Development and evaluation of large-enrollment, active-learning physical science curriculum

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Abstract. We report on the initial field tests of Learning Physical Science (LEPS), a new curriculum adapted from Physical Science and Everyday Thinking (PSET). PSET is an inquiry-based, hands-on, physical science curriculum that includes an explicit focus on nature of science and nature of learning. PSET was developed for small enrollment discussion/lab settings. The Learning Physical Science (LEPS) curriculum maintains the same research-based learning principles as PSET but is suitable for classes taught in lecture format. LEPS has been field tested by eight instructors at different universities. In this paper, we describe the adaptation process, the resulting LEPS curriculum, and present student learning outcomes for LEPS and PSET.

Keywords: physical science, active learning, preservice teachers, nature of science.
PACS: 01.40.G-, 01.40.Di, 01.40.Fk

INTRODUCTION

Learning Physical Science (LEPS) is a new curriculum designed to fill the need for a physical science curriculum that is inquiry-based, includes an explicit focus on nature of science and the nature of learning, and is suitable for a large lecture hall environment. During the development of LEPS, our goal was to adapt the existing Physical Science & Everyday Thinking (PSET) [1] curriculum for large enrollment classes. Like PSET, LEPS is a one-semester curriculum with a student-oriented pedagogy designed to enable students to develop a deep understanding of the conceptual themes of energy, forces, and the atomic-molecular theory of matter. LEPS (again, like PSET) is also intended to enable students to develop an understanding of important aspects of scientific thinking and the nature of science (NOS), and to enhance their ability to monitor and reflect on their learning.

The initial version of LEPS was piloted at two institutions by developers and revised based on these experiences. Later drafts were field tested by 8 instructors who attended a 2-day workshop. LEPS was again revised according to fieldtester feedback. In this paper, we describe the adaptation process, the resulting LEPS curriculum, and present learning outcomes for LEPS and PSET during the field test.

ADAPTATION: FROM PSET TO LEPS

LEPS was adapted from PSET, the original development of which was guided by seven principles based on research on learning (see first column of Table 1). PSET curriculum design assumed small classes in which students can engage in hands-on experimentation, small group work and discussions, and whole class discussion. PSET also assumed ~75 hours of class meeting time. Thus, PSET is not suitable for courses with large enrollments, courses taught in traditional classrooms, or courses with ~45 hours of class time (typical of courses without a lab component). LEPS was designed to preserve the learning principles of PSET, but be compatible with large-enrollment formats, making use of current technology to assist collaboration and interactive engagement both inside and outside the classroom.

The adaption of LEPS from PSET was guided by the following design objectives

- Provide opportunities for students to learn content, the nature of science, and to reflect on their own learning
- Follow the learning principles of PSET
- Use existing, proven instructional techniques for large enrollment classes (such as Peer Instruction) when appropriate
- Develop a standard structure for class activities and homework
- Provide sufficient flexibility for use in different institutional contexts
- Provide instructors with tools to guide their classroom implementation

Furthermore, since LEPS was developed for large-enrollment courses, we made several assumptions: students will be unable to engage in hands-on experimentation; participation in whole class discussions will be limited; uniform pacing will be required (students cannot work at their own speed); and total class time will be ~37 hours. We assumed instructors would have access to an in-class computer, projector, and an electronic polling system. Students were assumed to have access to computers with Internet access outside of class. To balance the design principles and constraints, LEPS employs alternatives to PSET features relying on small, discussion/lab format (see Table 2).

DESCRIPTION OF LEPS

LEPS contains in-class lessons and online homework for physical science content and the nature of science and nature of learning. Although optional laboratory activities were developed, the labs are not discussed in this paper due to space constraints. LEPS's content focuses on the themes of interactions, energy, forces, atomic-molecular theory, conservation of matter, and gas behaviors. The learning objectives address many of the physical science-related benchmarks and standards in the AAAS Benchmarks for Scientific Literacy and National Science Education Standards [2-3]. Each of six units is based on a small number of these benchmarks and standards.

In-class Lessons

Large enrollment university courses typically include two 75-minute periods or three 50-minute periods per week. We divided the LEPS material into 25-minute lessons during which the instructor guides the entire class using PowerPoint slides. Class time is spent on ‘clicker’ questions (which students answer with electronic response devices, often following a discussion with nearest neighbors [4]), videos of experiments and simulations, and making sense and summarizing questions. As the instructor navigates through the slides, the students fill in data tables and answer corresponding questions in lesson sheets that guide their work. We expect 2-3 such lessons to be completed during each class meeting.

Each LEPS lesson consists of 1) Purpose and Key Questions; 2) Predictions, Observations, and Making Sense; and 3) Summarizing Questions. The Purpose provides the rationale for the lesson. Key Question(s) provide the lesson’s focus. The major portion is the Predictions, Observations and Making Sense (POM) section. The questions in this section guide students

TABLE 1. Learning principles as implemented in PSET and LEPS

Learning Principle	PSET	LEPS
1. Learning builds on prior knowledge	Activities are designed to elicit and build on students’ initial ideas.	Similar to PSET
2. Learning is a complex process requiring scaffolding	Big Ideas/sci practices developed within & across units. For hw, students fill in question sheets, collect evidence via simulations	Similar to PSET except students complete on-line tutorials at home. Grades are reported to a Learning Management System.
3. Learning is facilitated through interaction with tools	Students use hands-on materials, data acquisition tools and simulations, and answer questions on activity sheets.	Students watch videos of experiments, demos and sims, answer questions with clickers and on lesson sheets.
4. Learning is facilitated through peer interactions	Students engage in small group and whole class discussions.	Students discuss thinking w/ neighbors, limited sharing with whole class.
5. Learning is facilitated through establishing behavioral norms	Written prompts/instructor comments support expectations of providing evidence, active participation, and responsibility for learning.	Similar to PSET except the degree of participation is less and students expect to reach consensus at end of each lesson.
6. Learning about NOS is facilitated by engaging in / reflecting on scientific practice	Conceptual activities and nature of science activities help students reflect on how knowledge is developed and compare with scientists’ work.	Similar to PSET except that students do not have the opportunity to conduct experiments to develop new scientific knowledge.
7. Learning is facilitated by reflecting on one's learning and others'	Activities help students keep track of how their ideas have evolved and how children talk about science ideas.	Similar to PSET plus studying how other college students talk about science ideas.

TABLE 2: Features of PSET and LEPS

Feature	PSET	LEPS
Class activity/ setting	Small group & whole class discussion	Near neighbor discussion and electronic polling
Source of evidence	Hands-on experiments/ sims in small groups	Videos of experiments and simulations
Scope of lesson	60-120 min, several ideas	25 min, single idea
Consensus	End of unit	End of lesson
HW	Paper/pencil	Online
Lab	Embedded	Optional

through predictions, observations and inferences to help them answer the key question(s). The particular questions asked are informed by the extensive literature on students' understanding of physical science. The POM section often begins with a scenario that elicits students' prior knowledge. A clicker question collects students' responses, with the results projected for the class to see. Occasionally, the instructor asks students to share their reasoning for particular choices without judging which answer is the 'best.' Videos of demonstrations, experiments or simulations typically follow and provide evidence for students to consider. Students record their observations on the lesson sheets and answer questions to guide their interpretations of the evidence. The POM section continues with additional clicker questions (typically following discussion with neighbors), videos and making sense questions. Occasional narrative text and/or diagrams introduce new terms or new ways of describing the situation (e.g., energy diagrams). The Summarizing Questions section consists of one or two clicker questions to see if students have synthesized the main ideas from the lesson. At this point, students are expected to come to consensus on the appropriate scientific idea.

Certain lessons focus on the nature of learning (NOL) or the nature of science (NOS), which have a structure identical to that of a conceptual lesson. However, instead of showing videos of experiments, the instructor shows classroom video of either elementary-aged children or students from previous LEPS classes talking about science questions. Students are expected to select excerpts from provided transcripts to support claims about the students' ideas.

Homework

A homework assignment is associated with almost every in-class lesson. The homework is online and consists of a series of narrative text and links to videos of demonstrations, experiments or simulations, or the actual simulations themselves, followed by questions with feedback. The focus of each assignment is either to practice using the ideas introduced in the associated lesson or explore new but related ideas. The homework is an Adobe Flash document that is compatible with a learning management system (LMS) such as Blackboard or Moodle. Questions within the homework proper provide feedback but are not graded. A graded quiz at the end of each homework activity consists of multiple-choice questions. The LMS automatically scores the responses and records them. In this way, students get instant feedback on their quiz scores and the instructor does not need to grade the homework (important in a large class).

Instructor Materials

The instructor manages LEPS as a large guided-inquiry class. We developed a set of PowerPoint slides for the instructor for each lesson. The slides include all clicker and making sense questions, embedded videos of demonstrations, experiments or simulations, and summaries of key definitions and ideas. The final slide for each lesson briefly describes the associated homework. Each slide also includes implementation notes, with answers to the questions.

OUTCOMES

Content learning goals were assessed with a multiple-choice, physics and chemistry assessment (Physical Science Questionnaire, or PSQ) consisting of 28 items, including 19 items used with permission from Horizon Research, Inc., 5 items used with permission from AAAS Project 2061, and 4 items constructed by project staff. Items were selected to match the specific learning objectives identified during the curriculum development process. The Colorado Learning Attitudes About Science Survey (CLASS) [5] was used to gather information on students' views about science and learning.

In Fall 2009 and Spring 2010, the PSQ and CLASS were administered as voluntary on-line pre- and post-assessments in 10 LEPS classes and 17 PSET classes Average class enrollment was 68 students in LEPS classes and 29 students in PSET classes. Response rates averaged about 50%.

The average course PSQ pretest was 38.5 ± 0.8% in LEPS courses and 38.0 ± 1.1% in PSET courses (uncertainties are standard error of the mean). For each course, an average course gain was calculated from individual students' gains based on matched pre- and post- scores. The average PSQ gain in LEPS courses was 18.2% and 18.4% in PSET courses (see Figure 1). There was no significant difference between the average course PSQ gains for LEPS and PSET classes, based on a two-tailed t-test: t(25)=0.94, p=0.35. An f-test indicated no difference in variance.

On the CLASS, the average course pretest score was 48.6 ± 1.9% for LEPS courses and 51.5 ± 1.5% for PSET courses. As with the PSQ, average course shifts were calculated from individual students' shifts based on matched pre- and post- scores. The average course shift was +6.9% for LEPS and +5.0% for PSET. As with the PSQ, there was no significant difference between the average course shift on the CLASS for LEPS and PSET classes, based on a two tailed t-test: t(25)=0.29, p=0.78.

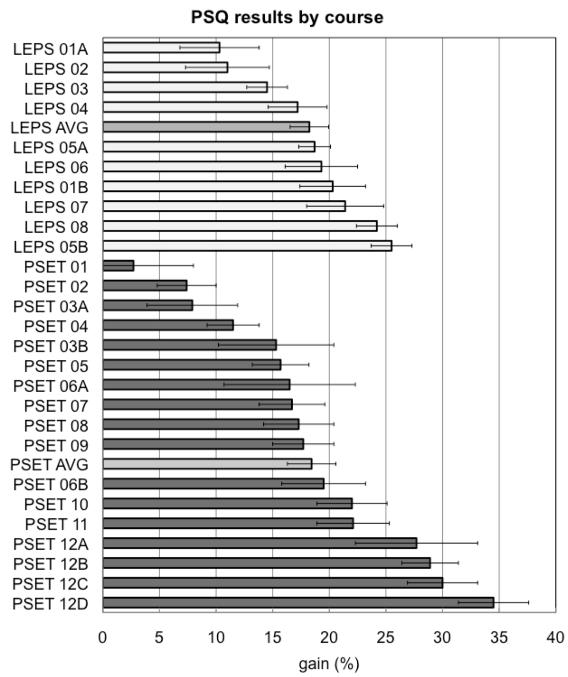

FIGURE 1. Average course gain on PSQ. Error bars are standard error of the mean. Letters in the course identifiers indicate different courses taught by the same instructor.

CLASS results for larger sections of introductory physics typically show changes in traditional courses of -8.2 to +1.5% in calculus-based physics (40 to 300 students in each course section) and -9.8 to +1.4% in algebra-based physics for non-science majors and pre-med students [6].

DISCUSSION

In developing LEPS, retaining the core learning principles of PSET required instantiating them differently due to differences in the course format. While LEPS is more lecture-oriented than PSET, students still have opportunities to construct understanding through discussions with peers based on scientific evidence (rather than based on claims by the professor or text).

Importantly, data from field tests suggests that students in LEPS and PSET courses make similar gains in content and views about science as assessed by the PSQ and CLASS. However, we caution that other aspects of student performance may differ. For instance, students in LEPS have fewer opportunities to participate in whole-class discussions or interact with the instructor, and are not asked to write scientific explanations (due to high grading load this would impose). Thus, we might expect less development of LEPS students' scientific discourse skills. However, this was not assessed in the present study. Our goal in developing LEPS is not to promote large classes instead of smaller ones. Rather, we recognize the resource constraints faced by many universities and accept large-enrollment classes as unavoidable. Given this reality, we believe LEPS is a valuable alternative to a lecture-based large enrollment course.

Finally, we note that LEPS offers the opportunity to introduce college faculty to research-based curricula and pedagogy through our 'educative instructional materials' [7] in a way that is not too far removed from traditional instruction and without requiring that they rewrite their curriculum themselves. It thereby gives faculty an opportunity to explore and practice using interactive pedagogy that allows for student construction of ideas, possibly supporting faculty transition to and their advocacy of smaller, more hands-on inquiry-based formats.

ACKNOWLEDGMENTS

This paper was supported by NSF grant 0717791. We are grateful for the field testers' valuable feedback.

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