INTRODUCTION TO SDI LAB TEACHER'S GUIDES*

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I. BENEFITS

Socratic Dialogue Inducing (SDI) labs have been shown by pre/post testing[1] to be one of the more effective methods for enhancing students conceptual understanding of Newtonian mechanics. Among other advantages SDI Labs, they:

1. are adaptable to a wide range of student populations - high school, college, university;
2. are well received and popular with students;
3. are easily modified to suit local conditions;
4. are inexpensive as far as equipment costs are concerned;
5. diminish the impersonality of large-enrollment introductory classes;
6. are compatible with other interactive-engagement methods;
7. may be inserted as the lab component in otherwise traditional courses so as to enhance student interactivity and conceptual understanding;
8. provide good training grounds for instructors who discover undreamed of learning problems when they "shut up and listen to students;"
9. are good examples of inquiry learning for prospective teachers;
10. are a source of valuable research data on physics learning, particularly if pre/post testing is carried out and dialogues and conversations are recorded and analyzed.

II. EVIDENCE FOR THE EFFECTIVENESS OF SDI LABS

Over a ten-year period at Indiana University, SDI labs were integrated into courses in which lectures, discussions, and exams emphasized conceptual understanding and interactive engagement.[2-6] Lectures usually employed a standard textbook and back-of-chapter problem assignments and, after 1993, included Concept Tests[7]; discussions were devoted to cooperative group problem solving with Socratic guidance. The courses enrolled a total of 1263 students (primarily pre-med and pre-health professionals) and achieved an average normalized gain on the conceptual Halloun-Hestenes tests[8] of $<g>_{IU}= 0.60$ (see ref. 1b), considerably higher than the average gains of other courses considered in the survey of ref. 1 : $<g>_{T} = 0.23$ for 14 traditional (T) courses, and $<g>_{IE}= 0.47$ for 43 interactive engagement (IE) courses. The Hestenes-Wells Mechanics Baseline test[9] of problem solving was administered in two of the Indiana courses. The course-averaged score was 58%, close to the 62% for 11 other university IE courses of ref. 1.

SDI labs have also been used with apparent success in high-schools,[10] colleges[11], and with physics majors and non-physical-science professors[3] at Indiana University. There is some evidence[1b] that SDI labs at Indiana University are (a) more effective when coupled with a physics-education-research-based text (Reif's *Understanding Basic Mechanics* was used in Spring 1994), and (b) less effective when grafted onto courses in which lectures, discussions, and exams are of the more traditional type.

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III. WHAT IS AN SDI LAB?

Socratic Dialogue Inducing (SDI) labs were originally inspired by the work of Arnold Arons,[12] and embody many of his instructional ideas. We strongly recommend study of Arons's *Guide to Introductory Physics Teaching* before attempting to implement them. Detailed descriptions and evaluations of SDI labs have been published.[2-6] Ref. 2 gives extensive references to the preconception literature upon which many of the SDI experiments are based. SDI Labs currently cover only introductory mechanics, but similar methods could be used advantageously in other areas of physics or in almost any conceptually difficult subject.

SDI Labs emphasize hands-on and heads-on experience with simple mechanics experiments and facilitate interactive engagement of students with course material. They are designed to promote students mental construction of concepts through their (1) conceptual conflict, (2) extensive verbal, written, pictorial, diagrammatic, graphical, and mathematical analysis of concrete Newtonian experiments, (3) repeated exposure to experiments at increasing levels of sophistication, (4) collaborative peer instruction, and (5) Socratic dialogue with instructors.

In addition to the emphasis on concepts, SDI labs attempt to enhance students' (a) understanding of the nature of science, (b) use of effective strategies for scientific thinking and problem-solving, and (c) research skills such as collaborative effort, drawing, written description, thought experiments, modeling, consideration of limiting conditions, experimental design, control of variables, dimensional analysis, and solution of real-world problems.

The most recent version of the ground rules for SDI labs can be found in SDI Lab #0.1 (portable document file version). For a summary of the ground rules with the pedagogical rational see refs. 4 and 5. Students work through lab manuals which encourage active student thinking and involvement by requiring them to:

1. Write down operational definitions of terms used in mechanics, e.g., vertical, horizontal; displacement; time interval, instant of time, clock-reading; average velocity and acceleration; instantaneous quantities: position, velocity, and acceleration.

2. Perform (often predict and then perform) simple hands-on experiments involving a BODY at rest or in motion.

3. Draw snapshot sketches at sequential clock-readings showing (a) color-coded vectors to indicate ALL the forces acting ON the BODY - labeled as $\vec{\mathbf{F}}_{\text{on A by B}}$, where A is the BODY and B is some other interacting body); (b) color-coded velocity and acceleration vectors "if they exist."

4. As the experiments proceed, discuss with other students and then write down answers to questions that probe for reasoning skills and basic conceptual understanding of Newtons laws. The question format is such as to require rather complete explanations, justifications, and/or sketches and not simply yes-or-no answers. In some cases "Out of Lab Problems" based on the lab experiments are suggested.

5. If stumped or confused on any of the above (after serious effort and discussions with other students) engage in Socratic dialogue with an instructor after signaling for help.

Ideally, the Socratic method involves questioning students in such a way that they are lead to express their ideas and figure things out for themselves. Instructors may at first fall short of this ideal, but generally improve with time. We recommend that an experienced dialogist be present at lab sessions to act as a second and role model for apprentice instructors. Our experience indicates that instructors should not wait for help signals to assist students, but should continuously oversee their work and attempt to lead them to clear up their misunderstandings as they proceed.

Students are required to hand in their filled-in manuals at the end of the period. These are annotated and returned at the next lab period but not graded. A lab grade is derived from periodic written exams containing questions demanding a good conceptual understanding of experiments similar to those performed in the lab.

IV. IMPLEMENTATION REQUIREMENTS

1. Conventional physics lab environment (e.g., 24 students per lab, 4 at each of 6 tables) except that its better to have a student/instructor ratio of about 12 rather than the more conventional 24. At Indiana University the cost of extra lab instructors was reduced through the employment of undergraduate physics majors and occasional postdoctoral volunteers.

2. Grade incentives for taking the SDI labs seriously, e.g., exam questions testing for conceptual understanding on SDI lab topics.

3. Education of instructors, preferably by serving apprenticeships with seasoned dialogists.

4. SDI Lab Manuals - see below under "Available Resources." SDI Labs #1-3 constitute the essential core of the material and selected sections could suffice for initial testing of the method.

5. Equipment - generally elementary and inexpensive, e.g., wooden blocks, rubber balls, plywood boards, 1 kg masses, meter sticks, spring balances, coffee filters, plumb bob, carpenter's level, steel balls, drawing compasses.

V. AVAILABLE RESOURCES

A. Nine lab manuals – the most recent versions are available electronically as portable document files downloadable with the free Adobe Acrobat Reader at <http://www.adobe.com/prodindex/acrobat/readstep.html>:

#0.1 - Frames of Reference, Position, and Vectors (with "Ground Rules"), 27 pages, 77 kB;
#0.2 - Introduction to Kinematics*, 26 pages, 55 kB;
#1 - Newton's First and Third Laws*, 51 pages, 220 kB;
#2 - Prelab Assignment on Operational Definitions*, 8 pages, 22 kB;
#2 - Newton's Second Law*, 44 pages, 231 kB;
#3 - Circular Motion and Frictional Forces*, 57 pages, 506 kB;
#4 - Rotational Dynamics*, 26 pages, 198 kB;
#5 - Angular Momentum, 47 pages, 275 kB;
#6 - Newtons Second Law Revisited*, 17 pages, 165 kB;
#7 - Newton's Laws Revisited, 11 pages, 33 kB.
*A Teacher's Guide is available.

For those wishing to try SDI Labs, we recommend starting with SDI Lab #1, Secs. I and III. Manuals #0.2 and #6 combine SDI and TST [Tools for Scientific Thinking - R.K. Thornton and D.R. Sokoloff, *Am. J. Phys.* **58**, 858 (1990)] methods under a crosslicensing agreement. The TST methods utilize a sonic motion detector. Manuals #1, 2, and 3 include optional computer-animation studies (see "D" below) to be done only after the relevant real-world experiments are completed. The manuals provide blank quadrille-ruled spaces for student sketches and answers. Manuals and experiments can be modified by instructors to suit local tastes or circumstances and considerable selectivity can be exercised since most of the manuals each contain more material than can be adequately covered in two two-hour lab periods.

B. Teacher’s Guides (as indicated above)
By request to R. Hake <hake@ix.netcom.com>.

C. Indiana University Course Handouts
Available at <http://carini.physics.indiana.edu/SDI/>:
- a. Objectives of the Course,
- b. Academic Background Questionnaire,
- c. Grading Acronym Guide,
- d. Diagnostic Student Evaluation.

D. Computer Animations
Written by Randall Bird for for SDI Labs (currently running only on Power Macs)
available by request to R. Hake <hake@ix.netcom.com>:
- a. Trajectory (SDI Labs #1 and #2)
- b. Pendulum (SDI Lab #2)
- c. Conical Pendulum (SDI Lab #3)
- f. Bucket (SDI Lab #3)

E. Equipment Set Up Sheets
Available by request to R. Hake <hake@ix.netcom.com>.

F. Sample SDI Lab Exams
Available by request to R. Hake <hake@ix.netcom.com>.

G. Videotapes of SDI Labs in Action
Available by request to R. Hake <hake@ix.netcom.com>.

References and Footnotes

1. R.R. Hake, (a) "Interactive-engagement vs traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses," *Am. J. Phys.* **66**, 64 (1998), also on the Web at <http://carini.phyics.indiana/SDI/>; (b) "Interactive-engagement methods in introductory mechanics courses," preprint, submitted to the potential new *Journal of Physics Education Research* on 5/97, also on the Web at the above address; (c) "Evaluating Conceptual Gains in Mechanics: A six-thousand-student survey of test data," *AIP Conference Proceeding No. 399, The Changing Role of Physics Departments in Modern Universities: Proceedings of the ICUPE,* edited by E.F. Redish and J.S. Rigden, (AIP, Wookbury, 1997), p. 595
2. R.R. Hake, "Promoting student crossover to the Newtonian world," *Am. J. Phys.* **55**, 878 (1987).
3. S. Tobias and R.R. Hake, "Professors as physics students: What can they teach us?" *Am. J. Phys.* **56**, 786 (1988).
4. R.R. Hake, "Socratic Pedagogy in the Introductory Physics Lab," *Phys. Teach.* **30**, 546 (1992).
5. R.R. Hake, "Socratic Dialogue Inducing Labs in Introductory Physics," in *Proceedings of the 1995 Conference on New Trends in Physics Teaching*," edited by J. Slisco (Univ. of Pueblo Press, Pueblo, Mexico, in press).
6. R.R. Hake and R. Wakeland, "What's F? What's m? What's a?: A Non-Circular SDI-TST-Lab Treatment of Newton's Second Law," *Conference on the Introductory Physics Course on the Occasion of the Retirement of Robert Resnick*, ed. by Jack Wilson (Wiley, 1997), p. 277.
7. E. Mazur, *Peer Instruction: A User's Manual* (Prentice Hall, 1997).
8. I. Halloun and D. Hestenes, "The initial knowledge state of college physics students," *Am. J. Phys.* **53**, 1043 (1985); D. Hestenes, M. Wells, and G. Swackhamer, "Force Concept Inventory,"*Phys. Teach.* **30**, 141 (1992), a revised 1995 version of the FCI due to I. Halloun, R.R. Hake, E.P. Mosca, and D. Hestenes is in ref. 7 and is available to password holders at <http://modeling.la.asu.edu/modeling.html>
9. D. Hestenes and M. Wells, "A Mechanics Baseline Test," *Phys. Teach.* **30**, 159 (1992).
10. (a) Lou Turner, honors class at Western Reserve Academy, <g> = 0.57 (see ref. 1b); (b) Cherie Lehman, regular class at West Lafayette High School, <g> = 0.42 (see ref. 1b).
11. (a) J.L. Uretsky, "Using Dialogue Labs in a Community College Physics Course," *Phys. Teach.* **31**, 478 (1993). (b) N.C. Steph, Improving the Instructional Laboratory with TST and SDI Labs: Mixing, Matching, and Modifying Ideas, *AAPT Announcer* **21**(4), 61 (1991).
12. A.B. Arons, (a) *A Guide To Introductory Physics Teaching* (Wiley, 1990); (b) *Teaching Introductory Physics* (Wiley, 1997), a compilation containing "a" with minor updates, *Homework and Test Questions for Introductory Physics Teaching* (Wiley, 1994), and a new monograph "Introduction to Classical Conservation Laws"; (c) "Guiding Insight and Inquiry in the Introductory Physics Lab," *Phys. Teach.* **31**, 278 (1993).