Promoting Problem Solving Through Interactive Video-Enhanced Tutorials

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Students in introductory college physics often have wide ranges of preparation, making it challenging to deliver effective instruction for all. While numerous educational products and strategies[1,2] have been shown to be broadly effective, there is a need for research-based online materials that support personalized learning and focus specifically on improving problem-solving abilities. Building from our Interactive Video Vignettes (IVVs),[3,4] we are developing freely available Interactive Video-Enhanced Tutorials (IVETs). These combine videos of real instructors who guide students through an expert-like problem-solving process using a series of required questions that motivate students to interact with the material. Research on the effectiveness of the IVETs is underway and preliminary results are encouraging.

IVET design

IVETs are web-based, self-paced, and short, often taking less than 10 minutes to complete. Each is focused on a challenging introductory-physics problem that exemplifies an important concept or principle. They include videos of mini-lectures interspersed with multiple-choice questions, where students must choose the correct answer before moving to the next video segment. Feedback is provided whenever a correct or incorrect answer is chosen. The questions and feedback are designed to carefully step students through each stage of an expert-like problem-solving process, while emphasizing the reasoning behind each step. Students who require less guidance can navigate through quickly by selecting text instead of video for the questions and feedback, while students who need more support can choose video summaries that provide extra guidance.

Even students who know the principles and concepts for solving problems often have not developed the necessary strategies for applying this knowledge consistently and effectively.[5] Research indicates that mastery is developed through deliberate practice,[6] which is different from solving lengthy or frequent problem sets. Rather, deliberate practice involves effortful activities specifically designed around predefined problem-solving learning outcomes to improve current levels of performance. These include abilities specific to certain physics concepts, such as drawing force diagrams for Newton's second law problems. In addition, it entails providing students with many opportunities to practice the strategies involved in expert-like performance, including explicitly highlighting how decisions are made for using specific principles, concepts, and procedures.[7] Deliberate practice in an IVET also involves supporting students with guidance and targeted feedback throughout the entire problem-solving process, with the support gradually reduced as self-reliance is developed.[8]

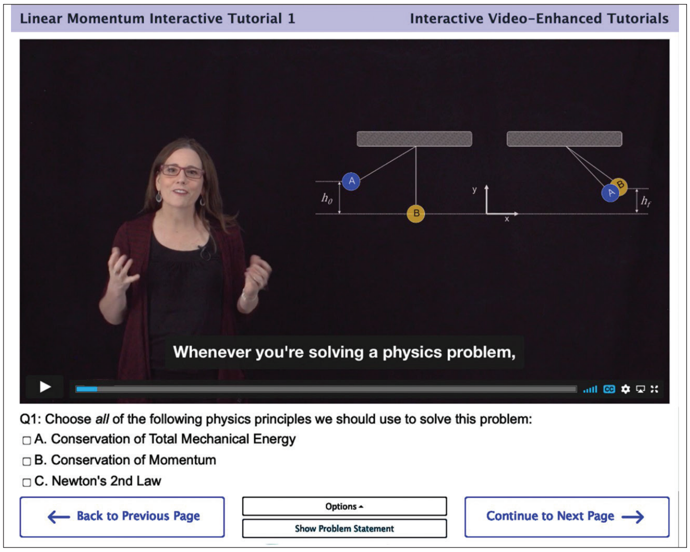

Fig. 1. A multiple-select question page.

Another important part of the IVET design is the application of multimedia learning principles[9] that are based on research in human learning and memory.[10] For example, students are given control over the pace and mode of presentation (either text or video), which has been shown to motivate students' engagement and impact learning.[11] The IVETs also provide support to encourage students and reinforce correct reasoning, similar to what a personal tutor would do.[12]

Linear Momentum and Energy IVET

Each IVET follows a similar pattern, which is described here for the Linear Momentum and Energy IVET. Like many IVETs, this one is based on a tutorial developed by DeVore et al.[1,13] as well as Singh's research on student difficulties in applying both conservation of energy and momentum.[15] The IVET begins by presenting the problem to be solved, where students are to find the final height of a pair of suspended balls after an inelastic collision. The default is to provide video instruction, but students can choose text at any time.

The students' first task is to sketch out a possible solution path and summarize their ideas in a text box before continuing. Although not graded, this serves to engage students early on. Students are also asked to write out their work on paper and submit their ideas by answering questions as they move through the IVET. These questions guide students through key steps in solving problems while providing expert feedback. Some steps include identifying relevant principles, drawing appropriate diagrams, breaking the problem into parts, and so on.

Most questions are multiple choice, with several multiple select, such as when students are asked which principles are needed. Multiple-select questions have the benefit of discouraging guessing. For every question, each answer choice leads to a page that provides feedback. If the answer is correct, the feedback explains the underlying reasoning before moving to the next question. If the answer is incorrect, the feedback provides encouragement by emphasizing what aspect was done correctly followed by hints before branching back to try again.

Figure 1 shows a multiple-select question page with the video option chosen. If text had been chosen, the video window would be replaced by a diagram with text explaining the question (see Options button near bottom of page). Other buttons include Previous Page, which is always active, and Next Page, which leads forward once an answer is selected or if the page shows feedback for a correct answer. The Problem Statement button brings up a reminder of the problem being solved. Other pages are similar, but only question pages include a question below the video/text window.

In this IVET, the problem involves two balls of the same mass hanging on separate strings. One ball is pulled back to a given height and released. It collides with the ball at rest and they stick together and swing to some final height, which students are to calculate. Students are guided to recognize that the solution involves three parts (before, during, and after the collision). Within each sub-part, students are guided to choose and apply the underlying principle(s) to determine information necessary for the subsequent part.

Guidance is provided by a sequence of questions with feedback for each possible answer. For example, if students choose only A for question 1 in Fig. 1, they are led to a page with a video of the narrator saying, “Yes! We will use conservation of energy to solve part of this problem… when Ball A swings downwards… also, after they collide and both swing upward… But there was a collision that occurred between Ball A and B. What concept do you use when there’s a collision?” The text option shows a similar response. Since the answer is incorrect, the student is returned to try again.

These question/feedback cycles are essential for leading students through key decision points in the problem-solving process. However, students can become disengaged, so after one cycle students are asked how they are feeling. They may indicate that things are fine, or they can select from a list of choices from the research literature for disengagement, including confused, frustrated, bored, or worried. Students must respond, although one of the choices is “prefer not to answer.” Depending on the selection, the IVET branches to a detailed explanation and/or empathetic comment by the narrator followed by a targeted suggestion (e.g., take a break, talk to the instructor, watch a video summary of work completed so far).

The question/feedback process repeats for the other subparts. Once a correct solution is reached, students can choose to watch a video summary (Fig. 2), which provides an overview of the strategies and key decisions. The IVET ends with the narrator posing another problem for students to do without guidance. Here, the new problem involves a stationary ball with half the mass of the ball that hits it. Although the problem seems similar, the results are not and students will need to go back through the entire calculation. For these problems, the narrator provides hints for how the problem differs to help students apply what they have learned to the new scenario, promoting self-reliance.

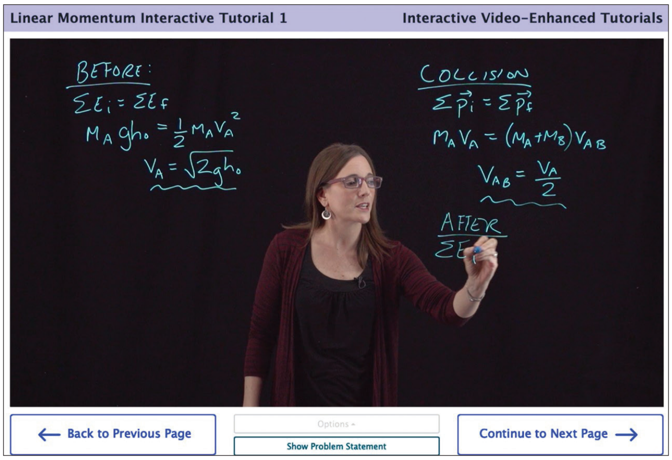

Fig. 2. Students can choose to watch a video summary.

Research on the impact of the IVETs

We have conducted research on the impact of several IVETs on student problem-solving abilities, but only have space to present the results for the Linear Momentum and Energy IVET. For this study, the IVET was assigned as homework to one section of algebra-based physics, while another section taught by a different instructor was assigned to watch the five-minute video from the end of the IVET. This summary video showed the narrator talking through the same problem-solving process and explicitly emphasizing key decisions but without the interactive questions. Students in both sections had covered conservation of energy and momentum in class, but neither had used these principles concurrently in the same problem, making the IVET/video problem new for students. During class after treatment, students were given a follow-up problem to complete individually for a grade. This allowed us to compare interactive video (IVET) with passive video, much like that experienced when watching instructional videos online. The follow-up problem, which is the same one used in DeVore’s research,[14] involves a truck rolling from rest down a hill and colliding with a smaller mass car at rest at the bottom of the hill. The question asks students to determine how high up a second hill the vehicles, now stuck together, will travel before stopping if friction is negligible. While this problem is isomorphic to the IVET problem, research has shown that students often answer such questions differently due to surface features.[16]

Based on the strategies emphasized in the IVET and video, we expected students who completed either to be able to (1) recognize that the follow-up problem needed to be solved in sub-parts, including before, during, and after the collision, (2) apply conservation of energy to the first and third sub-parts, (3) apply conservation of linear momentum to the collision, and (4) use the result from each sub-part to reach a final answer.

Table I. Distribution of student solutions.

Video	IVET	Code Description
11%	1%	Haphazard use of equations, no clear solution path, or applied incorrect concepts (ex. work-kinetic energy theorem).
4%	0%	One-Step Solution – Solved the problem in one step by applying conservation of momentum only for the collision.
18%	4%	One-Step Solution – Solved the problem in one step by applying conservation of energy only to when vehicle(s) at rest on each hill).
12%	8%	Two-Step Solution – Solved the problem in two steps and applied conservation of energy to the first and last segment of the problem and ignored the collision.
7%	10%	Three-Step Solution – Appeared to have memorized the solution from the video/IVET and reproduced it. However, incorrect answer was achieved due to the car and truck having unequal masses.
5%	0%	Three-Step Solution - Applied conservation of energy for each of the three problem parts and didn't use conservation of momentum.
43%	77%	Correct Three-Step Solution, includes those involving minor math errors.

Analysis

Only students who completed the treatment and follow-up problem were included in the analysis, which involved 105 students (80% of those enrolled) in the IVET group and 124 students (95% of those enrolled) in the video-only group. Pre-FCI data showed the groups to be similar, with a mean score of 27.8% for the video group (standard error 1.57%) and 29.1% for the IVET group (standard error 1.89%). These averages are comparable ($p = 0.60$, Cohen's $d = 0.07$). All students' handwritten solutions for the follow-up problem were scored using a 10-point rubric that allotted three points for each correctly solved sub-part and a point for a final correct answer. Figure 3 shows a histogram of students' scores, where the IVET group had a mean of 8.83 (standard error is 0.29) and the video group had a mean of 6.33, with the IVET group performing significantly higher ($p < 0.001$; Cohen's $d = 0.91$).

In addition, all students' solutions were coded based on emerging themes. As shown in Table I, the majority (77%) of the IVET group had a correct solution compared to the video-only group (43%). The most common incorrect strategy involved using only conservation of energy and ignoring the collision. This occurred for 30% of the video-only group, who used this principle for solving the problem in either one or two steps, but only 12% of the IVET students. Likewise, 11% of the video-only group used no clear approach to solve the problem, whereas that occurred for only 1% of the IVET group.

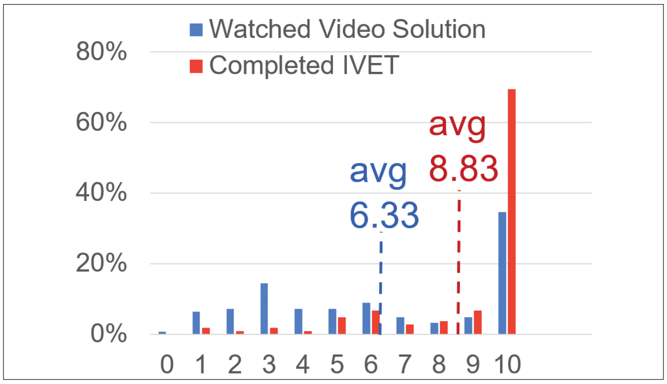

Fig. 3. Histogram of students' scores.

Although one may question the impact of differences in time on task for the two groups, research has highlighted the importance of the activities themselves for mentally engaging students rather than time involved.[17] Within the IVETs, students have a choice for how they engage, and although they can randomly click on answer choices to get through quickly, less than 5% appear to do this based on log file data. Rather, it appears that the IVETs motivate students to use time productively and effectively to learn new problem-solving strategies.

Conclusion

Our results indicate that the Linear Momentum and Energy IVET is effective, both in helping more students learn expert-like problem-solving approaches and in reducing the prevalence of common difficulties. The study was repeated for our angular momentum IVET using these same students, and again the IVET group significantly outperformed the video group ($p < 0.001$; Cohen's $d = 0.63$). Several other IVETs have been tested with our calculus-based physics students, but in those studies the data were only coded for emerging themes, with the IVET group outperforming the video group, much like the findings shown in Table I. Given space constraints, these outcomes will be reported elsewhere, but all results so far point to the limited educational value of video alone, which essentially mimics traditional face-to-face lecture or assigning instructional videos as homework. In addition, whereas DeVore et al. found that tutorials delivered through PowerPoint needed to be completed in-person to be effective, our research has found that the online and interactive environment of the IVETs is able to motivate students to engage, providing more flexibility for their use and providing another tool to support personalized instruction.

Because of their interactivity, IVETs are web applications written with JavaScript rather than being simple videos. We have now finished 15 IVETs, some of which are based on the tutorials by DeVore et al.,[13,14] and plan to make 15 more during the coming months. The IVETs are freely available at the project website, https://ivet.rit.edu.

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