Professors as physics students: What can they teach us?

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(Received 26 May 1987; accepted for publication 15 October 1987)

Ten nonphysical-science professors studied Newton's laws for a 3-week period along with 323 students in a noncalculus-based introductory physics course for science majors. The course contained innovations described in an earlier article [R. R. Hake, Am. J. Phys. **55**, 878 (1987)]. Pre- and post-course mechanics exams indicated substantial increase in conceptual understanding for both professors and students over that obtained by students subjected to conventional instruction. The perspectives of the professorial peers on the innovations and various other aspects of the course are quoted at some length. Their major suggestions for instructional improvement of introductory physics courses are: (1) slow the pace at which topics are covered; (2) relate all educational activities to precisely stated course objectives; (3) devote some lecture time to setup and solution of problems with emphasis on models and strategy; (4) use a pedagogically advanced textbook; (5) relate abstract concepts to everyday concrete phenomena as achieved in demonstrations, "The Mechanical Universe" videotapes, and labs of the Socratic dialogue-inducing (SDI) type; (6) teach the course with much smaller lecture sections and with greatly increased faculty–student interaction.

I. INTRODUCTION

There is widespread agreement that science education in the United States needs to be improved.[1–5] Because physics is fundamental to an understanding of technology and other sciences, it is commonly offered as part of the general education of liberal arts students and as a prerequisite and filter for entry into technological and scientific fields. One of us (T), a veteran of the math anxiety campaign,[6] was moved by the high student-failure rate and the underenrollment of women and minority students in introductory physics courses to develop a "peer perspectives" program[7,8] in which nonphysical-science professors ("peers") attempt to learn introductory physics as it is taught to undergraduates and then report on "What makes physics hard?" It was conjectured that the insights and opinions of articulate educators from diverse disciplines might eventually lead to the increased assessibility and effectiveness of beginning physics courses. The other of us (H),[9] after several years of introductory physics teaching and a study of the relevant literature,[10] devised and taught a beginning physics course with innovations that appeared to be effective as measured by pre- and post-course tests[11] of students' conceptual understanding of Newtonian mechanics.

In the present article, we report[12] a study carried out at Indiana University in the Fall semester of 1986 in which the above two programs were combined. The goal was to further test the effectiveness of the previous innovations,[9] and to provide perspectives on physics instruction from peers who experience all aspects of a standard multicomponent beginning physics course for science majors. After indicating the nature of the course and students, we discuss the peer program and the professorial evaluations, reports, and suggestions. We then describe and analyze the pre- and post-course exam results, and finally conclude with a summary of the peer proposals for improvement of introductory physics courses.

II. NATURE OF THE COURSE AND STUDENTS

As in the earlier Indiana program,[9] the present testing ground is the General Physics I course, P201, a standard noncalculus-based introductory course for science (but not physics) majors. An important difference is that the previous study was carried out in a 6-week summer session for 53 students, whereas the present work involves a 14-week full semester course for 323 students. For this program, the 370 students who started the course were required to fill out an "academic background questionnaire"[13] and information thus generated for the 323 students who finished the course is shown in rows 1–4 of Table I. In addition, the distributions of the "preparation index" (the sum of the raw scores of the mathematics and mechanics pretests discussed in Sec. VII) and the final course grades are tabulated in rows 5 and 6. Questionnaire responses also indicated that courses in high-school physics, high-school calculus, and university calculus had been completed by, respectively, 75%, 52%, and 88% of the 323 students in the program. All the above data reflect a student body profile very similar to that of the earlier study.[9] The text,[14] topic "coverage," problem assignments, exams, and general procedures of the course were also all nearly the same as previously described.[9]

III. PEER PERSPECTIVES

In March 1985, 30 nonscience faculty and staff at the University of Chicago received physics instruction in "waves in elastic media" and "relativity" and then reported their various learning problems. This Chicago peer perspectives program[7,8] was somewhat artificial in that professors received only about 4 h of lectures and did not partake of discussions, labs, text study, problem assignments, and exams. The present Indiana "immersion" study (called "immersion" because of the intensity and time commit-

Table I. Some characteristics of the 323 students who completed P201, Fall 1986, Indiana University.

1.	Class	Freshman	Sophomore	Junior	Senior	Graduate
	No.	7	118	161	34	3

2.	Major	Biology	Chem.	Medical science, physical therapy	Math, computer science	Business	Education	Psychology	Geology	General major	Environmental science	English	Other
	No.	104	95	60	19	13	7	6	4	3	2	1	9

3.	Postbaccalaureate intention	Medical school	Other graduate schools	Physical therapy Medical professions Sports medicine	Dental school	Optometry school	Law school	Seminary	No response
	No. of students	128	67	64	21	21	6	1	15

4.	Grade thought needed in P201:	A	B	C	"Any"	No response
	No. of students	205	98	8	1	11

5.	Preparation index (P)[a]	High	Average	Low
	No. of students	74	111	138

6.			A			B			C			D		F	GPA
	Final course grade	A+ (4)	A (4)	A− (3.7)	B+ (3.3)	B (3.0)	B− (2.7)	C+ (2.3)	C (2.0)	C− (1.7)	D+ (1.3)	D (1.0)	D− (0.7)	F (0)	(weighted ave.) 2.74
	No. of students	8	31	30	18	73	35	43	51	15	8	10	0	1	

[a] P (max 64) $= S_{\text{mech I}} + S_{\text{math}}$ ["High" when $P \geqslant 40$, "Average" when $30 < P < 40$, "Low" when $P \leqslant 30$.]
$S_{\text{mech I}}$ (max 36) = correct responses on precourse H^2-mechanics exam (Ref. 11a).
S_{math} (max 28) = correct responses on precourse H^2-math exam (Ref. 11a).

ment) removes these deficiencies. About 1 month prior to the start of the present P201 course, we distributed a "call for consultants" memo to all 1649 campus faculty. This missive explained the program and solicited volunteers to form "...a balanced and representative group of nonphysical-scientist faculty members to serve as planners, participants, and consultants in an attempt to bring faculty peers into the Newtonian world by involving them in actual classes of a multicomponent physics course...[requiring]...6½ class hours per week...[for 3 weeks]...devoted to mechanics with innovations designed to promote physical understanding of Newton's laws." We offered a $500 consultant's fee to volunteers who completed the program. Although a large fraction of faculty were off campus at the time (late July), the memo netted 37 positive responses within 1 week. From these we selected 11 peers so as to promote a balance in rank (6 full and 5 assistant professors); sex (7 men and 4 women); and fields (anatomy, classics, economics, education, English, fine arts, folklore, journalism, music, speech and hearing sciences, and psychology). (The journalist, a female assistant professor, was forced by illness to withdraw after the first week.) The peers agreed to spend 3½ h per week studying physics outside the 6½ class hours per week and to take pre- and post-period mechanics exams. They attended lectures with the students but due to scheduling problems their discussions and labs had to be conducted separately by H. In addition, peers met with T, H, and other interested physics faculty for 1-h debriefing sessions each week and for pre- and post-period working dinners. The professors attended classes during weeks 2–4 of the course, coinciding with coverage of Newton's laws (Chaps. 2–5 of the text).[14]

The notion behind peer perspectives is that by inviting evaluations and reports from adult scholars who are relatively new to the field (as are the students), but who are better able to monitor their own learning process, the experimenters could begin to find out "what makes physics hard" for the nonphysics major. To be sure, peers were not—across the board—as recently familiar with algebra and trigonometry as ordinary P201 students might be. (See Sec. V D for a discussion of peers' observations about the relation between physics and mathematics.) Nor are they as grade motivated as most undergraduates (see Table I, row 4). While initial peer ignorance of mechanics was about the same as that of the students (see Table II, column 6), their willingness and ability to articulate that ignorance and their growing comprehension were substantially better. Peers entered the course at the start of the second week of classes and thus were confronted immediately with free-body vector diagrams without the 1-week introduction presented to the regular students. (This omission severely handicapped and discomforted the peers and would not be repeated if the experiment were to be done again with increased funding.)

A. Methodology

Peers were requested to take notes during class periods on the difficulties posed by the material and on the strengths and weaknesses of the instructional methods. Their class notes were to serve as the basis for a final report in which they would explore the reasons for their failures and successes in understanding the material. After their 3-week period and after they had submitted reports, we also requested that the peers respond anonymously to relevant portions of the same course evaluation form[15] that had been given to students at the end of the fifth week (1 week after the first exam). The evaluation form requires computer-sheet responses in the usual A to E multiple-choice format, thus allowing calculation of an evaluation point average (EPA) for each question. [The letters A,B,C,D, and E have the usual weighting 4,3,2,1,0, respectively, so that the EPA is similar to the more familiar student's grade point average (GPA).] The evaluation form also includes a comments page asking for (a) written statements on the major strengths and weaknesses of the course and (b) written suggestions for improving the course. All ten professors returned evaluation computer sheets but only eight re-

Table II. Pre- and post-course mechanics and mathematics test results for students in various noncalculus-based introductory physics courses.

Institution	Number of students	Pre-course math test $M \equiv$ Mean $(M/28) \times 100$	SD[c]	KR[d]	Pre-course mechanics test $M \equiv$ Mean $(M/36) \times 100$	SC[c]	KR[d]	Post-course mechanics test $M \equiv$ Mean $(M/36) \times 100$	SD[c]	KR[d]	Mechanics gain $(M_{post} - M_{pre}) \equiv \Delta M$ $(\Delta M/36) \times 100$	Row
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	
Ind. Univ.[a] (Fall 1986)	323 (Entire class)	17.43 (62.25%)	4.96	0.79	15.58 (43.28%)	5.28	0.76	26.48 (73.56%)	4.99	0.81	10.90 (30.28%)	1
	53 (SDI labs)	16.92 (60.43%)	4.95	0.78	15.17 (42.14%)	5.12	0.75	27.83 (77.31%)	3.95	0.75	12.66 (35.17%)	2
	270 (No SDI labs)	17.51 (62.54%)	4.94	0.79	15.65 (43.47%)	5.30	0.77	26.22 (72.83%)	5.13	0.82	10.57 (29.36%)	3
	10 Profs. (3 weeks)	···	···	···	16.70 (46.39%)	5.83	0.84	25.70 (71.39%)	4.03	0.75	9.00 (25.00%)	4
Ind. Univ.[e] (Summer 1986)	53	15.47 (55.00%)	4.66	0.75	14.81 (41.14%)	5.32	0.77	26.23 (72.86%)	4.64	0.81	11.42 (31.72%)	5
Ariz. State[b]	82	10.48 (37.43%)	4.58	···	13.48 (37.44%)	5.00	···	19.00 (52.78%)	5.16	···	5.52 (15.33%)	6

[a] Present work, math test same as Ref. 11a. Mechanics test same as Ref. 11a except for minor corrections and clarifications.[13,23b]
[b] These data are for professor "E's" class,[11a] the only class for which post-course mechanics exam scores were available in the noncalculus-based courses tabulated in Table I of Ref. 11a.
[c] SD = Standard deviation.
[d] KR = Kuder–Richardson reliability coefficient.[27]
[e] Ref. 9. All students took SDI labs.

turned the comments page. Thus the peer impressions of major strengths and weaknesses of the course, as given below, refer to an eight- rather than a ten-peer survey.

B. Findings

In Secs. IV–VI we summarize peer evaluations,[16] comparing them to those made by students on various aspects of the course; and we quote portions of their lengthy written reports. First a caveat: For the experimenters, the new features[9] of the course as taught at Indiana (i.e., the SDI labs, the qualitative approach to problem solving, and the use of "The Mechanical Universe" videotapes) were of particular interest. However, these activities were not perceived as "innovations" by most peers and students taking the course, because for them *everything* about introductory physics was new. In general, neither the peers nor the regular students were able to sort out the new from the old in their evaluations or to imagine what the course would have been like without these special features. Thus while we begin with their respective evaluations of the innovations, we note at the outset that in some respects the peers and the students focused as much if not more on the *standard* features of P201 as on its special aspects.

IV. SPECIAL FEATURES OF THE COURSE

A. Socratic dialogue-inducing (SDI) labs

SDI labs have been thoroughly described in Ref. 9. They emphasize hands-on experience with simple concrete mechanics experiments and facilitate *interactive engagement* of students with course material. They are designed to promote concept formation through "disequilibration,"[17,18] collaborative discussion among students, and Socratic dialogue[1,19,20] with instructors. The peers took only SDI labs. The test-group students took SDI labs during weeks 2 through 5 of the course.

Five of the eight peers who returned the comments page of the evaluation form listed SDI labs among the major strengths of the course. As indicated above, all ten peers returned evaluation computer sheets. Here and below we shall usually give their ratings only in terms of the evaluation point average (EPA), *followed by the student-given EPA in parentheses for comparison.* The peers rated the interest level of the labs as 3.30 (2.90), the quality of the lab manual as 3.30 (2.97), and the lab as a help in learning physics as 3.70 (3.36). For comparison, student responses to the same three questions for *standard* labs were: (2.40), (2.59), (2.29).

As an undergraduate 10 years previously, the economist had taken part of a beginning physics course. He contrasted his laboratory experiences in the following way: "I had anticipated the sort of lab experience that I had been exposed to as an undergraduate, in which we would time and measure movements of blocks or balls on inclined planes, etc. In contrast, the SDI labs had us simply holding weights in our hands, watching pendulums in motion, etc., and *thinking about* what had to be taking place [emphasis added]. These simple exercises probably did more to help me understand the relationship between force, acceleration, and velocity than any problem, lecture, readings, or other learning device that I can visualize. The SDI labs also aided in gaining an improved understanding of the homework problems since setting up the problems required an ability to visualize the qualitative aspects of given situations."

The professor of anatomy, who had also experienced physics as an undergraduate, wrote: "The SDI labs were just great. They spent time teaching observation, analysis, and thought concerning the concepts of mechanics. There was room then to go on and solve the problems after the completion of the analysis in lab. Maybe physics labs should be more of this type early in the semester to get the students into this type of thought processing, which will benefit them the rest of the year in physics as well as in other science courses, professional school, or whatever."

The fine arts professor saw the labs as the counterpart of the art studio: "I was impressed at the similarity of teaching science and art. Most learning in physics occurs in the lab just as most learning in art takes place in the studio. . . .I think that understanding what is going on—the physics—is more important. . .than correct numerical solutions. As a teacher of art I am more interested that students get a feel for the creative process rather than they become overly technical at first. I think the SDI labs provide the opportunity for students to figure things out for themselves with timely prodding from the instructor."

Not all peers were equally enthusiastic. The professor from the department of music felt manipulated by the very same exercises that so aided the economist. "I certainly enjoyed the SDI labs but, by and large," he wrote, the SDI labs "were frustrating. I felt I was trying to re-invent the wheel." For the professor of English, the labs were somewhat alien: "I don't think that I learned much in the laboratories. . .I don't have that taste for seeing [how a particular thing] really works and I was impatient and uneasy working in groups. . .(I do admit that when I took the examination at the end I pushed a pad of paper off the end of the table a couple of times to check out the arc of its fall. I felt that I was cheating, that I ought to be able to work out this matter in my head). . .[While] I admire and endorse the principle,...SDI labs just seemed to be inefficient for my style of learning. . .the style of my discipline—a private and abstract working out of problems that have no right solution but only a series of more or less satisfying provisional closures... ."

B. Problem solving

The present course placed great emphasis on problem solving. A total of 190 problems was assigned, of which 45 were submitted for grading, and the homework grade counted for 15% of the course grade. Although all exams were multiple choice, most of the questions probed for the problem-solving ability to link conceptual understanding with critical thinking. About 30% of the mechanics lecture time was devoted to systematic solution of problems, emphasizing a qualitative approach to their initial formulation. The method combined features previously incorporated by Hake,[13] Wright and Williams,[21] Reif and Heller,[2b,22] Hestenes and Halloun,[23] and the text.[14] Partially following Ref. 21, the strategy was introduced to students as the "WIESE" (pronounced "wise") method: (1) *W*hat's happening? (2) *I*dealized model, (3) *E*quations, (4) *S*ubstitute, (5) *E*valuate. As applied to mechanics problems, the *W* and *I* steps involved the domain-specific "generation of a theoretical description" formulated by Reif and Heller[22] and shown by them[2b,22] to be effective when employed by students in problem solving. As in the SDI labs,[9] great emphasis was placed on (1) drawing time-sequential vector diagrams of objects in motion with color-coded force, velocity, and acceleration vectors, and (2) an operational approach[19,24] to definitions and concepts.

The generally negative reaction of students to those aspects of the course most directly related to problem solving is indicated by their responses to the following course-evaluation items: Degree of fairness of homework assignments (1.61); Quality of examination questions (1.93); The level of difficulty of exam #1 was (a) about right (91), (b) too difficult (143), (c) too easy (3). On the other hand, peers displayed a generally positive reaction to the problem-solving emphasis (see below).

That peers reacted more favorably to problem solving than students may be due in part to the different circumstances of the two groups. Peers attended problem-oriented discussion sections with H rather than with graduate student associate instructors. They were not obliged to struggle with and then submit homework problems for grading, they did not take the fairly difficult (average raw score 57%) exam (which occurred just 1 week prior to the student evaluation), and they did not perceive the homework and exam problems as adversely affecting final grades or professional aspirations. Unlike students, most peers tended to evaluate problem solving only with regard to its contribution to their own understanding of the material. Another factor in the difference between student and peer reaction to problem solving may be associated with differences in the average maturity of thinking processes[17,18] of the two groups.

On problem solving, the folklorist commented: "When the problems were worked out completely, together with verbalization of thought processes, even I began to follow." The professor of speech and hearing sciences, after recounting ups and (mostly) downs of the early stages of the course, wrote: "Eventually and inevitably I became more concerned with what I was learning. . .and less. . .with my reactions to the material [and the] learning process. . .I realized the problems required a lengthy qualitative analysis prior to the quantitative synthesis step I had been having so much trouble with, and that realization alone made me feel like there might be some hope for me in physics."

The anatomist appreciated the problem-solving structure, but observed that the students undervalued it because they only wanted "answers." She wrote: "If the students use the WIESE method. . .they should be able to solve the problems but. . .they [prefer to] be given the equations so they can plug the numbers in... ."

The professor of education, who is also the director of the learning skills center, finally concluded that the "real game" of physics was not in actually *solving* problems but in *setting them up*. He wrote: "I took notes in lecture, read as much of the text as time allowed, did what I could in lab with the prelab preparation 45 min could provide, and hoped a pattern of clear priorities would emerge. . .As H went through the excruciating details of *setting up* all the elements and interrelationships before actually attempting to do a problem, it became clear that seeing and setting up those interrelationships was the *real* game. Everything else was subservient to that. The notations, the Newtonian laws, the mathematics, and the laboratory experiments were all just support and foundation for understanding how objects operated in space in conjunction with each other.

Peers found themselves viewing the world differently as a result of the problem-solving approach. The English professor recalled in his final report: "One day I looked at the cover of an issue of *The New Yorker*—some telephone lines drawn across a composition of gabled roofs. I started to draw force diagrams in my head. That happened a lot; I'd watch a basketball game in the gym and convert the arc of an outside jump shot to one of the diagrams H drew in the lecture, or I'd watch a car pass me on the highway and pull away and wonder about how to calculate the relative velocities. I won't say that I began to think or even to see like a physicist. It was only a 3-week course. But I think that I began to understand the relationships that physics studies in the world, and the kinds of questions that flow from setting objects in such relationships. . .It was in the discussion sections, while watching H work out problems, that I got the perspective that started me organizing the world into force diagrams."

The psychologist was not sure that the problems produced as much insight as anxiety: "At the end of each chapter, there were about 45 problems, some significantly more difficult than any examples in the chapters. Students were supposed to do only three problems on each homework assignment, but suppose the instructor asked a question from the set of 45 that was *not* on the homework?...The enormity of the number of problems. . .and the difficulty level. . .produced high anxiety."

C. "The Mechanical Universe" videotapes

In the present course we showed 10 of the $\frac{1}{2}$-h videotapes from "The Mechanical Universe" series,[25] seven in the lectures, and three (on thermodynamics) in the labs. In addition, four tapes were shown for optional viewing outside regular class hours during the last (review) week of the course. Students were also able to view the tapes at the library and the audiovisual center. At the time of the fifth-week student evaluation, three tapes had been shown: "Introduction to the Mechanical Universe," "The Law of Falling Bodies," and "Inertia." The peers viewed only these three tapes during their 3-week period. Both the lectures and the SDI labs made frequent reference to the videotape material. In addition, each exam included several questions that could not easily be answered had not careful attention been paid to the tapes.

Although one peer rated the videotapes as among the major strengths of the course, there were mixed responses to the evaluation form question, "To what degree do you approve showing of 'The Mechanical Universe' tapes in lectures? (a) strongly approve [4(37)]; (b) approve [2(82)]; (c) neutral [1(62)]; (d) disapprove [2(32)]; (e) strongly disapprove [1(25)]; EPA 2.60 (2.31)."

The professor of anatomy strongly approved the tapes, but thought that the students had been too indoctrinated in lock-step instruction to appreciate them: "The videotapes were really a saving grace for the class. . . .They present good examples of concepts. . .[requiring]. . .a student to make observations and come to a conclusion before they present the results. This is a good method for teaching science, but the students don't know how to react to this type of approach. They are too used to being told, 'you must know 1, 2, 3, etc.' "

The professor of speech and hearing sciences had warm praise for the second tape: "The next lecture started out with Aristotle's view of the world, and the film 'The Law of Falling Bodies.' Both made a lot of sense to me. These more verbal and descriptive parts of the class were always easier for me to get something out of. . . .'The Law of Falling Bodies' gave me more information than just about anything else we did in the class (with the exception of the labs). I felt I finally understood the relationship between distance, speed, and acceleration."

In a debriefing session, the education professor pointed out the advantage of the videotape's repeated replay demonstrations over the lecture's one-play versions. A good example of the former is the videotape's dramatic enactment of Galileo's thought experiment involving the dropping of a stone from the mast of a moving ship. In his report he wrote: "The videotape series with balls dropping from the masts of moving sailboats clarified counterintuitive principles."

Negative reactions to the videotapes by both peers and students seemed to have less to do with their quality and interest than with their perceived displacement of more critical exam-preparing instruction from the lecture. The economist offered a "cost-benefit analysis" from a hypothetical student's viewpoint: "Time spent on 'history of thought' is not wasted time, but the amount of time spent on that topic, from the perspective of a student, should only be in direct proportion to performance expectations as measured by coverage on exams, problems, and laboratories. Like many students, I was frustrated to be struggling with problems that influence the course grade only to find a large bulk of class time devoted to 'history of thought.' If historical issues are important, then I, as a student, should perceive some substantive benefit (i.e., a higher grade) from time that is spent discussing them."

V. STANDARD FEATURES OF THE COURSE

A. Demonstrations

Peer evaluations of the demonstrations performed during lectures mirrored rather closely the response of their counterparts during the Chicago experiment.[7,8] Three peers classified the lecture demonstrations as among the major strengths of the course. When asked to evaluate the "quality of lecture demonstrations," they were fairly positive: 3.20 (2.92). But their rating dropped nearly a full point when asked: "To what extent do demonstrations enhance your understanding of the subject?": 2.30 (1.96). For some, the demonstrations provided what they were waiting for: in the words of the English professor,..."a rush of understanding"..."the moment that H, wheeling a bucket in a circle said, 'Why doesn't the water fall out of the bucket? For the same reason that the moon doesn't fall out of the sky'...That's *right*, I thought, that's really beautiful that physics works all over, that it provides such a large and elegant frame of explanation."

For the professor of education, the demonstrations brought back memories of a high-school physics course he had taken from a basketball coach who "wasn't much of a scientist or scholar, but did have a knack for linking principles of mechanical motion to understanding everyday activities. [The coach] pointed out that Hank Aaron was able to hit home runs not because his bat was so heavy, but because his wrists were able to swing the bat so rapidly."

The professor made the connection"....H's lecture hall demonstrations and laboratory experiments will be with me always. Dry ice on glass makes the interaction of forces and inertia apparent for me. . . .So, too, did the film of a flea pulling a weight on a frictionless surface as well as H's gruesome discussion. . .of why the fat lady was thrown from the roller coaster to her death."

The reason many students are impatient with demonstrations was, we think, well stated by the psychologist, who, on the second class day, wrote himself the following note: "Like a lot of teachers, H didn't teach me what I need to know to do well on the exams. Who needs a showy demonstration on pulling a tablecloth? I need a review on how to calculate vector forces."

B. The text[14] and the study guide[26]

We were surprised by the generally negative reaction of peers to the tried-and-true text.[14] One peer rated the text as among the major weaknesses of the course. On clarity, the peers rated the textbook 1.90 (2.03); on interest level, 1.40 (1.87); overall, 2.00 (2.24). On the other hand, peers thought better of the companion study guide,[26] giving it an average rating of 3.38 (2.46). Both the folklorist (who had had very little training in science) and the anatomist (who had done advanced work in the life sciences) had the same complaint: too much jargon and too many symbols "...without any introduction to them. The book contained so many [new words and symbols] it was hard to focus on the ones that were important for that day's lecture."

The psychologist thought the text a poor model. "The book gives a bare bones explanation of the concepts and then jumps right into mathematical problems using the concepts. Students at that point have no real comprehension of the concepts, so all they can do is try to fit numbers into formulas. The instructor decries the fact that students don't think through the situation carefully. . .but the book 'teaches' the students by example to jump as quickly as possible to the process of plugging numbers into formulas... ."

The professor of English was upset by his difficulty with the text. He wrote: "I found the reading of the textbook the hardest reading I have done in a long time. I was frustrated and irritated by that. I kept telling myself, I read harder stuff than this in my own field: I can read Derrida if I have to, and prose about 19th-century printing and publishing compared to which the syntax and energy of this prose reads like a newspaper." He decided it was his lack of mathematical skill and the fact that he was not concurrently doing the problems that got in his way. But another reason may lie in what the peer from education, a specialist in learning skills, called the "pedagogical deficiencies" of the text.

He wrote: "The textbook, which I had anticipated would provide a framework for determining priorities, introduced even more densely packed concepts and problems and didn't provide me with a clue as to how I should start. Simple study strategies like previewing chapters, reading summaries, and examining end-of-chapter questions were of some help, but seemed inadequate to the task at hand. . .I did learn some from reading the text, but it never seemed clear, complete, or adequate to the end-of-chapter problems I used to monitor my comprehension."

The professor of music, who is also director of undergraduate studies in the school of music and the author of several texts and programmed manuals, had the least patience with the text. He even tried his hand at rewriting certain of the pages attempting, as he put it, "to make crystal clear what information is essential, and what information is peripheral...." Also he recommended that a certain number of "*abstract* problems (involving concepts, formulas, etc., but no numerical data) and *concrete* problems (involving numerical data)" be appended *immediately* after the introduction of new material, with solutions shown for the first few problems and answers in the appendix for later problems. And finally, he would box off in the text those basic mathematical concepts necessary to the unit under study. Students able in mathematics could skip these; students less familiar with the mathematical procedures would at least know what was expected of them. "The trouble with the text as it stands now," he concluded, "is that you are never sure what you can skip over and what you need to zero in on. Sometimes essential information appears [hidden] in a figure caption and not [even] in the text itself."

The professor of education was also looking for a strategy (his term) for dealing with the text. He wrote: "....the reading was very, very slow going since the text provided no clear means for highlighting key ideas and interrelationships. Later a colleague's remarks directed me to a workbook (Ref. 26) that provided clear summaries and programmed learning on key concepts and problems. I had relegated the workbook to one of the 'if there is time' steps of my study plan. I moved it to step one and used the textbook to clarify points I couldn't follow in the workbook. . . .I used the workbook for an overview and check on comprehension. I read the [text] chapters, listened to lectures, and [in labs took] special care to clarify points not clear to me in the workbook. Once this structure for deciding how to use time was in place, I could begin to enjoy the physics class without being overrun by chaos and disorganization."

C. Pace of the course

At Indiana, as at most large universities, the introductory course for science majors normally "covers" nearly all of physics from kinematics to quarks by moving at close to the speed of light through a densely packed text of nearly a thousand pages. Year after year, student evaluations of P201[13] show that students regard the fast pace of the course as one of its major weaknesses. These student opinions are generally ignored by faculty. According to Arons[1b]: "What we do in our instruction is predicated on the following idea: You take an enormous breadth of subject matter—the bigger the better—and if you pass it by the student at sufficiently high velocity, the Lorentz contraction shortens it to the point where it drops into the hole that is the student mind."

The Indiana peers joined their colleagues at Chicago,[7,8] the students at Indiana,[13] and Arons,[1,19] in condemning the rapid pace at which introductory physics is taught. Five peers classified the present pace (actually slower than usual since only 19 rather than the customary 24 chapters were "covered") as among the *major weaknesses* of the course. Several peers recommended reduced coverage. "It is better to cover a few things well," wrote the psychologist, "than to cover a large number of topics superficially. After all, this is just an *introductory* course." The professor of English noted that physics is not unique in this regard, that many introductory courses become rapid-speed surveys because of professorial politics:

"The problem is the same as that in my discipline. We define physics, or English, as the entire field of our knowledge, and we organize surveys that try to take students through as much of it as we can get into a semester or an academic year. It would be better to do what historians call post-holing, digging deep into some one problem or set of related problems and showing how literary historians or physicists define and solve them. In my subject, the reasons we don't organize courses in this way are wholly political. Each of us owns a piece of the subject, has cultivated a field on the estate, and we want to make sure that students have to cross our land and pay the fee before he or she gets a degree. . . .I'd like-to take a whole semester's course from H on Newtonian physics in which he assigned only a handful of problems each session, worked through a few of them in discussion sections, and used the lecture to consolidate the learning that I acquired mostly from the patient working out of problems. I would not emerge a physicist. But I think I would emerge with a confident idea of what physics is and what physicists do."

The economist wrote: "...based on my brief experience with physics, learning physics is a very disjoint process; understanding comes in pieces and at discontinuous intervals of time. Therefore, the rapid pace at which a course like P201 proceeds is quite unrealistic for both the teacher and the new student in the field. A major stride toward improvement in the depth of learning physics would be either to reduce the breadth of coverage in a course like P201 or to spread out the coverage across three semesters rather than two."

D. The relationship of mathematics to physics

Many physicists believe that the reason physics is "hard" for nonmajors is easily explained by students' lack of competence in algebra, trigonometry, and calculus. As stated, our peers came to the Indiana experiment with a wide variety of mathematics backgrounds, some having had as many as 30 h of undergraduate mathematics (the economist), some having studied none at all at the college level. Most found, within the first two weeks, that strong or weak, their mathematics backgrounds were not going to be the key to understanding physics. Indeed, the stronger the math background, the faster that insight was gained.

The economist wrote that his mathematical training (which included undergraduate level courses in calculus, differential equations, linear algebra, and probability and statistics) at first "turned out to be very useful in terms of problem solving, once the problem was properly set up; however, my mathematical background turned out to be of relatively little help in actually understanding the essential aspects of Newtonian mechanics. Newton's first law, for instance, remains counterintuitive at first glance even if you understand that the vector forces cancel one another out to produce no net acceleration on the object so that velocity is constant. Likewise, the notion that an object that rolls off a table top and cuts out a path in the horizontal direction before striking the floor will arrive at the floor at the same time as an object that was simply dropped vertically contradicts intuition even if it can be made obvious with equations and diagrams of force vectors, velocity vectors, and acceleration vectors. Hence, a major surprise to me was that training in mathematics will not necessarily aid in the learning of physics, at least as it is taught at the introductory level."

The psychologist, whose mathematical training was rustier than that of the economist, developed a similar appreciation after his math skills had been recalled. He wrote: "But as my fear of the mathematical problems was going down, it was dawning on me that the concepts behind the numbers were not so easy to grasp fully. It was very hard to rid oneself completely of all vestiges of Aristotelian physics. I began to appreciate why a student might be great at solving the mathematical problems and yet miss conceptual questions about mechanics."

The professor of speech and hearing sciences perhaps best summed up the group's reflections on the relationship of mathematics to physics when she said, "I finally realized that you don't treat a physics problem like a math problem. You cast a wide net when you do a physics problem. You almost free associate. You ask: How does Newton's first law fit in here? Ah, there's acceleration. Newton's second law must be around. When I finally stopped looking for quantities to set equal to one another I did a lot better."

VI. WHAT MAKES PHYSICS HARD?

The peers were asked to comment generally on "What makes physics hard?" from their brief encounter with the subject as surrogate learners. The professor of speech and hearing sciences wrote "Subjects like physics require *analysis* and *synthesis*, subjects like the humanities only *analysis*. One does not need to 'do' history in order to understand history, as T pointed out in one of our seminars. But I think some courses, such as physics, foreign language, and computer programming are fundamentally different. In these courses, analysis—being able to pick apart and understand a concept, interpret an author's point of view—is a mere first step. Understanding the rules is very secondary to actually *using* them, applying them toward some end. . . .I feel that physics was difficult for me because it required synthesis skills while I was still struggling with analysis, and because I never had any feel for what were the important questions in the field, and how Newton's laws fit in."

Another perspective, from the professor of classics who also functions as the director of "learning support services" for Indiana undergraduates, resides in the following concluding comment: "There was nothing about learning physics which was beyond my control or capabilities. I do not mean by this, however, that I was totally prepared for doing [physics] well or without difficulty. I did indeed struggle at times to grasp ideas and concepts, and I did agonize over problems to be solved. I found, as most of us did, that physics requires different analytical and more quantitative skills than we in the humanities. . .regularly utilize in our teaching and research. But in as short a time as 3 weeks, I was well on the way to recovery of these skills learned long ago in science or mathematics courses and to development of some which I never had to learn or use."

"The problems which I encountered and which may be obstacles for many other physics students are primarily these two: inadequate math skills and inability to extract with ease the essential elements of physics from the plethora of materials and experiences assigned or offered. In short, the abundance of assignments, although designed to assist me in coming at the theories and methods in various ways, tended to be counterproductive. . . .In practical terms, what I am suggesting is that physics teachers (indeed all teachers). . .spell out clearly what the objectives are. . . .But even more important than this, attempt to indicate *how* the many and different assignments and experiences have been designed to assist students in achieving the objectives. Make it clear (and permissible) that some [of the assignments] could be omitted or abbreviated if needed."

VII. PRE- AND POST-COURSE TESTS

How much did the peers (and the students) actually learn? To test their "crossover to the Newtonian world" we administered the Halloun–Hestenes[11a] (H^2) mathematics and mechanics exams in a manner similar to that of the earlier program.[9] The mechanics exam was given to the peers both before and after their 3-week minicourse. It was given to the students at the start and end of the semester. Table II shows the pre- and post-test results for this and previous studies. Significant features tabulated in column 12 are:

(1) Row 4 shows an H^2 mechanics exam gain of 25% for the peers, reasonably high considering their (a) relatively short 3-week exposure to the subject and (b) lack of instruction on energy- and momentum-conservation principles relevant to some of the test questions.[11a] Although the present peer group is too small and possibly highly atypical (being drawn from a subgroup containing only those rare professors who volunteered for the program, see Sec. III), the present results suggest that nonphysical-science professors have no insurmountable difficulties in understanding basic concepts of Newtonian mechanics. This standpoint is consistent with the peer report comments quoted in Secs. IV–VI.

(2) Rows 1–3 and 6 show that mechanics exam gains of the present students are in the 29%–35% range, about twice that of the conventionally instructed[11] Arizona State students. This adds weight to the earlier evidence[9] (rows 5 and 6) that the previously discussed innovations[9] enhance student understanding over that achieved by the standard lecture–discussion method.

(3) Rows 2 and 5 show only a 3.4% increase in the mechanics test gain in going from the 6-week summer-session course to the present 14-week full-semester course. Here, in order to keep other factors more or less constant, we compare the summer students (all of whom took SDI labs) with the present SDI lab test-group students. The present data suggest that ultrafast-paced summer-session physics classes need not be completely ineffectual.

(4) One of the motivations of the present work was to attempt an assessment of the *relative* importance of three innovations[9] (SDI labs, a qualitative approach to problem solving, and "The Mechanical Universe" videotapes) in promoting conceptual understanding of Newtonian mechanics. Table II, rows 2 and 3, show that SDI labs, by themselves, do not appear to be the sole factor responsible for mechanics test-score gains in excess of those reported at Arizona State (row 6). These data suggest to us that SDI labs, per se, played a relatively small but nevertheless positive, role in the 35.2% H^2 mechanics exam gain of the test group, although possible test teaching[9] of certain exam questions by the SDI labs clouds the interpretation. A standard statistical t-test analysis[27] indicates a probability $p = 0.10$ that the column-9-indicated 4.5% mean-score difference of SDI (77.3%) and non-SDI (72.8%) students is merely the result of chance.

The present results indicate that the lectures and/or "The Mechanical Universe" tapes play an important role in the present course design. Additionally, in our judgment, the SDI labs probably had an important *indirect* effect because the lecturer (H) unavoidably carried over much of the methodology and philosophy of the SDI labs to the lectures. In retrospect, a more valid test of SDI lab efficacy might have been obtained had the lectures been conducted by a separate instructor in a conventional manner.

VIII. CONCLUSIONS

Peer perspectives programs are easy to run, relatively inexpensive, stimulating for both instructors and peers, and could be beneficial in a wide variety of educational settings. Even where peer ideas for course improvements are not new, the fact that they come from academically sophisticated colleagues with first-hand receiving-end experience gives them added weight. Although many of the peer suggestions are included in Secs. IV–VI, we summarize below their major proposals for the improvement of introductory physics courses.

(1) Slow the pace at which topics are covered. Treat all material in sufficient depth that adequate understanding and skill can be developed by students. For a course like P201-2 one might: (a) Reduce the number of topics; (b) change it from a 2- to a 3-semester course; (c) establish a Newtonian mechanics-oriented physics "precourse" emphasizing study methods, problem-solving techniques, SDI labs, critical thinking, history and method of science, and math review.

(2) Relate all educational activities to precisely stated course objectives: (a) Enunciate the course goals in operationally meaningful terms; (b) give students better guidance as to how they might selectively take advantage of the wide variety of course offerings; (c) relate the exam content to the course objectives in a very obvious way.

(3) Make use of a more pedagogically advanced and less densely packed textbook: (a) Encourage students to use programmed study guides such as Ref. 26; (b) point out especially valuable and relevant features of the text during lectures.

(4) Concentrate on relating abstract concepts to familiar concrete examples by emphasizing SDI labs, demonstrations, videotapes, and even tours of the campus in which the physics of everyday phenomena is pointed out.

(5) Teach the course with much smaller lecture sections and with greatly increased faculty–student interaction.

(6) Follow the math diagnostic test with enough math review periods to bring math skills up to the required level.

(7) Stress role models for women and for minority students.

(8) Consider more use of calculus.

(9) Eschew put-down statements such as "this is the easy part," "as you know from...," "it is obvious that...," etc.

(10) Discuss some problems of major significance (e.g., planetary orbits) rather than concentrating solely on "woman-pushing-block" type exercises.

ACKNOWLEDGMENTS

We wish to thank the Rockefeller Foundation, the Indiana University Foundation, the Indiana University Physics Department, and the Indiana University offices of

Research and Graduate Development, Learning Resources, and Teaching Resources for financial support. The program was assisted by Addison-Wesley's generous donation of texts and study guides for the peers. We have benefited from conversations and correspondence with A. B. Arons, N. J. Castellan, D. Hestenes, L. C. McDermott, H. A. Neal, M. Intons-Peterson, F. Reif, B. A. Sherwood, D. Trowbridge, and J. R. Franz. We are especially indebted to the latter for her invaluable advice and help on the peer perspectives program. Most important, we gratefully acknowledge the venturesome and hard-working Indiana faculty peers whose perspectives form the major theme and substance of this article: Mary Ellen Brown, Folklore; Jerry Chertkoff, Psychology; Marylou Gelfer, Speech and Hearing Sciences; Donald Gray, English; Kathleen Klueber, Anatomy; Larry Mikulecky, Education; Gus Nelson, Classics; Holly Stocking, Journalism; David Van Hoose, Economics; Allen Winold, Music; and Jeffry Wolin, Fine Arts.

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