Who are our Students – And why does it Matter?

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1. Introduction

When designing courses in astronomy – or any other science – there is a tendency to assume that the students whom we are addressing are younger versions of ourselves. As undergraduates we studied astronomy and now we are practicing it: it is natural to assume that the students we teach are destined to go on to become scientists themselves. But while this was a perfectly valid assumption in the past, it is valid no longer; and if we do not adjust our teaching methods accordingly, we do our students a grave disservice.

The sad truth is that most of them cannot possibly go on to become practicing scientists – because there are not enough jobs to accommodate them. We are all familiar with the terrible employment market nowadays: there is no need to belabor the point except to make the obvious observation that the situation is not going to get better in the foreseeable future. It is for Malthusian reasons that the job market for scientists is bad, and is going to stay bad on the average except for temporary fluctuations. If each astronomer guided, say, ten students on to PhDs in the course of his or her entire career, the population of astronomers would have multiplied tenfold over that time span – obviously an impossible situation over the long run.

Among the students who have majored in astronomy at my home institution during the past decade, most have not gone on to graduate school. One is now a computer scientist. Another edits a newspaper. We might assume that these young men and women were not particularly bright, and that they wisely got out of the field because they found it too difficult. But in reality this is not the case: these two were among the best students I have ever had the pleasure to teach.

I am concerned that we – and I include myself here – might have a tendency to ignore such students. We might relegate them to the outskirts of our attention, and regard them as "less serious" in their study of astronomy. And more than this: we might even feel an unconscious kinship with those who share our love of astronomy and plan to make it their life work – and, conversely, to feel an absence of kinship with the others. I do not mention these unpleasant issues to accuse us of misconduct. I mention them to emphasize that, unless we recognize them, they might subtly guide us away from fulfilling our responsibilities to all our students.

How, then, might we design methods of instruction which will serve those of our students who do not plan to become scientists – while at the same time, serving well those who do?

2. Project-oriented courses

Let me briefly describe a course explicitly intended to address these needs, developed by members of the Five-College Astronomy Department in Amherst. The prerequisites of the course are one semester each of astronomy, physics and calculus. It is normally taken in the sophomore year.

The course begins with four images of the same star cluster, in the IR, V, B and UV bands. The students are asked to describe what they see in these images. Their reaction to this question is instructive: they often react with consternation and uncertainty. "We can't figure out what you are trying to get us to say" is a common response. Evidently we are presenting them with a task they have not encountered very many times before. But surely, the ability to recognize patterns in an unfamiliar situation is the very hallmark of an educated person.

After much hemming and hawing, the recognition emerges that the brighter stars are bright in all four images, while the fainter ones show up only in the long-wavelength ones. The course now proceeds to quantify this intuitive result: students are presented with numerical data and, over several weeks, taught how to analyze it on a computer. An essential component of this segment of the course is that the students are learning methods of image analysis, not in a conceptual vacuum, but as a response to their felt need to progress further in chasing down an intriguing regularity which they themselves have spotted. The final product of their efforts is a graph, in which apparent brightness at one wavelength is plotted against the ratio of brightnesses at two wavelengths – with error bars, no less.

The course then proceeds to a demonstration of blackbody radiation from a lamp, and to a series of measurements of these same two quantities for it. Qualitatively similar results are obtained, but a direct comparison with the astronomical data is impossible because the lamp's temperature does not, of course, approach that of stars. So the course now proceeds to a brief series of lectures in which the physics of black body radiation is presented. The students then pass on to a segment in which they learn to write scientific programs for themselves. They integrate the Planck function over the relevant wavelength bands to assemble the theoretical analogue of the graph they have drawn. Here too, they are learning programming skills in response to needs dictated by their ongoing research.

A critical juncture occurs when the theoretical and observational results are compared. By this point the students have invested great time and effort in working out the theory of the regularity they have found in the data, and they are understandably committed to this theory – and they seem to have completely forgotten those error bars in their observational data. The agreement between theory and observation is not perfect, but the students declare the agreement to be "good enough." Only after much prodding do they admit that the theoretical curve falls significantly outside the error bars.

This failure is a crucial component of the course. The goal here is to give the students practice in being honest, and in recovering from mistakes. In this case the mistake was the unstated assumption that all our black bodies were of the same size. The course concludes with a determination of the relative diameters of stars based on the theory.

A further essential element is a heavy emphasis on writing. Students are asked to maintain an intellectual diary: they write about the logical progression the course has been following, they make note of their own questions and unresolved issues and of any important insights which have been reached. The goal here is partially to give students instruction in writing clearly, but more significantly it is to allow them to clarify their own thoughts by writing them down. Expressing something clearly is a good way to reach an understanding of it.

3. Comments

A revealing moment in the course occurs when a student suddenly says of the graph of observational data that has been assembled with so much effort "Wait a minute – I know this graph. Isn't it the HertzsprungRussell diagram?" It is indeed, and it is significant that this recognition does not occur right away. Indeed, the recognition might have occurred the very first day of class, as the students were examining the four images of the star cluster. But it did not – and the crucial question is: why? All students taking this course have taken a previous one in astronomy, and all have encountered the HR diagram before. But somehow, it seems not to have lodged firmly in their minds.

Lightman and Sadler (1993: see also Flick 1987, Lightman and Sadler 1988 and Schnepps 1986) have presented data indicating that this suspicion, unhappily, is precisely the case. Students retain far less of the contents of a course than their instructors believe. Even those who do well on homework and tests seem not to fully internalize what they have learned: an element of rote learning seems to be present. But students in this course, given their semester-long immersion, are sure to remember the HR diagram. They have made it their own, by discovering it for themselves .

But this, while certainly the case, is not a sufficient reason to ask our students to spend so much time on a single facet of astronomy, no matter how important it may be. A further reason to teach in this manner lies in the nature of the understanding of the HR diagram which is imparted in a normal lecture course. Traditional accounts of the HR diagram present it as a plot of luminosity versus temperature, or of apparent magnitude versus color. Surely there is no logical gap between these accounts and the visual appearance of stars in a cluster in the four images with which our course begins. But there is indeed an experiential gap, and it is one which students evidently find difficult to bridge. So a second reason for teaching the HR diagram in this manner is to give our students a greater understanding of the meaning of the somewhat abstract and theoretical accounts which are traditionally given.

But this, too, while valid is not in itself sufficient reason to spend so much time on this one area of astronomy. This brings me to the central point I wish to make about a project-oriented course such as this: the course is only partially about the HR diagram. Indeed. it is only partially about astronomy. Far more. it is about the honing of skills.

The real curricular goals of this course include exposure to some modern astronomy, but they go significantly further. Additional goals are (1) hands-on experience with data, (2) the acquisition of computer skills, (3) the development of independence in both formulating and solving problems, and (4) the development of critical thinking. I want to emphasize that these are essential skills for all of our students, not just those preparing for careers as professional scientists.

One final comment. Were this the only course of this nature a student encountered, it would do little good. Our department has developed two: a discussion of the other, together with further pedagogical reflections, can be found in Greenstein, 1994.

4. Drawbacks

It is obvious that I am personally excited by this method of instruction. But I would never argue that all our teaching should be done in this manner. The method suffers from many drawbacks.

One stems from the fact that this method of instruction is so very slow. An entire semester is spent on a set of topics which would be covered in a mere week or so of an ordinary lecture course. Scanning over the list of purely astronomical topics which our students have learned in this course, as opposed to those they would encounter in a more traditional lecture course, is enough to engender a profound sense of unease. How can we justify spending so much time on these few topics at the expense of all the others?

A second set of drawbacks stems from the fact that most of us are simply not used to this style of teaching. That the course operates in the seminar format is essential to its nature, but few of us have much experience in teaching in this way. It takes time to learn how to do it. Some students speak up hardly at all, and need to be encouraged: others speak far too much, and need to be discouraged without crushing their spirits. Delicate interpersonal skills come to the fore. It is also important that our students are equally unfamiliar with such a loose, wandering method of instruction. They often react initially with incomprehension and, indeed, a certain level of fear. This, too, needs to be handled with delicacy.

So I would never advocate relying entirely on such project- oriented courses. But at the same time, their advantages are many, and it makes sense to leaven our traditional methods of instruction with them from time to time.

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