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# Incoming Undergraduate Literacy in Physics

## **Abstract**

This article details a study comparing the entrance literacy of physics majors into UC Davis from the perspectives of both students and professors. Students frequently comment upon feeling under- or entirely unprepared for the expected literacy at the university level, whether they come from a community college or high school background, and many professors are left frustrated because they are unsure of where to begin with teaching students. Through the use of student surveys and professor interviews, it is revealed that the primary pre-university literacy issues arise in mathematics, theory, and coding. Suggested changes to how these three forms of literacy are taught in physics and math courses are then presented.

## **A Background of Physics Literacy**

There is a persistent effort amongst science educators to determine just how to teach physics in a more accessible way. The mere idea of taking a physics course strikes fear into the hearts of many students, even those who have chosen the major. This can be largely attributed to the wide variety of literacies required to be deemed "competent" in university-level physics—many of which students either had not known they needed to know or lacked the means to access previously. Physics literacy now encompasses mathematical, theoretical, coding, visual, technical, and verbal literacy on the most general level, and more than that, requires students to be able to move between these literacies seamlessly. This connection is ever present in physics, which Kennefick (2007) makes especially clear in his book detailing the search for gravitational waves. He notes:

> Experiment and other forms of technique... dwell in the present and inform all scientific work, even theoretical, since we must include here the battery of mathematical techniques employed by theorists in their calculations. A good deal of this analytic work is, however, rooted in the past... In the typical picture of the rational approach to physics, one builds towards the final answer in a series of steps, each sure and incontestable in itself. The more logically secure each step, the more rigorous is the calculation or proof. Intuition on the other hand, leaps into the future to recognize the final form of the answer before one has arrived there. As such, intuition is both highly suspect and indispensable to any mathematical or scientific discipline. (p. 6-7)

Intuition here can be attributed to both theoretical and verbal literacy in the list above. Lacking in any form of literacy can easily throw off a physics student, leaving them feeling behind before they have even started. Efforts are being made by educators to restructure physics courses in a way that makes gaining all of these forms of literacy more attainable. One approach to this is by using interactive engagement teaching methods in introductory university physics courses, which involves more discussion-based and hands-on learning (Hake, 2002), which serves to link verbal, theoretical, and mathematical literacy. Other educators at the university level have begun teaching introductory physics (both theoretical and mathematical) through a primarily visual approach—drawings, graphs, and diagrams (van der Veen, 2012). However, these changes have not yet become widespread, and perhaps more importantly, assume certain starting levels of literacy in multiple areas from their students. This assumption is far from an assurance. Prior to university, many students simply memorize physics concepts and equations until they no longer need them, as “too many students experience science education as an experience dominated by the transmission of facts, as involving content of little relevance, and as more difficult than other school subjects" (Linder et al., 2007). Thus, it becomes clear that steps must be taken to make early physics courses more literacy-focused than memorization-focused. Some smaller steps have been taken in this direction, such as educating future elementary and middle school teachers in how to integrate physics and verbal literacy (van Zee, 2013), which will assist students in blending mathematical, theoretical and verbal literacies. However, physics is not simply composed of those three forms of literacy, as discussed above. In this study, I have gathered the opinions of UC Davis physics majors and professors on what areas of literacy entering undergraduate students are either lacking or well-prepared in. Comparing the two sets of results presents four subsections of literacy to examine: where both students and professors feel students are underprepared, where both students and professors feel students are adequately prepared, and where the two groups disagree. Each individual category has its own interpretation and set of suggested actions moving forward.

## Method

My initial idea for this study was to poll physics majors at UC Davis about what forms of literacy they felt inadequately prepared in when they first entered the university. However, I soon realized that only following this poll would provide biased information, as imposter syndrome is incredibly prevalent within the major. As such, I decided it would be the most beneficial for me to compare these results with the opinions of the physics professors who teach undergraduate level courses, so I could compare and contrast the results. The students were given a survey which asked for their gender and racial identity, age, prior educational background, what areas of physics literacy they felt over or underprepared in, and the option to provide an anecdote. For options of literacy, I listed math or math-based physics, theoretical or word-based physics, coding, reading and writing for scientific journals, use of technical equipment, specialized field knowledge, along with the options of none, all, and write-in responses. For professor interviews, I first contacted a number of professors to see if they would be willing to participate in the study. If they responded yes, I followed up with asking them for their opinions on what forms of literacy entering students struggled in and succeeded in, and if they wanted to provide any specific anecdotes. Prior to these questions, I also provided UNESCO's definition of literacy along with the list of examples from the student survey, though it was made clear that these were far from the only forms of literacy applicable.

## Data Collection

### *Student Data*

The student survey was taken by twenty UC Davis physics majors. Of those twenty, fourteen came from a community college, five came from high school, and one came from another four-year university, and ten were male and ten were female. Twelve identified as Caucasian, four as Asian, three as Latinx, one as Pacific Islander, one as Armenian, and one as Persian, with two students identifying as multiple races, hence the total of twenty-two responses. Nineteen students were between 18-30 years old, with the one remaining being between 31-40. The numerical results of student responses to what forms of literacy they felt under- and over-prepared in are shown in the tables below.

**Table 1**

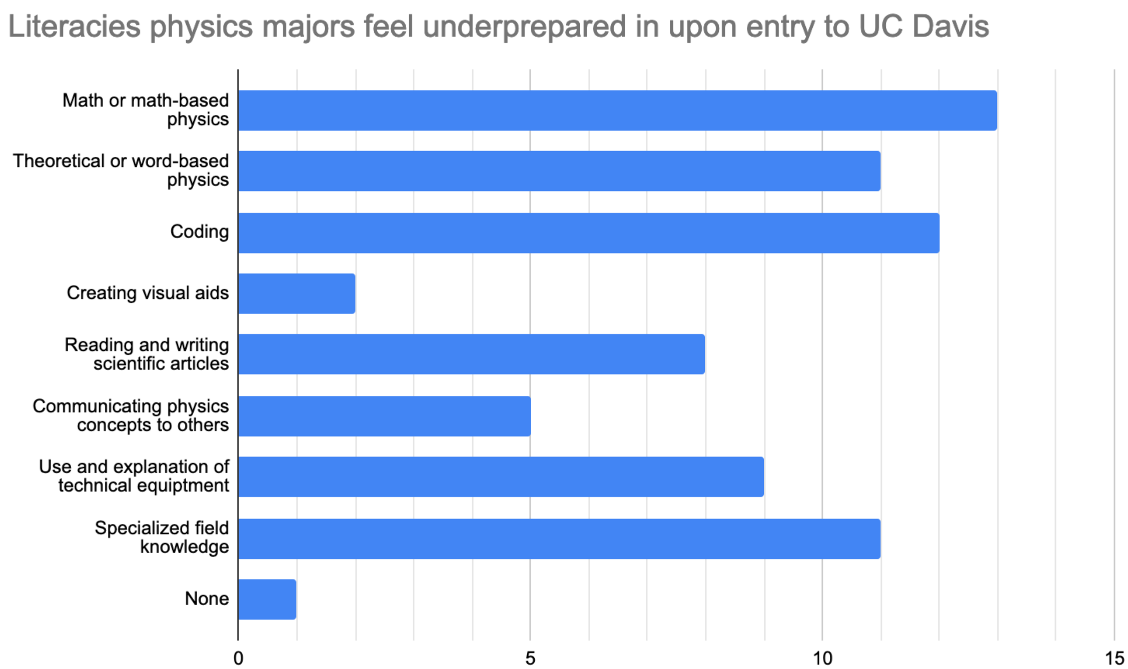
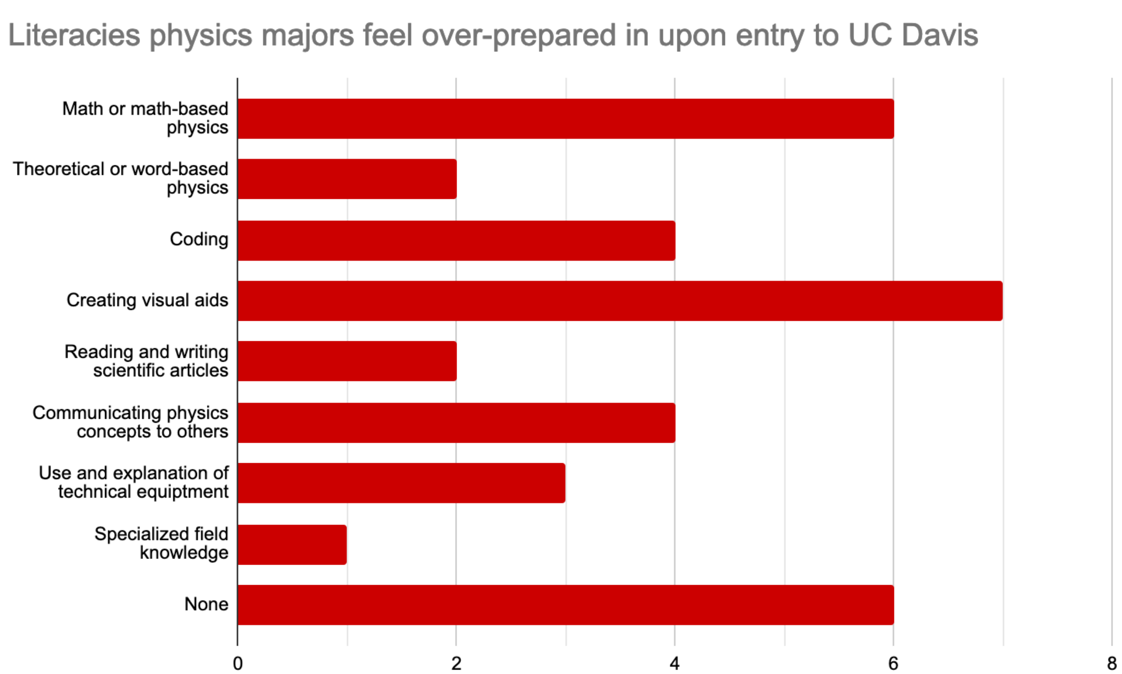

Literacies physics majors feel underprepared in upon entry to UC Davis
Math or math-based physics
Theoretical or word-based physics
Coding
Creating visual aids
Reading and writing scientific articles
Communicating physics concepts to others
Use and explanation of technical equipment
Specialized field knowledge
None
0
5
10
15

**Table 2**


Literacies physics majors feel over-prepared in upon entry to UC Davis
Math or math-based physics
Theoretical or word-based physics
Coding
Creating visual aids
Reading and writing scientific articles
Communicating physics concepts to others
Use and explanation of technical equipment
Specialized field knowledge
None
0
2
4
6
8

Perhaps the most interesting initial thing to note here is that out of twenty students, only one felt that they were adequately prepared in all areas of physics literacy upon arrival to UC Davis. In comparison, six felt there was no area they were over-prepared in at all—and there are no individual areas whatsoever that a majority felt over-prepared in, either. Mathematical literacy is the field that most students feel underprepared in, with thirteen out of twenty responding as such. However, six students responded that they felt over-prepared in math, meaning that only one student out of the twenty had no specific feelings on math preparedness at all (the same student who said they were adequately prepared in all areas). There were no trends associated with age, race, gender, or academic background within these responses, nor were there any trends associated with the other fields. One student shared this anecdote with me:

> Ironically, I felt a huge shock when we began our mathematical methods course (104A). I say ironically because math was my best subject in community college, and I thought this would be the one class I was going to really excel in. But when we started, I couldn't believe how familiar some students were already with a lot of the concepts. One such example was index notation, which I had never seen before in my life. Every other student seemed to know what index notation was and how to apply it. It was something that I felt like everyone just knew right away, and no one needed clarification. I remember after an exam review session one time, the professor was showing me what index notation was (probably expecting that I'd remember having gone over it before in another class, and I'd have an "aha" moment). When he was done explaining it to me, he looked absolutely shocked and he asked "Have you really never seen this before?" When I answered back "no" in a serious tone he shook his head and said that was a shame. And I think that was the first time I genuinely felt like an imposter in physics, like I had stumbled into the wrong class and got stuck and was just trying to blend in with

> everyone else who understood the material right away without needing constant clarification. Of course, the professor knew it wasn't my fault I hadn't seen that before and he didn't mean for me to take it personally. But with others standing around and listening to that exchange, and having that comment direct right towards me, I initially interpreted it as, "You don't belong in this class if you don't know what this is."

Others who shared anecdotes about math had similar sentiments. Rather than feeling like they struggle with math as a whole, students often are not informed on specific techniques that show up in physics, such as the example of index notation shown above. The students couldn’t have studied more on the topics, because they didn’t know that they needed to know them. The next field where most students did not feel appropriately prepared is coding, with twelve students, compared to the four that felt overprepared. Coding is not a prerequisite to become a physics major as a transfer or a freshman, so many students enter UC Davis entirely illiterate in coding. However, some physics courses and most undergraduate research opportunities assume an initial level of coding literacy. Even students did have the option to take coding courses prior to UC Davis, offerings at community colleges and high schools are often quite limited. One student elaborates upon this in their anecdote:

> I think one of the biggest problems with a lot of physics major programs, both at community college and 4-year institutions, is that they have only one or two programming courses instead of integrating it into the major. This means that most students (myself included!) who want to do undergraduate research find themselves having to teach themselves programming on the job in order to keep up with their research groups. [This] definitely contributes to impostor syndrome, going into research and abruptly feeling like your classes didn't prepare you at all for the kind of work you're actually going to be doing.

If a student chooses not to do undergraduate research, they still cannot escape the need to code in physics. As another student put it, “102 (the first physics-based coding class offered at UC Davis prior to Spring 2019)... made me cry every day even though I’d taken multiple coding classes before.” The other two types of literacy that more than half the respondents felt under-prepared in were theoretical physics and specialized field knowledge. The lack of specialized field literacy can easily be understood—many students do not have the ability to take courses in physics outside of the core three (mechanics, waves and thermodynamics, and electricity and magnetism) prior to entering a four-year university. At times, professors can forget this, and assume that students have more prior knowledge in specialized fields than most actually do. The lack of theoretical literacy, on the other hand, is somewhat more complex to understand. For some students, it can be attributed to the fact that their prior teachers did not actually meet the prescribed standards for theoretical physics—I am personally part of this subsection. While I credit my high school physics teacher with getting me deeply interested in physics, as I went on to higher education, I found out there were a lot of “basic” concepts that she never mentioned at all. Others may struggle with the initial theoretical comprehension, which educators are currently attempting to address by modifying the ways in which they teach physics concepts, as seen in the studies mentioned above.

The other student response I’d like to address is that of visual literacy, which includes creating and interpreting graphs, diagrams, and the like. This is the only field where more students felt over-prepared than under-prepared, and had the highest number of students (seven) feeling over-prepared out of any form of physics literacy. This is most likely because reading graphs and drawing diagrams are introduced long before any physics concepts are in early education. Students have the time to truly become literate in the basics before applying visuals to physics concepts, so they struggle less.

### *Professor Data*

I interviewed five different professors about their opinions of undergraduate literacy, all of whom have regular contact with undergraduate students in classes, in research, or in both. All professors responded about mathematical and theoretical literacy, specifically in tandem. From their point of view, many students are simply unable to unify the mathematical physics they've learned with the theoretical. While a majority of students felt under-prepared in both of these literacies, none of them wrote anecdotes about struggling to connect the two. The disconnect between students and professors here can most likely be explained by the fact that if a student is not sufficiently literate in math, theory, or both, they may not even be ready to attempt to combine the two. Beyond this, some professors chose to further comment upon the raw mathematical literacy of students. Here, the consensus was that in high school (with a particular nod towards AP), students are more focused on raw memorization than understanding the actual steps, as this is what allows them to get high grades. One professor, Dr. Patricia Boeshaar, wrote that, "[AP] Calculus is taught as a series of operations to be memorized, hence students seem unaware of what a derivative or integral actually physically means, let alone when to use or interpret what they attempt properly." There were other comments upon the "actual" literacy of the students, looking at the word in the most traditional sense of reading and writing, which none of the students who took the survey mentioned whatsoever. Two professors shared especially extreme examples, one of which is shared below:

> An extreme writing anecdote here: I had a student who had never heard of paragraphs. His first draft of a paper was just a set of independent sentences. This was not just a visual thing. The sentences were disconnected contextually. Each one would talk about something different in a more or less random way. Related thoughts were not grouped together but widely spaced throughout the document. So we had a

talk about how jumping back and forth would make his arguments harder to follow. (I made an analogy with the physics concept of random walks which I don't think helped much.)

Perhaps the reason no students commented is because those who struggle with reading and writing might not be inclined to take a survey entitled “Undergraduate Physics Literacy”, or because students are just less critical of their own writing skills than professors. Four of the professors commented upon coding, and even if the phrasing was different, they all reached the same conclusion: Students either enter with substantial coding knowledge or none at all, which agrees with the student consensus above. Nothing was said in regards to specialized field literacy. One professor did mention that some students struggle with creating diagrams to go along with problems (however, there was no problem with reading them). However, this mention did come with a caveat: The students who especially avoided using diagrams in their work were most often international students, particularly those from China. I cannot begin to guess why this might be the case, as my own experience and studies were into European and North American physics education, as is the case for all the students who participated in my study.

## **Recommended Courses of Action and Conclusion**

While there are certainly many areas of pre-university physics education that can be improved upon, here I have chosen to focus upon the fields which both students and professors majorly addressed in their responses.

### *Coding*

Coding must become a mandatory part of high school physics courses in a more substantial way than just the one project some teachers may put in, with a particular focus on either Python or C++, the two most prominent languages used in physics. An example of this could be that, when introducing simple projectile equations, students must first solve them on paper, and then write a code to solve the same problem, proving they know how to go from a question to a written solution to a coded solution.

*Mathematics*

More emphasis needs to be placed upon understanding math, rather than just memorization. This goes for both math and physics courses. Additionally, pre-university level physics instructors need to realize that there will be certain mathematical techniques not covered in general math courses that the students will need in the future. This is especially true at the community college level, as they serve as the basis of a student's college-level physics knowledge and can include calculus (unlike high school, where AP Physics is now algebra based to reach more students).

*Theory*

Improving how physics theory must be approached two-fold. First, there must be more adherence to and agreement upon what theoretical knowledge is considered necessary on pre-university levels. Currently, many students are never taught certain concepts prior to entering UC Davis, though specifics of which theory is left out varies on the individual's path. Second, there must be more focus on connecting math and theory, which educators are currently studying as seen above. A step to changing this is as simple as asking students to explain what each equation they are using to solve a problem means in the context of the real world and why that applies to the problem.

## Conclusion

Physics has never been thought of as an easy subject—though, the study of all interactions between objects never really could be something easy. However, it seems especially dreaded amongst students, even by those who choose to major in the subject. Lacking literacy education prior to entering university can explain a lot of this fear. If students start from behind where professors expect them to start, how can they ever exceed that expectation? Educators, mostly on the university level, are trying to change how physics is taught by incorporating and reinforcing multiple types of literacy. But we must begin to incorporate multiple literacies in physics earlier so as to assuage the fear before university. With less of a negative reputation attached to physics, more students may be interested in entering the field. Improving incoming physics literacy would also serve to make fewer students suffer from imposter syndrome, which is currently a very prevalent problem in the field that causes many students to transfer out. Even in fields commonly thought of as solely numerical, we must promote all forms of literacy to maintain high levels of communication and a sense of understanding, without which many are left feeling mute and alone.

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