

Toward an Integrated Online Learning Environment

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Abstract. We are building in LON-CAPA an integrated learning environment that will enable the development, dissemination and evaluation of PER-based material. This environment features a collection of multi-level research-based homework sets organized by topic and cognitive complexity. These sets are associated with learning modules that contain very short exposition of the content supplemented by integrated open-access videos, worked examples, simulations, and tutorials (some from ANDES). To assess students' performance accurately with respect to a system-wide standard, we plan to implement Item Response Theory. Together with other PER assessments and purposeful solicitation of student feedback, this will allow us to measure and improve the efficacy of various research-based materials, while getting insights into teaching and learning.

Keywords: curriculum development, online teaching, cognitive development, physics education research.

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INTRODUCTION

In this paper we describe a freely accessible Integrated Learning Environment for Mechanics, (ILEM) which is hosted and being developed by MIT's REsearch in Learning, Assessing and Tutoring Effectively (RELATE) group [1]. Ultimately this framework will feature sufficient embedded assessment that it could suggest the most efficient next step for each student. Currently, it gives students some choices in an overall plan designed by us and modifiable by instructors. Our environment has the following characteristics:

- It is focused on problem solving and cognitive development, and features many PER-based activities.
- It is highly interactive and student-centered - students actively exercise critical and creative thinking.
- It is suitable for online, in class and hybrid teaching of introductory calculus-based mechanics.
- The text and the links are modifiable by teachers who adopt it.
- It involves Modeling Applied to Problem Solving (MAPS) [2] - a promising pedagogy to imparting strategic knowledge.
- The integrated environment is available to others wishing to extend it to other subjects.

DESIGN

Both the content and the activities in our course utilize the Learning Online Network with Computer Assisted Personalized Approach (LON-CAPA) platform [3]. We have chosen this learning management system because it is a free open-source system that can enable high schools and colleges to rearrange and customize content to their particular needs.

Problem-solving Activities

Promoting cognitive development through physics problem-solving has been recommended for helping students adopt expert-like habits of thinking [4]. The problem-solving activities that we've included in this course are designed to expose students to selected contexts, problem features, knowledge and cognitive processes so that students expand their declarative and procedural knowledge and gradually become engaged in higher-level thinking. In this way, students have the opportunity to acquire a great deal of strategic knowledge. Problem selection is guided by a Taxonomy of Introductory Physics Problems (TIPP) [5] that classifies the problems according to the knowledge and the cognitive processes that are involved in solving them. Currently, we have selected research-based problems like *multiple-representation*

problems [6], context-rich problems [7] and ranking [8] and evaluation tasks [9]. By solving these problems students exercise cognitive processes like *integrating*, *symbolizing*, *matching*, *representing* and *analyzing errors*. As we experiment with such processes, we will select appropriate additional ones.

Our problems target declarative knowledge (vocabulary terms, facts, time sequences, generalizations and principles) as well as procedural knowledge (single rules, algorithms and tactics). In addition to the types of problems mentioned above, we designed and implemented tasks that focus on systems, interactions and core physical models that are appropriate for modeling pedagogies. The present collection of problem-solving activities features around 200 problems, half of which are standard end-of-chapter numerical problems, with the other half having the characteristics described above.

Integrated e-text

The e-text is designed for easy integration of interactive learning, whose beneficial impact on student knowledge acquisition has been extensively documented in the last ten years. It builds on the existing on-line wikis that our group has created [10] and includes worked examples, videos, simulations and ANDES tutorials.

The current list of units is fairly standard (see Table 1).

TABLE 1. List of Current Topics. (Those being written indicated TBW.)

| Unit | Topic |
|------|--|
| 1 | Newton's Laws |
| 2 | Interactions and Forces |
| 3 | Applying Newton's 2 nd Laws |
| 4 | Describing Motion |
| 5 | Momentum and Multi-body systems |
| 6 | Mechanical Energy and Work |
| TBW | Rigid bodies and Torque |
| TBW | Describing Angular Motion |
| TBW | Angular Momentum |

The highlight of our e-text is that it is *very* concise and organized in a way that we hope will better help students when solving problems compared with traditional textbooks. We solicit students' comments on what to add to our presentation of the material. We have striven to give the learner several ways to get an overview of the content. Concept maps are used at the beginning at each unit to help students achieve local and global coherent knowledge structures. The key material for problem solving is condensed in a hierarchy of about a dozen models. Whenever necessary, hyperlinks are provided to facilitate assimilation of the unknown terms. The worked

examples feature real-world scenarios, and contain clickable parts. Videos [11] and simulations [12] are often integrated in the content together with ANDES physics tutor [13] that helps students acquire initial practice of new procedural knowledge. Currently, we are introducing videotaped lectures.

The unique features of our e-text is that students actively participate in its development and discussion, while teachers are encouraged to enrich, cut or modify its content, based on their students' experience and suggestions (see the Section Teaching Methodology).

TEACHING METHODOLOGY

Our teaching methodology is guided by the following principles for online and in-class teaching [14-16]:

- Instruction should be interactive – we limit non-interactive declarative knowledge acquisition to ~ 500 words (< 5 minutes of reading time).
- Instruction should include social interactions – LON-CAPA discussion boards will be used to discuss problems and specially posed questions.
- Instruction should facilitate student knowledge construction – our e-text is “too short” and students are encouraged to ask questions (the TA will respond creating an FAQ list) and to recommend additional helpful information to others. The end product should still be far shorter than current textbooks.
- Students should link the knowledge they acquire into coherent knowledge structures – we are supplying a hierarchy of physical models, a pictorial domain map, and explicit models for core principles (in contrast to conventional textbooks).
- Students should learn how to apply the content they are learning and when to use it – several activities that we involve specifically target strategic knowledge acquisition.
- Timely feedback should be provided and attended to by students - we will institute data mining on wrong answers followed up by specific feedback for commonly given wrong answers. (This is projected to reduce the number of students who cannot obtain the correct answer by a factor of two [17].)

To enhance cognitive development we offer to students tasks of progressively increasing cognitive complexity while following a technique that was demonstrated to help them develop problem-solving abilities and achieve better attitudes [5].

Our pedagogical emphasis is Modeling Applied to Problem Solving (MAPS) pedagogy [2], but the curricular materials are editable and re-arrangeable to accommodate any pedagogy. MAPS was able to raise students' problem-solving skills from D-level to B-

level in a three-week intensive ReView Mechanics course at MIT. Additionally, it improved students' attitudes as measured by the Colorado Learning Attitudes about Science Survey (CLASS) [18] and resulted in an enhanced problem-solving performance by 0.6 standard deviations in a subsequent Electricity and Magnetism course [19]. The key idea of MAPS is to teach students to state the *system*, the *interactions*, and the *models* for each problem they solve. By *system* we mean the relevant constituents of the presented scenario. By *interaction* we mean an agent of change of the initial state of the system. By *model* we mean a simplified representation of the structure and behavior of a core concept (e.g. momentum). In mechanics all our core models are centered on a particular law of change – an equation that expresses how some physical quantity changes with time due to particular types of forces – and include applicable systems and relevant interactions.

We use various strategies to make students active participants in their own process of learning. For example, within each homework set, the problems are organized in three levels of complexity determined by a balanced combination of knowledge and cognitive processes. Students have the freedom to choose more lower-level cognitive problems or fewer higher-level cognitive problems to acquire the required number of homework points, thus configuring their own personalized problem-solving activity.

Our curriculum features 9 units accompanied by 12 homework sets. Figure 1 shows a suggested organization for the first four weeks of our syllabus.

ASSESSMENT

The multi-dimensional assessment that we will apply will target both instructors and students. The instructors-related part is motivated by research on faculty beliefs about problem solving [20], while the student-related part relies on research that reveals the complexity of the problem-solving process [4]. The assessment of our framework will seek to answer the following questions:

- 1) *To what extent are the learning and teaching materials flexible and usable by teachers and faculty?* – Interviews and surveys will be conducted with our collaborators to address this question.
- 2) *To what extent do the learning materials affect the relevant student outcomes?* – We will use a variety of methods to address this question.

To probe student conceptual understanding, we will administer the Mechanics Baseline Test (MBT) [21] pre- and post-instruction. In addition, to evaluate student understanding of Systems, Interactions and Models in physics, we specifically designed a Mechanics Reasoning Inventory (MRI) [22]. It will be administered pre- and post-instruction. CLASS [18] will be used to assess students' attitudes and expectations.

Besides these assessments, we will rely extensively on data mining on the data LON-CAPA collects. We will apply psychometrics tools that involve Item Response Theory (IRT) to establish benchmarks that compare certain students and classes with all students doing the problems, with students taking the same course in previous years, or with performance on standard tests like MBT and MRI.

| Week | Physics Topic | Systems (S) Interactions (I) Models (M) |
|------|--|--|
| 1 | Newton's Laws & Interactions and Force | S: Point particle I: Contact Forces, Gravity, Tension, Elastic Restoring Force |
| 2 | Applying Newton's 2nd Law | S: Point particle I: Contact Forces, Gravity, Tension, Elastic Restoring Force M: Newton's 2nd Law |
| 3 | Describing Motion | S: Point particle I: Gravity M: Velocity and Net Force |
| 4 | Momentum and Multi-body systems | S: Any number of point particles I: Contact Forces, Gravity, Tension, Elastic Restoring Force M: Momentum and external impulse |

FIGURE 1. The proposed first four weeks of a course using our approach.

With IRT diagnostics, students' weekly homework will be used to monitor their problem-solving abilities, as well as the progress of the class.

IMPLEMENTATION AND GOAL

Our Integrated Learning Environment for Mechanics will be refined and improved from use and student feedback, starting with small classes and then continuing with larger classes (approximately 10 this Fall, 150 next spring, etc. – see Table 2). Ultimately we hope that the multi-dimensional assessment that we are developing will provide a sufficiently accurate evaluation of students' learning so that the system can act like a personal tutor and select the next appropriate activity for each student.

TABLE 2. The Initial Implementation of our Framework.

| Institution | No. of Students |
|---|-----------------|
| 1. MIT – Fall 2010 | 10 |
| 2. Univ. of Wisconsin Platteville – Sp 2011 | 20 |
| 3. MIT – Sp 2011 | 100 |

COLLABORATORS

We welcome collaborators at several levels:

1. To use our problem-solving activities, with or without student freedom to select problems
2. To upload their content or assessment instruments for use by us and other collaborators
3. To use the full ILEM to teach their class
4. To use our Integrated Learning Environment for a course of their own.

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