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Problems with problem sets

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Undergraduate physics problem sets and textbook examples often assume prior knowledge that is more common in men than in women. Could that difference be deterring women from pursuing careers in physics?

The underrepresentation of women in physics at all levels has been recognized by the community as a serious problem for many years. As long ago as 1972, the American Physical Society created the Committee on the Status of Women in Physics to deal with the issue. Since that time many studies have been done on the participation of women in physics at all levels, from high school to senior faculty, and a rather clear narrative has emerged about the nature of the problem the community faces.

We begin the narrative by looking at figure 1, which shows the percentage of bachelor’s degrees in physics awarded to women since 1981. The graph illustrates a classic good news–bad news situation. The good news is that over the last several decades the physics community has been doing something right: The percentage has increased from about 12% in 1981 to 21% in 2010, though a plateau started around 2003. The bad news, of course, is that large improvement started from a small base, and for every woman receiving a bachelor’s degree in physics there are still four men. Since a bachelor’s is the entry into graduate school and a high-level career in the field, most of the problems with the underrepresentation of women in senior positions can be traced back to that statistic. Thus if we are to begin to approach the problem, we must begin by examining the status of women in undergraduate programs.

Figure 2 shows the percentage of men and women in physics programs from high school to full professorship. Such so-called scissors diagrams tell a strange story. Women make up almost half of the high school students enrolled in physics courses. We would therefore expect, all other things being equal, to see roughly the same percentage receiving bachelor’s degrees—something that figure 1 shows does not happen. Instead, through college years, the percentage of women physics majors drops precipitously, an effect termed in reference 2 as the “leaky pipeline.” The decline of women in astronomy programs, while real, is considerably less steep. Clearly, then, the root of the problem in physics lies in the undergraduate experience, and it is there that we should look for solutions.

Possible explanations

Some useful data for our discussion are presented in figure 3, which shows the percentage of bachelor’s degrees awarded to women in various fields of science; the highest number of degrees earned are in chemistry, mathematics, and the biological sciences, with physics and engineering having the least.

We suggest, then, that the proper way to approach our problem is not to ask “Why are there so few women in physics?” but “Why are there so few women in physics compared with other fields of science?” Many of the common explanations for the underrepresentation of women in science fail to address that question. The following are some of those explanations:

Larry Summers explanation. The former president of Harvard University famously speculated that the low representation of women in science had to do with differences between specific types of abilities between the sexes. While that is a complex and fraught issue in the social sciences, it does not seem to be consistent with the data shown in figure 3. It would be hard to argue that those innate differences, should they exist, would keep women out of physics but allow them to be successful in chemistry, for example.

Physics is too mathematical and abstract to appeal to women. Although this argument is often heard, it, too, cannot be supported by the data.
Although social (and perhaps even biological) factors may discourage women from pursuing the study of science, it is hard to see how these factors could disadvantage physics more than other fields that are equally difficult, equally mathematical, and equally analytical. Given that realization and the leaky pipeline of figure 2, the problem has to lie in the undergraduate physics experience.

Whatever the problems with the undergraduate program turn out to be, they are extremely unlikely to be solved by a single magic bullet. In their article for PHYSICS TODAY (September 2003, page 46), Barbara Whitten, Suzanne Foster, and Margaret Duncombe likened the situation to a piece of woven cloth, in which many interlocking threads produce the whole. In such a situation, the best that anyone can hope for is to deal with one of that large number of threads. It is to our own particular thread, then, that we now turn.

Surprising questions
A series of unusual events at George Mason University in the spring semester of 2011 eventually led to this article. One of us (Trefil) is a senior academic with a long history of interest in undergraduate education. Like most male physics faculty members, he was aware of the problem of the underrepresentation of women, and he felt that the appropriate response was to be encouraging to his female students. It certainly never occurred to him to look at the curriculum for subtle biases. The other of us (Swartz) is typical of a large group of students at George Mason who go back to school as an adult. She already has a degree (in art history from Stanford University) and had worked in investment management and as a commissioned artist before returning to the university to take physics classes. In spring 2011 she was taking a directed reading course from Trefil at the same time that she was taking the standard introductory course in Newtonian mechanics.

The mechanics course was well organized and taught by a seasoned faculty member, and it used a standard university physics textbook. Soon, however, Trefil noticed that she was asking him unusual questions. A problem on centrifugal force, for example, spoke of the car going around a banked curve: “What is a banked curve?” A statics problem asked for the forces on a strut: “What is a strut?” It began to dawn on him that subtle messages were being sent in the problem sets and worked examples in the textbook—messages that have largely gone unnoticed but which may well constitute one of the “threads” that make introductory physics less welcoming to women students than it might be.

Textbook publishers have made enormous efforts over the past decades to make their products more accessible to people of all backgrounds. Anyone who has worked on textbook production knows there will always be an assistant editor whose job it is to go through the illustrations and text to make sure there are appropriate representations of women and minorities—which is why newer books are full of examples involving female astronauts and sprinters. That care on the part of publishers...
may even be partly responsible for the upward trend of physics bachelor’s degrees in figure 1. Nevertheless, a more subtle point in the wording of some problems seems to have been missed.

Assumptions create barriers

As we hope the examples below will show, homework problems are often posed in a way that assumes a certain body of knowledge on the part of students. Furthermore, given the social processes discussed above, young men are much more likely to have acquired that body of knowledge than young women. For people who have not acquired the knowledge—and we are guessing that they are disproportionately female—examples based on it pose an additional challenge, an additional and unnecessary barrier to learning physics.

The following examples were taken from a popular university physics text. We could have compiled a similar list from other texts we examined.

The 200-kg steel hammerhead of a pile driver is lifted 3.00 m above the top of a vertical I-beam being driven into the ground. The hammerhead is then dropped, driving the I-beam 7.4 cm deeper into the ground.

The motor of a table saw is rotating at 3450 rev/min. A pulley attached to the motor shaft drives a second pulley of half the diameter by means of a V-belt. A circular saw blade of diameter 0.208 m is mounted on the same rotating shaft as the second pulley.

A uniform strut of mass \( m \) makes an angle \( \theta \) with the horizontal. It is supported by a frictionless pivot located at one-third its length from its lower left end and a horizontal rope at its upper right end. A cable and package of total weight \( w \) hang from its upper right end.

Fig (000) shows two disks: one (A) an engine flywheel, and the other (B) a clutch plate attached to a transmission shaft.

This is called elastic hysteresis. Rubber with large elastic hysteresis is very useful for absorbing vibrations, such as in engine mounts and shock-absorber bushings for cars.

The next examples are from a popular calculus textbook:

One way to think about the definition (of a limit) is to suppose we are machining a generator shaft to a close tolerance. We may try for diameter \( L \), but since nothing is perfect, we must be satisfied with a diameter \( f(x) \) somewhere between \( L - \epsilon \) and \( L + \epsilon \). . . . The value of \( \delta \), how tight our control setting must be, depends on the value of \( \epsilon \), the error tolerance.

The even and odd parts of \( e^x \), called the hyperbolic cosine and hyperbolic sine of \( x \), respectively, are useful in their own right. They describe the motion of waves in elastic solids and the temperature distributions in metal cooling fins.

Though textbooks still assume a body of knowledge that not all students possess despite the heroic efforts of publishers to eliminate factors like this, we hasten to add two caveats. The first is that many young women do, in fact, have the kind of background needed to understand such problems ab initio. Trefil’s daughters, for example, grew up around tools and construction, and they are almost as skillful with a chain saw as he is. Nevertheless, a significant fraction of women, particularly those raised in urban or suburban environments, do not have that background. For them, eliminating the assumptions of prior knowledge might help make the undergraduate experience in physics more welcoming. Even though some students, like Swartz, see these examples as more interesting things to learn about the workings of the world, others may not and may see them as barriers instead.

The second caveat is that in some cases, the terms we are discussing have been defined earlier in the book in some way, maybe clearly or maybe just from context. But anyone who has ever taught an introductory course knows how unlikely it is that students will actually read all the assigned material and remember that kind of information. More important, though, it places an asymmetric burden on women, in effect telling them that they have to do some extra work in order to be accepted into the physics community. Wrong message!
If our purpose is to teach Newtonian physics, those subtly biased problems aren’t necessary. In fact, they are a very poor representation of what modern physics is about, and they may actually reinforce negative images of the field for both men and women.

What is to be done?
Subtle biases in the statement of homework problems is one very small part of the picture attendant on the underrepresentation of women in our field—one small thread in the fabric. Nevertheless, it is a situation that is relatively easy to fix. Here are some approaches that publishers and individual physics instructors might take.

Publishers could easily ask the editorial assistant mentioned above to read through the text and problem sets to eliminate the kind of unspoken assumptions we have described. In most cases, a simple rewording is all that would be required. For example, the pile driver example above could be rewritten as follows without loss of physics content:

A cylindrical rod is being driven into the ground by a machine that drops a heavy weight on it, lifts the weight, and drops it again. Such a machine, called a pile driver, is frequently used in construction projects.

Individual instructors can look at the problems they assign to see if the kind of assumptions we are discussing are being made. If they are, the instructor can either assign another problem or include a short definition in a lecture.

More useful, however, would be to point out the assumptions to the publishers’ sales representatives when they come to talk to you about book adoptions. In most publishing houses, if two or more professors make a specific complaint, it goes directly to the senior editors and things happen.

The progress shown in figure 1 is encouraging. Perhaps the field has reached the stage at which further progress will come from addressing the small matters that remain, such as those we have considered here.

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References
1. For a description of the American Physical Society’s Committee on the Status of Women in Physics and a list of its activities, see http://www.aps.org/about/governance/committees/cswp.