0.1: Why Physics?

Not Just for Physics Majors

Introductory physics like you find in the 9-series at UC Davis is not just offered to the relatively small number of students that have chosen to major in Physics. Indeed, the vast majority of these classes are populated by students majoring in some branch of engineering, with a few other STEM fields represented as well. This sometimes leads to questions of why the courses that don't closely relate to the majors are required at all. Here we attempt to explain why such a broad physics curriculum is required of otherwise very focused majors...

Human Intellectual Capital

Let's start with a decidedly non-ivory-tower perspective on higher education – the view of businesses and macroeconomics. Investopedia.com defines ***intellectual capital*** this way:

... the collection of all informational resources a company has at its disposal that can be used to drive profits, gain new customers, create new products or otherwise improve the business

The phrase "informational resources" is broad and very vague. Naturally it includes things like patents, secret formulas, and computer algorithms, but we will be focusing on the *human* element of intellectual capital – "brain power," if you will. And in particular, we will confine ourselves to brain power in STEM fields.

Knowledge vs. Understanding

It is useful to divide "informational resources" in the context of human intellectual capital into essentially two types – knowledge and understanding. Most people have some inkling of the difference between these two things, even if only vaguely. A simple example that clarifies this difference is the act of riding a bicycle. One can look up "how to ride a bicycle" in Google, and retrieve all of the relevant information:

1. what actions to take
   - hold the handle bars
   - sit on the seat
   - get the bike rolling
   - start pedaling
   - lean the bike in the direction you want it to turn
2. tricks for how to master riding
   - lower the seat so that your feet can easily reach the ground
   - roll the bike forward by pushing with your feet
   - raise your feet intermittently to get used to balancing while rolling
   - bring your feet up to pedals to continue the rolling, removing them to use ground to regain balance as needed

The first of these lists obviously falls squarely in the category of knowledge. The second list also constitutes knowledge, but in some sense it is *meta*-knowledge in that it gives you tips for achieving understanding. But most notably, *it doesn't directly give you that understanding* (measured by your ability to actually ride) – you absolutely have to gain this on your own by your own efforts. This is a general feature of understanding; humans cannot simply look something up to achieve understanding – we must deliberately immerse ourselves into the pursuit before we can reach that point.

When considering the difference between these two aspects of human intellectual capital, it should be clear which is more valuable. Engineering firms do not gain a lot of value by recruiting people that have information committed to memory, when that is merely a web search away. Instead, they are looking for people that have a deeper understanding, as that requires time and effort to acquire, and cannot be replicated in short order. Furthermore, understanding has a certain organic quality to it, in that understanding of one pursuit can often quickly be re-purposed for another task. Riding a motorcycle and ice skating both rely on the same basic method for turning as riding a bike, and though there are other skills involved with these two activities, having some core understanding of the turning process is useful.

Applying this to STEM

When it comes to human intellectual capital for STEM fields, it is clear that having an understanding of physical, chemical, and biological processes is far more valuable than essentially memorizing a database of example processes. Knowing *why* a certain chemical reaction occurs is more valuable than remembering the components and final product for a specific reaction. Understanding how to compute the stresses and strains of a system of beams is better than memorizing certain standard structures of beams that are used. And so on.

As clear as the value gap between memory and reasoning is for STEM fields, when it comes to STEM education, we do run into problems with emphasizing what is important. This is not the place to go into all of these, so here's the most dramatic example of such a problem: All education involves an evaluation process (grading). It is much easier to evaluate based on memory than on understanding. It is also much easier to study for exams that test memory rather than understanding. Unfortunately, this has led to ubiquitous testing based on students' ability to remember, rather than their ability to figure things out. This in turn introduces an incentive to study in the manner most effective for those tests, which means that many STEM students are not "practicing their bike riding" to gain understanding – they are essentially memorizing search engine results on how to ride a bike instead, because it is much easier and less time-consuming to do this than practice riding. Imagine teaching a class in bike riding, and at the end the exam consists of a multiple choice exam that covers the elements of riding a bike listed above, but *doesn't actually require that students get on a bike to demonstrate that they can now ride it.* This is unfortunately exactly how many STEM classes are structured.

Where Physics Comes In

This is an ongoing problem, and one that shows itself particularly clearly in physics, which is perhaps the subject where the value gap between understanding and knowing is the greatest. A physics class where exam problems are given that are similar to previously-assigned problems (in homework or "practice exams") incentivizes memorizing, and students taking such a class gain very little value from it, even though they may believe otherwise. Given that classes taught in this manner exist from elementary school, high school, and unfortunately even into college, it can be difficult to "right the ship" later – students have never trained themselves to study toward understanding rather than knowledge, and can become quite frustrated when they finally need to do so. Then student exasperation over this sudden change feeds back into instructor behavior – instructors want students to be happy, and exams based on knowledge are easier to write anyway, so changes creep in that can make the problem endemic in higher-education.

While this problem presents a serious challenge, the subject of physics, taught correctly, provides perhaps the best training ground for teaching students to reason rather than memorize. For this reason, far more than any other, introductory physics is required of virtually all STEM majors, even if physical principals are rarely, if ever, directly used in that field. The wisdom of this university policy is often lost on students, especially those majoring in STEM fields that seem to be the farthest removed from physical principles, like the life sciences. What complicates matters even more is that physics (again, when taught with a goal of understanding rather than knowledge) is a *very* challenging subject, a fact that is the subject of the next section.
