

Design of a Synthesizing Lecture on Mechanics Concepts

Natalie E. Strand¹, Jennifer L. Docktor¹, Gary E. Gladding², José P. Mestre^{1,2,3},
and Brian H. Ross^{1,4}

¹*Beckman Institute, University of Illinois at Urbana-Champaign, Urbana, IL 61801 USA*

²*Department of Physics, University of Illinois at Urbana-Champaign, Urbana, IL 61801 USA*

³*Department of Educational Psychology, University of Illinois at Urbana-Champaign, Urbana IL 61801 USA*

⁴*Department of Psychology, University of Illinois at Urbana-Champaign, Urbana, IL 61801 USA*

Abstract. Within the context of traditional physics problem solving instruction, major concepts are mentioned but often marginalized by the focus on equation manipulation, resulting in students perceiving concepts as unimportant in problem solving. Additionally, since topics are covered as isolated pieces, students also perceive concepts as unrelated. In response to this disconnect, we discuss the development of a short, animated, web-delivered synthesizing presentation modeled after the “common learning resource” from the *preparation for future learning* construct. In the presentation, major concepts of introductory mechanics are structured hierarchically. More specifically, the presentation is an overview of major theorems and conservation laws in mechanics and the conditions under which they are applied. It is linked to previous problems solved by the students and intended to prepare them for future learning by illustrating how concepts guide problem solving processes.

Keywords: physics education research, conceptual learning, problem solving.

PACS: 01.40.Fk, 01.40.gb, 01.50.F-

INTRODUCTION

Physicists have a deep understanding of the hierarchical nature and interconnectedness of physical principles and are able to apply those principles flexibly in solving problems across a wide range of contexts. Studies of how experts approach problem solving indicate that they cue on underlying principles when deciding on a solution strategy [1-4]. Once a target principle/concept is selected as promising, they implement a procedure for applying it in mathematical form.

Unfortunately, most students view problem solving in physics as a matching exercise between equations and the variables in problems, and then continue by manipulating the equations until the desired quantity is isolated (see reviews in refs. [5] & [6]). Lacking the hierarchical perspective and understanding of the physical situation that physicists possess, novices tend to rely on equations to solve problems and largely ignore the underlying concepts.

Preparing students for future learning is a critical part of education. Ideally, students should be able to use the knowledge they acquire early in a course to help learn information presented later, and in doing so, construct an integrated and coherent understanding of the domain. A central component of the preparation

for future learning (PFL, [7]) construct is a focus on how initial experiences can prepare students to acquire differentiated knowledge structures that shape later learning. In initial learning activities, students may be lost or see knowledge as disconnected but yet become prepared for later activities that integrate and tie concepts and procedures together. Prior information / knowledge, therefore, can serve as a resource for later structuring and reshaping into more coherent structures.

There have been several studies in PFL (e.g., [8] and [9]) that incorporate a common learning resource (CLR), which can be a synthesis lecture or summary of the main ideas, to compare the learning that resulted through the CLR by students experiencing different initial learning activities. One study [8] covered memory concepts in psychology. The experimental groups participated in different initial trainings on the material, where the students in one group analyzed contrasting cases by graphing memory data, and the students in the second group read a description summarizing the important patterns in the data. After this initial training, both groups went on to a common learning resource (CLR), in which they listened to a lecture that described two memory theories. After the CLR, the participants took a verification test and made predictions about a novel memory experiment. While

both groups performed equally well on the verification test, the “analyze cases” group performed much better than the reading group when making novel predictions about the new memory experiment. The authors concluded that the analyze cases group was prepared to learn more deeply from the lecture, which subsequently led to better performance on the prediction task.

The PFL construct has largely remained untested in extended science domains containing multiple, difficult-to-learn concepts. In this paper we will discuss the design of an experiment to explore the PFL construct by testing two different initial activities used to prepare subjects to later learn from a CLR. In particular, our focus here will be on the details behind construction of a CLR aimed to help students understand the hierarchical structure of conservation laws, namely how conservation laws flow from basic principles in introductory mechanics. To set the context for the CLR, we first provide a description of the experiment in which the CLR is used.

STUDY DESIGN

We have adopted a double-transfer [10] paradigm for our study, as shown in Figure 1. Subjects in the conceptual problem solving (CPS) treatment group are asked to solve problems by first identifying the major principle(s) and justifying why the principle(s) applies to the specific problem context; then they write a “two-column solution” where one side contains principles, concepts, and/or procedures being applied (described in words) and the corresponding side contains the equations used to instantiate them [11]. The control group, or the equation problem solving (EPS) group, solves the same problems, attempting to construct two-column solutions, but without strategizing beforehand (i.e., no initial identification of principle to be applied or justification).

The first three problem solving sessions cover the topics of work/energy, impulse/momentum, and angular impulse/angular momentum. In the last two sessions of the study, subjects read and solve multi-principle problems combining these concepts (e.g. conservation of momentum and conservation of energy). Between the first three sessions and the final two sessions we present a common learning resource (CLR) to a subset of subjects from each of the CPS and EPS groups. At the end of the experiment, several problem solving and conceptual assessments are administered to all subjects.

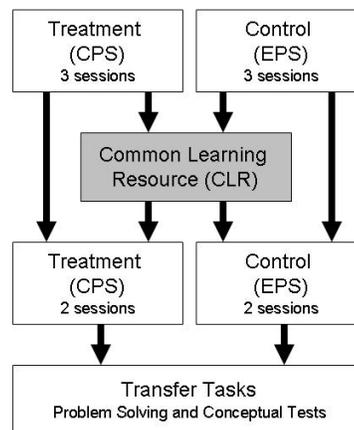


FIGURE 1. Illustration of the double-transfer structure of our study. The common learning resource (CLR) is presented to a subset of each experimental group between the first three sessions and the final two sessions.

The CLR provides a multi-media lecture (described in the next section) for a subset of subjects in both experimental groups. Since the CLR focuses on the conceptual structure of mechanics, we hypothesize that the CPS group, having focused more than the EPS group on conceptual principles and justifications, will be better prepared to learn conceptual information from the CLR, and do better on later conceptual measures. At the heart of the PFL construct is how to structure the initial learning activities so that students are prepared to learn maximally from the CLR, as well as how to construct an effective CLR. Hence this experiment is designed to compare two initial learning activities, and a CLR covering multiple major concepts/principles in mechanics. The experiment is currently in progress and so here we will focus on our design of the CLR.

CLR CONSTRUCTION

The CLR developed consists of a relatively short (~15 minutes), animated, web-delivered presentation that synthesizes the major concepts covered in our study and the procedures for applying those concepts in solving problems¹. The CLR reviews the concepts of work & energy, momentum & impulse, and angular momentum & angular impulse—the same topics covered in the first three sessions of the experiment.

Groups of subjects will view the presentation together, with a proctor monitoring and facilitating the advancement of the “slides.” Therefore, the subjects progress linearly through the presentation, and all spend the same amount of time watching it.

¹ The authors can be contacted (mestre@illinois.edu) for the link to the online presentation.

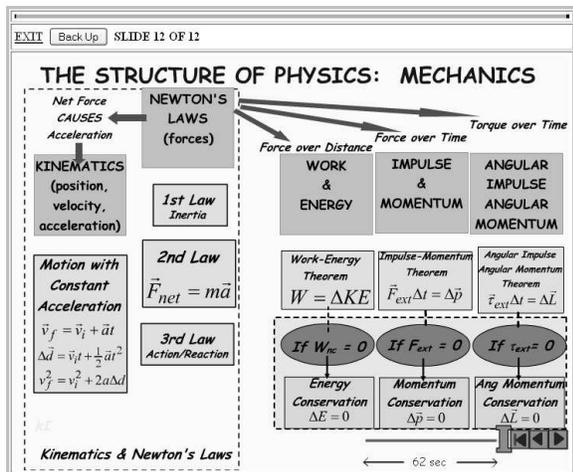


FIGURE 2. Screenshot of the introductory (and final) summary slide from the CLR. The three major physics principles covered in the study are compared to each other and linked to other physics principles.

Colors are used to highlight the common elements in each topic. The major principles are given by blue boxes at the top, and the basic equations that represent each theorem are presented directly below in pink boxes that are linked to each principle. Arrows from the theorems connect to a purple oval describing the condition that must be satisfied in order to be able to apply the orange conservation law boxes at the bottom. Thus, color is used to draw the viewers' eyes along each layer of the diagram, emphasizing the structural similarity between the focal branches. In addition, we have adhered to multimedia learning principles (e.g. [12]) in the design of the CLR by having a voice overlay that narrates the presentation in a conversational style and including Adobe® Flash® animations to aid viewers in connecting the visual and verbal representations we present.

The CLR begins with an overview of a summary diagram, shown in Figure 2, which depicts the hierarchical nature of the structure of physics. The three major concepts covered in the experiment are presented and linked to earlier concepts in introductory mechanics. We have decided to show Newton's Laws as the fundamental ideas from which the theorems and conservation laws in energy, momentum and angular momentum are derived. Those topics are linked to Newton's Laws by red arrows that state how forces are combined with other physical quantities to arrive at the concept. For instance, impulse is a force that is exerted over a time interval, while work is a force that is exerted over a distance. Next, the major topics used in our study are presented, highlighting the connections between each of the vertical branches and Newton's Laws. The three focal branches are presented in parallel: the basic theorems are introduced after the major concepts are presented. Then, the

conditional statements are introduced, leading to the three conservation laws.

Once the overview is presented, each branch is reviewed in detail, beginning with a reminder of how the concept is related to Newton's laws and forces. Figure 3 shows a screenshot of the review for the work and energy branch. The major equations pertaining to each concept are revisited and briefly re-derived to show how they are interconnected.

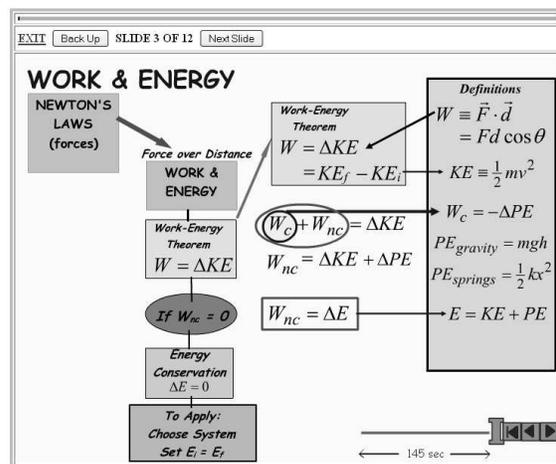


FIGURE 3. Screenshot from the CLR showing the review slide that describes the Work & Energy branch of the structure of physics diagram.

After the overview for all three branches, viewers are shown six example problems. We use examples previously seen by subjects in the initial three sessions of the study; thus they are familiar, and the subjects have already seen detailed worked solutions and/or solved the problems themselves. It is important to note that the examples are *not* re-solved in detail during the CLR; instead, a conceptual strategy for solving each problem is presented using the appropriate diagram branch(es) as a guide. As the specific conditions in the problem are described, the appropriate branch is built dynamically onscreen. For the example shown in Figure 4, the narration is as follows: "...there are two forces exerted on the block over different distances, so again, you'll follow the work & energy branch [concept header & theorem boxes appear] Now, you'll need to determine whether there are any non-conservative forces that do work. The spring force is a conservative force [green force vector appears, then gradually disappears], but there is a non-conservative force exerted on the block as it traverses the region of friction, [red force vector appears] namely the friction force [red prohibition symbol appears]. Because of that, mechanical energy is not conserved and you need to apply the work-energy theorem."

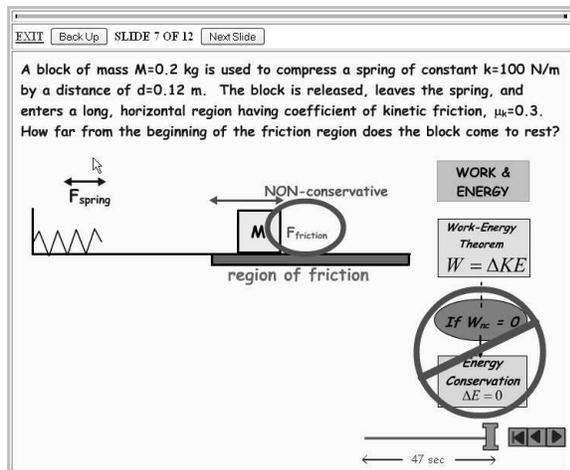


FIGURE 4. Screenshot of a slide from the CLR illustrating the problem-solving strategy for an example problem involving the impulse momentum theorem.

FINAL REMARKS

In this paper, we have presented the design of a common learning resource (CLR) to synthesize three major concepts in introductory mechanics (work/energy, momentum/impulse, and angular momentum/angular impulse). The CLR is part of an experiment that begins with initial learning activities (conceptual problem solving) designed to prepare students to learn maximally from the CLR. Unlike previous studies of the preparation for future learning (PFL) construct, this study is in the discipline of physics and covers multiple complex topics.

There are two major issues in any PFL experiment: The first is how to design the initial learning activities to prepare students to learn (maximally) from the CLR. It has been shown in previous studies [7, 10] that “teaching by telling” is not as effective for preparing students to learn from a CLR than are other more open-ended activities where students explore the targeted concept(s) (with students often making seemingly little progress in understanding the concept deeply during the initial activities). The second major issue is the design of the CLR itself. The CLR must build on the initial learning activities so that students make an incremental jump in understanding.

This paper focused on the design of a CLR that illustrates the relationship among three major concepts in mechanics (energy, momentum and angular momentum). Although there are commonalities among these concepts (e.g., conservation laws and how they are applied), students often miss these commonalities. The multimedia CLR presentation described here is intended to highlight the similarities and differences among these three concepts, while at the same time

anchoring the concepts to specific examples solved by students in the initial learning activities, thus illustrating how they are applied.

We are currently in the process of collecting and analyzing data from this experiment. College student subjects will complete a set of dependent measures that will allow us to test the type of learning and transfer resulting from the learning activities and CLR.

ACKNOWLEDGMENTS

Research supported by the Institute of Education Sciences, U.S. Department of Education, through Grant R305B070085 to the University of Illinois. The opinions expressed are those of the authors and do not represent views of the Institute of Education Sciences.

REFERENCES

- Chi, M. T. H., Feltovich, P. J., & Glaser, R., *Cognitive Science* **5**, 121-152 (1981).
- Glaser, R., “Expert knowledge and process of thinking” in *Enhancing Thinking Skills in the Sciences and Mathematics*, edited by D. Halpern, Hillsdale, NJ: Lawrence Erlbaum Associates, 1992, pp. 63-75.
- Hardiman, P. T., Dufresne, R., & Mestre, J. P., *Memory & Cognition* **17**, 627-638 (1989).
- Schoenfeld, A. H. & Herrmann, D. J., *Journal of Experimental Psychology: Learning, Memory, & Cognition* **8**, 484-494 (1982).
- Mestre, J. P., *Physics Today* **44**, 56-62 (1991).
- Etkina, E., Mestre, J. P., O'Donnell, A., “The impact of the cognitive revolution on science learning and teaching,” in *The Cognitive Revolution in Educational Psychology*, edited by J. M. Royer, Greenwich, CT: Information Age Publishing, 2005, pp. 119-164.
- Bransford, J. D. & Schwartz, D. L., *Review of Research in Education* **24**, 61-100 (1999).
- Schwartz, D. L. & Bransford, J. D., *Cognition and Instruction* **16**, 475-522 (1998).
- Schwartz, D. L. & Martin, T. *Cognition and Instruction* **22**, 129-184 (2004).
- Schwartz, D.L., Bransford, J.D., & Sears, D., “Efficiency and innovation in transfer” in *Transfer of Learning from a Modern Multidisciplinary Perspective*, edited by J. Mestre, Greenwich, CT: Information Age Publishing, 2005, pp. 1-51.
- Mestre, J. P., Ross, B. H., Brookes, D. T., Smith, A. D., & Nokes, T. J., “How cognitive science can promote conceptual understanding in physics classrooms,” in *Fostering scientific habits of mind: Pedagogical knowledge and best practices in science education*, edited by I. M. Saleh and M. S. Khine, Rotterdam: Sense Publishers, 2009, pp. 144-171
- Mayer, R. E. (2009). *Multimedia learning* (2nd ed). New York: Cambridge University Press.