Consumer-Oriented Physics: What Do Engineering Instructors Want From Us?

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At the University of Minnesota, we conducted a survey of the engineering and science departments who require their students to take the introductory calculus-based physics course. The purpose of the survey was to learn why our engineering and science professors require physics for their students. We also asked about goals for our course, topics we might want to teach, and how best to teach them in the laboratory and recitation sections. This paper presents the results of this survey.

INTRODUCTION

As with many universities, introductory calculus-based physics at the University of Minnesota is primarily offered as a service course to other science and engineering departments. Only about 5% of the 1200 students in our introductory course for scientists and engineers intend to major in physics. Most students in this introductory physics course do not take another physics course. Rather these students will hone their technical expertise in whatever engineering or science discipline they are majoring in. Physics instructors who teach this service course realize they are not teaching to future physicists and that this may require a different design than a course for majors.

Designing any effective introductory physics course requires knowledge of the initial state of the learner, how these students learn, appropriate instructional techniques, and a suitable learning environment[1]. Designing an effective course also requires the planners to make difficult choices about what goals and objectives the course should address. Without a careful selection of a few focusing goals and achievable objectives, any course is doomed to fail. Designing a service course additionally requires the instructors to know why the science and engineering departments require their students to take an introductory physics course. What techniques, skills, and knowledge do they expect their students to have after leaving our courses? Are they satisfied with how we are using the elements of our course, namely the lecture, laboratories, and recitation sections?

To help our physics instructors understand the motivation of science and engineering faculty for requiring introductory physics of their students, a seven-question survey was developed and distributed. This survey was based on an earlier questionnaire we used to redesign our algebra-based course[2]. The results of the science and engineering faculty survey are presented in this article. This information was essential input for the design of the introductory, calculus-based physics course at the University of Minnesota.

SURVEY METHODOLOGY

The questionnaire for the survey was created collaboratively between the Department of Curriculum and Instruction and the School of Physics and Astronomy. It was designed to solicit responses on what the science and engineering instructors expect their students to gain from our physics course and how they think we should teach it. The survey was distributed only to those departments which require their students to take the calculus-based physics course. Less then ten percent of the students who take the course are biology majors and they are required to take either the calculus-based course or the pre-med algebra-based course. Due to this ambiguity, the biological science departments were not included in the survey. It was not the intention of the survey to address every conceivable issue that might arise at the interface of physics instruction and the academic community. It was also not the intention to conduct a general survey of the science and engineering faculty. A copy of the questionnaire used in this survey is available in on-line at <http://www.physics.umn.edu/groups/physed/engsrvy.html>.

The questionnaires were distributed to a non-random sample of instructors in our science and engineering departments. These instructors were selected by the Directors of Undergraduate Studies (DUGS) of their respective departments. The DUGS were asked to create a list of professors in their department who had the most interest in undergraduate preparation for their courses. In only one case did a

DUGS (the Department of Statistics) decide not to participate in the survey. The questionnaires were then mailed to each of these select faculty members and follow-up letters were sent as needed. The questionnaires were not collected anonymously. After three rounds of follow-up letters, the response rate for the survey was 50 out of 74, or 68%. The participating departments are indicated in Table 1.

SURVEY ANALYSIS

Before the analysis of the survey could begin, we had to determine the number of students in each engineering and science department at the University of Minnesota. There are several possible measures of departmental size, including the number of faculty teaching in each department, the total number of students majoring in each program, or the number of degrees granted by each program. We decided to use the number of bachelor's degrees granted by each department. While there is some over-counting of students due to double-majors, there is no under-counting students who haven't declared a major. The relative sizes of each department survey are listed in Table 1. Although the physics department is listed in Table 1, their responses were not included in the analysis of the survey.

Insert Table 1 about here

The results from each questionnaire were combined to get a single result for each department. These results were then analyzed in two different ways. The first analysis technique has the departmental results weighed according to the number of students in the program, so the larger departments have more effect on the overall results. To citizens of the United States, it is useful to think of this weighed average as the "House of Representatives" model. The other analysis technique combines the departmental results equally so that every department has the same effect on the results. It might be useful to think of this unweighted average as the "Senate" model.

The utility in the two analysis techniques is that if there is consistency in the results of the survey between the two analysis models, then we know that there is agreement between the opinions of the departments and what would be best for the bulk of our students. Presumably we can act on these consistent results without disadvantaging any group of students. The analogy to the U.S. Congress is useful to understand this. On the one hand, if both Houses of Congress agree on an issue, then we should have confidence that both the wishes of the small states and individual citizens are respected. On the other hand, if there is a difference, we would have to make a choice as to which (if either) population we should satisfy and which (if either) population we would annoy.

Results

The results from the first six questions of the survey are presented in this article. The last question asked the science and engineering instructors to give examples of specific courses in their departments that assume proficiency in physics. These responses are not presented here because they are specific to the program requirements at the University of Minnesota. The results of the remaining questions are presented using both analysis techniques.

Reasons for Requiring Physics

The first question asked the respondents their opinion as to why their departments require their students to take physics. This is ultimately the most basic question of this survey. We have a lot of assumptions about the importance of physics to other disciplines, and this question can provide evidence to test our assumptions. The question was asked in a open-response format so the instructors were not constrained to a selection of choices which might not match their opinion. The responses to this question were then grouped by themes present in the comments and then analyzed using both models. The results are presented in Table 2. The percentages presented in this table have a statistical uncertainty of about 3 percent.

Insert Table 2 about here

As seen in Table 2, there were four reasons that physics is required by the science and engineering departments at the University of Minnesota. It can also be seen that, in both models of analysis, the frequencies that each of the four reasons occurred are essentially equal. Learning physics is important not only for its own sake, but because it underpins much of engineering, forms the foundations for later course work, and imparts certain reasoning skills. These are all familiar reasons we have used for years to motivate our students and these reasons are represented by the rest of the survey.

TIME

The second question asked the science and engineering instructors how much time their students should spend in physics. We asked them this question to place a more concrete value on physics for their students. In the current political and economic climate, most colleges and universities are being pressured to graduate their students in four years and the University of Minnesota is no exception. There is also pressure on our engineering faculty to include more specific, program courses for their students. These faculty are very aware of these pressures and want to be as efficient as possible while maintaining high standards. If they felt that physics was not an important element in their curriculum, such a question would allow them to express this priority.

Since the University of Minnesota is on the quarter system, we asked the science and engineering instructors how many quarters of physics should be required. These answers were then averaged within their respective departments and this average number of quarters was then compared to the current requirements of the department to see if the instructors favored having their students spend more or less time studying physics. This comparison was done for both models of analysis. The results suggest that our science and engineering faculty are satisfied with their current requirements. Using the unweighted average, the difference between the number of quarters of physics the respondents to the survey favored and the current requirement of their departments was 0.5 ± 0.2 quarters. However, using the weighted average, any difference between the respondents and the departmental requirements disappeared; 0.0 ± 0.2 quarters of physics instruction. The difference between the two models is that some of the smaller departments (Geology and Mathematics) would prefer that their students take more physics.

GOALS

The third question addresses the many possible goals that the science and engineering instructors might have for our introductory physics course. While the expectations of the science and engineering departments are only one input into designing an introductory course, we feel that either we should try to meet their goals, or if those goals violate the essential coherence of physics or are counter to effective teaching, we should explain why we cannot meet those goals.

The questionnaire presented a list of 17 different possible goals for an introductory course. The respondents were asked to rate each goal on a 5-point Likert scale with 5 representing the most important goal. The results are presented in Table 3 using both the weighted and the unweighted averages and is sorted highest to lowest according to the weighted average.

Insert Table 3 about here

The consistency between the two analysis models regarding the goals for the course is evident from Table 3. We concluded that our science and engineering faculty, in both large and small departments, strongly value some of the traditional goals of introductory physics classes, such as the emphasis on problem solving. As might be expected, the respondents thought that knowing the fundamental physical concepts was very important, and as the small uncertainty associated with both models suggests, there was very little disagreement over the importance of this goal. The science and engineering faculty are not as positive about other goals traditionally valued by physics departments, such as being able to formulate an experiment or becoming familiar with the historical development of physics.

TOPICS

The fourth question analyzed dealt with selecting which topics should be covered during the course. The question explicitly reminds the respondents that it is impossible to cover all of physics in one year, and they should select the number of weeks (out of 24) we should spend on each topic. The topics listed in the question are chapter titles from our introductory physics textbook[3]. Since most teachers select their curriculum from the textbook[4], this clustering would seem reasonable. This clustering of topics into chapters was also used to judge how difficult the respondents thought each topic was to learn. The last part of the questions asks the respondents to select the four most important topics from the entire list.

Unfortunately, the data we received on the number of weeks that should be spent per chapter was not discriminating enough to draw any conclusions. Several respondents ignored the 24-week maximum, others refused to choose, and most tried to fit the maximum number of topics into the 24 weeks without any apparent consideration about how difficult some topics might be to learn.

However, the items that were selected by the science and engineering faculty as the most important topics to be covered in the introductory course for their students proved very enlightening. The top ten topics are presented in Table 4 using both the weighted average and the unweighted average and are sorted highest to lowest according to the weighted average. The percentages presented in Table 4 have a statistical uncertainty of about 3 percent.

Insert Table 4 about here

Again we can see in Table 4, some consistency between the two analysis models in which topics are considered the most important to be taught. The topics of Newton's Laws and the conservation of energy were first and second in both models by a wide margin. The top ranking of these two topics is consistent with the "know the basics principles behind physics" goal selected in Question 3 by the science and engineering faculty as most important. In the results to this question, we can observe the influence of the larger departments in the selection of some topics such as statics (favored by Civil Engineering, Mechanical Engineering and Electrical Engineering) and DC circuits (favored by Chemical Engineering and Computer Science) which have different rankings depending on analysis technique.

What was most revealing about this question is those topics that were not selected as important by any of the responding faculty. Those topics were: linear motion; momentum and collisions; angular momentum; molecules and gases; electric potential; capacitors and dielectrics; currents in materials; Faraday's law, magnetism and matter; magnetic inductance; and AC circuits. While we believe that some of these excluded topics are necessary for a complete presentation of physics, we should also remember that we are not teaching physics to physics majors. Perhaps the presence of some of these topics in our curriculum might be re-evaluated when we design our courses.

LABORATORY STRUCTURE

The fifth question deals with how the laboratory component of the course should be structured. Asking about the structure of the lab is different than the goals of the lab (which were explored in Question 3), because the structure is more concerned with the amount of guidance provided to the students rather than what should be taught or emphasized. Respondents were asked to select one of four items. The first item represents a laboratory structure with maximal guidance typical of the traditional "verification" labs. The third item represents no written guidance, which is typical of inquiry-based labs that usually emphasize scientific processes. The second item represents a laboratory with minimal guidance but still has the guiding questions framed for the students. These minimal-guidance labs should not be considered equidistant between the extremes of verification labs and no-guidance labs on this laboratory structure dichotomy. Table 5 shows how the engineering and science faculty responded.

Insert Table 5 about here

With the results in Table 5 evenly split between "verification" labs and the minimal-guidance structure, the immediate conclusion based on the results of this question is that the responding faculty do not want us to teach unguided (inquiry) labs. About 12% (in the weighted average model) of the "other" respondents favored a staged approach where the lab structure progressed through these options during the course of the year.

RECITATION STRUCTURE

The last question analyzed asked the respondents to comment on how our recitation sections should be structured. Respondents were asked to select one of five items. The first item represents a traditional, teacher-centered recitation. The next two items represent the students in a more active role in recitation. The fourth item represents a student-centered discussion section, and this structure is what we are currently using in our introductory physics courses at the University of Minnesota. Table 6 presents the results.

Insert Table 6 about here

It is clear from the results in Table 6 that the traditional teacher-centered recitation is not a popular choice among our science and engineering faculty. The clear choice is item four, which is the cooperative group problem-solving we use at the University of

Minnesota. This choice is especially clear considering that 13 percent (in the weighted average model) of the respondents who chose "Other" in fact chose to slightly modify the fourth item. The conclusion from this question is that the respondents to our survey favor collaborative learning in recitations.

SUMMARY AND IMPLICATIONS

It is an encouraging result that our science and engineering faculty believe that physics is an important part of their curriculum. We have been able to gain some insights into what our engineering and science faculty want us to teach and how they would like us do it. When asked about goals, we know that they want us to teach fundamental principles in depth, not just covered lightly. We also know from their choice of goals that they value both qualitative and quantitative skills in problem solving. We know that they would like students to work collaboratively in recitation and lastly, we know that they do not want their students to have inquiry-based labs in our physics courses. It is enlightening to see that our engineering and science faculty have thought about these issues and have reached conclusions similar to many physics educators[1,5].

Two other issues need to be emphasized. First, the results presented in this article are only statistically valid to the engineering and science departments at the University of Minnesota - Twin Cities campus. While there is no reason to expect that the opinions of the engineering and science professors at other large research universities should be any different, the results of this survey cannot be statistically generalized beyond our university. Secondly, the purpose of the survey is to *inform* our decisions about the introductory course based on the opinions of our engineering and science faculty. It is not meant to imply that everything recommended by the engineering and science faculty needs to be executed.

One final question that could be asked is whether a calculus-based course and an algebra-based course need to be very different designs. One might anticipate that the faculty in departments that require their students to take the algebra-based course would want a course design that gives their students a broad overview of physics, with little emphasis on quantitative problem solving. This is opposite to what the engineering and science instructors want, and would require different course designs. However, we have some evidence that different course designs are not necessary. Five years ago we conducted a survey (using a different questionairre) with the faculty of departments that require their majors to take our algebra-based course. The two different groups of instructors both wanted their students to learn the basic principles of physics (i.e., not quick coverage of a large number of topics), as well as qualitative and quantitative and problem-solving skills[6]. They did not want inquiry-based labs. This is a very reassuring result, since we transported what we learned about cooperative group problem-solving (which mirror these goals) from the algebra-based course to the calculus-based course. Fortunately, our science and engineering instructors are not opposed, in principle, to this instructional transfer.

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Table 1
Percent of total degrees granted by engineering and physical science department

Department	% of degrees*
Mechanical Eng.	31%
Electrical Eng.	18%
Civil Engineering	14%
Chemical Eng.	11%
Computer Science	11%
Mathematics	4%
Chemistry	4%
Material Science	1%
Agricultural Eng.	1%
Geology	1%
Astrophysics	1%
Physics	2%

* This column does not add to 100% because the Department of Statistics (1%) did not participate in the survey.

Table 2
Reasons Students Should Take Introductory Physics and the Percentage* of Faculty With This Opinion

Reason	Weighted Average	Unweighted Average
To learn the basic principles behind physics. Physics is important for everyone to learn.	23%	30%
Physics provides important underpinnings to my discipline.	21%	26%
Physics serves as an introduction to my more advanced courses. I build where physics left off.	18%	19%
To learn problem solving and reasoning skills. To learn to think at the college level.	18%	11%
Others	1%	2%
Blank	19%	12%

* The statistical uncertainty is about ± 3%.

Table 3

Goals for the Introductory Physics Course

Goal	Weighted Average	Unweighted Average
Know the basic principles behind all physics (e.g. forces, conservation of energy, ...)	4.5 ± 0.1	4.7 ± 0.1
Solve problems using general qualitative logical reasoning within the context of physics	4.5 ± 0.3	4.7 ± 0.2
Solve problems using general quantitative problem solving skills within the context of physics	4.3 ± 0.3	4.6 ± 0.2
Apply the physics topics covered to new situations not explicitly taught by the course.	4.2 ± 0.3	4.5 ± 0.2
Use with confidence the physics topics covered.	4.2 ± 0.3	4.1 ± 0.2
Know the range of applicability of the principles of physics (e.g. conservation of energy applied to fluid flow, heat transfer, plasmas, ...)	3.9 ± 0.4	4.3 ± 0.3
Express, verbally and in writing, logical, qualitative thought in the context of physics.	3.8 ± 0.4	3.7 ± 0.3
Overcome misconceptions about the behavior of the physical world	3.6 ± 0.5	3.8 ± 0.3
Analyze data from physical measurements	3.6 ± 0.4	4.0 ± 0.3
Be familiar with a wide range of physics topics (e.g. specific heat, AC circuits, rotational motion, geometrical optics,...)	3.3 ± 0.4	3.7 ± 0.3
Use modern measurement tools for physical measurements (e.g.. oscilloscopes, computer data acquisition, timing techniques,...)	3.3 ± 0.4	3.4 ± 0.3
Formulate and carry out experiments	3.2 ± 0.4	3.2 ± 0.4
Understand and appreciate the historical development and intellectual organization of physics.	2.9 ± 0.4	3.0 ± 0.3
Learn to work in teams to solve problems within the context of physics.	2.8 ± 0.4	2.8 ± 0.2
Understand and appreciate 'modern physics' (e.g. solid state, quantum optics, cosmology, quantum mechanics, nuclei, particles,...)	2.7 ± 0.5	3.2 ± 0.4

Program computers to solve problems within the context of physics.	2.6 ± 0.4	3.0 ± 0.4

Table 4

The most important topics by the percent* of stars received

Weighted Average	Unweighted Average	Topic
80	85	Forces and Newton's laws
64	63	Potential Energy and Conservation of Energy
32	13	Statics
32	26	Application of Newton's laws
28	26	Units, dimensions, vectors
24	15	Kinetic energy and Work
24	22	Simple harmonic motion
16	6	DC circuits
12	22	Waves
12	16	Superposition and Interference of waves

* The statistical uncertainty is about ± 3%.

Table 5:
Percentage* of Faculty Who Prefer Each Laboratory Structure

Weighted Average	Unweighted Average	Laboratory Structure
36	32	A lab with well defined directions which verifies a physical principle, previously explained to the students, using the given apparatus.
27	38	A lab where the students are given a specific question or problem for which they must conduct an experiment with minimal guidance using the given apparatus.
10	13	A lab where the students are given a general concept from which they must formulate an experimental question, then design and conduct an experiment from a choice of apparatus.
27	16	Other. Please describe.

* The statistical uncertainty is about ± 3%.

Table 6
Percentage* of Faculty Who Prefer Each Recitation Structure

Weighted Average	Unweighted Average	Recitation Structure
7	6	Students ask the instructor to solve specific homework problems on the board.
15	15	Instructor asks students to solve specific homework problems on the board.
12	15	Instructor asks students to solve unfamiliar textbook problems, then discusses solution with class.
43	51	Students work in small collaborative groups to solve real-world problems with the guidance of the instructor.
23	13	Other. Please describe.

* The statistical uncertainty is about ± 3%.

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[5]For example: Redish, E. F.,Implications of Cognitive Studies for Teaching Physics, Am. J. Phys. **62** (6), 796-803 (1994); L. C. McDermott, "Guest Comment: How We Teach and How Students Learn - A Mismatch?" Am. J. Phys **61** (4), 295-298 (1993); A. Van Heuvelen, "Learning to Think Like a Physicist: A Review of Research-based Instructional Strategies." Am. J. Phys, **59** (10), 891-897 (1991).

[6]Reference 2. A brief description of the survey results for the algebra-based course can be found in this article on page 628.