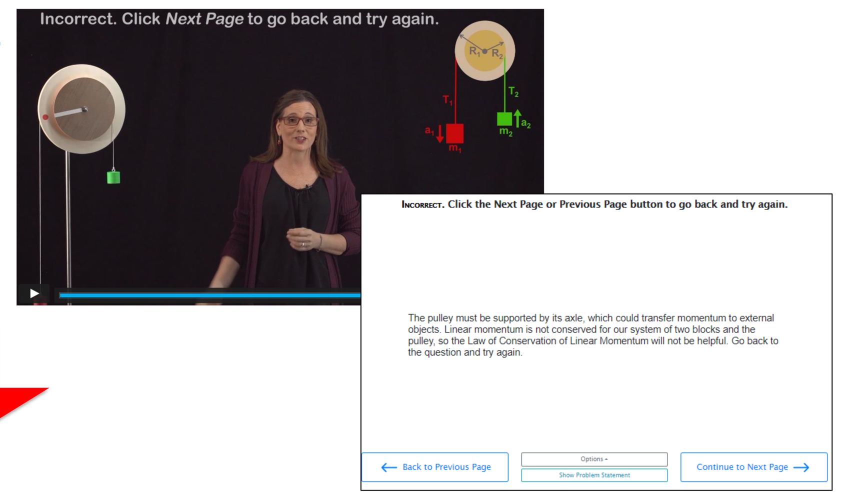
Multiple choice questions (below left) guide students through an expert-like problem-solving process, starting with an understanding of what principles are involved. Multi-select questions are used when appropriate to dissuade students from guessing. Each question includes feedback for correct and incorrect answers, which students can choose to receive from the narrator (below right) or in text form. Hints are often provided as part of the feedback.

Q1: Which physics principle(s) should we use to solve this problem? Choose all that apply. If necessary, scroll down to see all four choices.

- A. Newton's 2nd Law for translations: $\sum \vec{F} = m\vec{a}$
- B. Conservation of Mechanical Energy
- C. Conservation of Linear Momentum
- D. Newton's 2nd Law for rotations: $\sum \tau = I\alpha$ where τ is the torque about a chosen point



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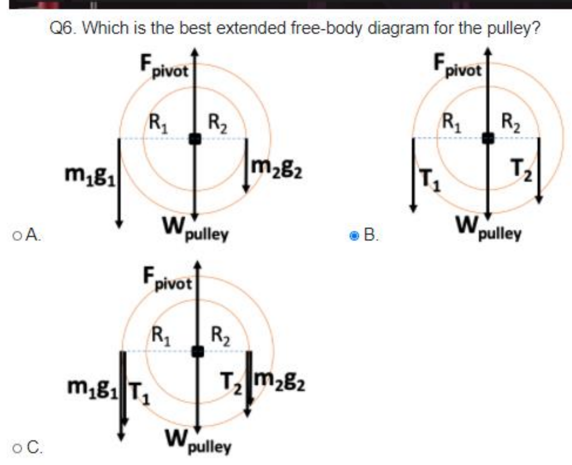
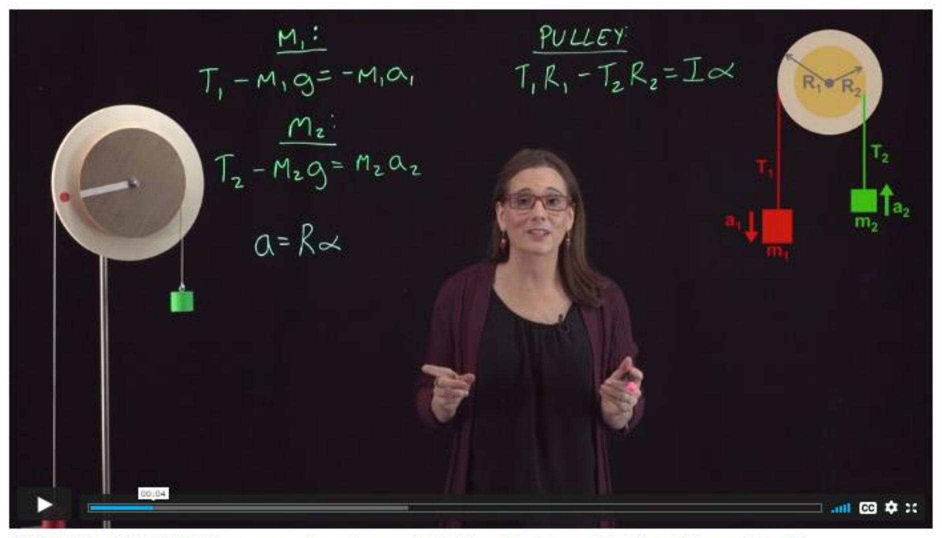
Mini-lectures provide guidance for how to set up the problem, such as drawing free body diagrams (below left) or how to break the problem into parts, as part of the problem-solving process. Multiple choice questions are designed to engage students as they apply the ideas posed.





Q8. Which of the following expressions is correct for the angular acceleration of the pulley α?

- A. $\alpha = \frac{(m_1R_1 - m_2R_2)}{(m_1R_1 - m_2R_2 - I)}g$
- B. $\alpha = \frac{(m_1R_1 - m_2R_2)}{(m_1R_1^2 + m_2R_2^2 + I)}g$
- C. $\alpha = \frac{(m_1R_1^2 - m_2R_2^2)}{(m_1R_1 + m_2R_2 + I)}g$

Show comments by other students

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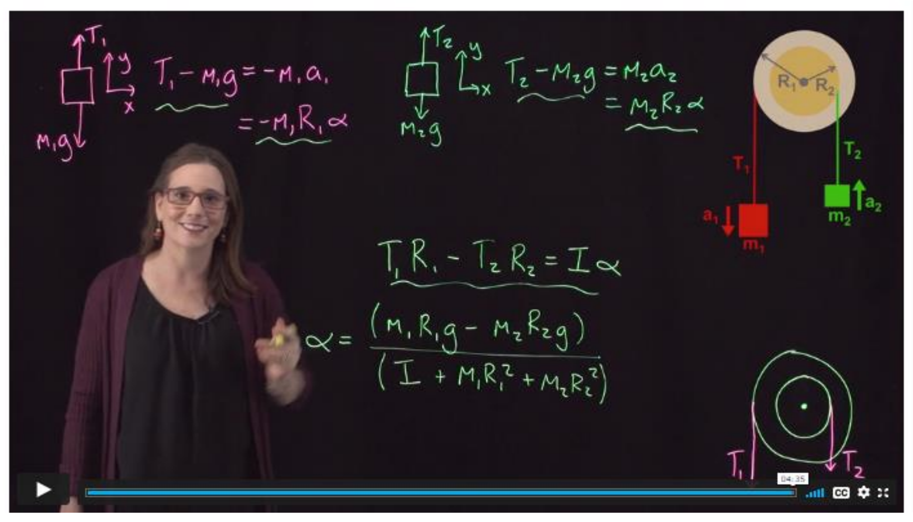
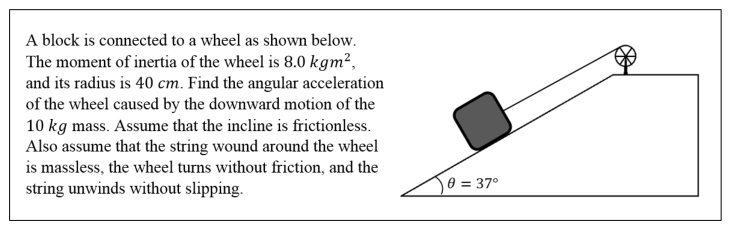


Each IVET ends with a short video summary, with emphasis on the reasoning behind the problem-solving strategies applied. This is followed by the narrator posing another problem students can work through on their own without guidance. Here, the narrator may provide hints for how the new problem differs from the one just solved in order to help students transfer what they just learned to the new scenario. The last page is a completion certificate, which students can print and submit to their instructor, if requested.

Research on Impact of IVET

As part of our research to determine the impact of the IVET on student problem solving abilities, we assigned the IVET as homework to one section of Calculus-based Physics I and assigned the 4-minute summary video from the end of the IVET to another section taught by the same instructor. Each group was then given a follow up problem[5] (shown below) as a graded assignment at the beginning of the next class.

Follow up problem given post-treatment to assess impact of intervention.



Expectations for Students' Solutions

Based on the problem-solving strategies emphasized in the IVET and video, we expected students to (1) draw a FBD for the block shown above, (2) recognize that the block would accelerate, and (3) apply Newton's 2nd Law separately to the block and pulley to generate 2 equations with 2 unknowns as part of their solution.

Analysis

All responses to the paired problem were scored using an 8-point rubric designed around the IVET's learning outcomes (Table 1). Solutions were then coded based on emerging themes (Table 2). Students who didn't complete the treatment were put into a "no treatment" group. All 3 treatment groups were deemed similar based on no significant difference in ACT Math scores, which we've found to have moderate correlation to exam performance.

Table 1. Mean scores for follow-up problem for three treatment groups.

Treatment	N	Average (of 8 pts max) (SD)
IVET	73	4.10 (1.74)
Video-only	66	3.17 (1.83)
None (control)	61	2.57 (1.97)

A one-way ANOVA yielded a statistically significant difference in the follow-up problem scores for all three groups ($p < 0.05$) with a marginal large effect ($\eta^2 = 0.11$; suggesting 11% of the variance in scores was due to treatment type). Post hoc analyses found that the IVET group performed significantly better ($p < 0.001$) than the no treatment group, as well as the video group ($p = 0.013$).

Emerging Themes from Student Solutions

1. **No plan** – Haphazard use of equations, no clear solution path
2. **Assumed a = 0** – These students assumed that the box didn't accelerate down the ramp so they could quickly solve using **τ=Iα** given just one unknown.
3. **Free body diagram** – A correct FDB was included for the box.
4. **2 Equations with 2 Unknowns** – Recognized equations were needed for both the motion of box and pulley, with 2 equations and 2 unknowns, but may not have correctly solved.
5. **Correct** –may include a minor math error in solution

Table 2. Percent of students in each treatment group demonstrating theme.

Treatment	N	No Plan	Assumed a = 0	Correct FBD	2 Eqns with 2 Unknowns	Correct Solution
None	64	42%	16%	20%	8%	3%
Video Only	66	27%	24%	41%	18%	6%
IVET	73	8%	10%	47%	30%	10%

Conclusion

The study outcomes demonstrate the need for web-based learning materials that mentally engage students. The outcomes also shed light on the limited impact of videos, which can easily become passive learning experiences. This is important given the increased use of video lectures to replace or supplement in-person instruction, particularly in light of the pandemic.

The Torque and Rotation IVET is just one example from our collection.[1] We have now evaluated ten IVETs for impact on students' development of problem-solving abilities, and the results are promising.[2] In addition, student surveys indicate that most students like the immediate and relevant feedback provided by the IVETs and feel that they are beneficial to their learning.