Reflections on Physics Education:

An investigation of physics instruction
for better recruitment and retention in the discipline

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I. Introduction

The purpose of this thesis is to present an approach to physics instruction that will help recruit and retain more students into physics and by association, science in general. I investigate some of the issues that I have observed, through my experience as a recent physics graduate, to be integral to an increase in physics recruitment and retention. These include: disinterest in, and phobias of math and science; state standards; diversity within the discipline; learning theories and pedagogy; and methods of assessment. In the following pages, I not only introduce these topics for readers unfamiliar to them, but also discuss their relevance to learning and incorporation with instruction to make science success more conducive to students across the nation.

A fortuitous secondary role of my thesis to respond to the presidential agenda for technology and education as outlined by the recently inaugurated Obama administration. This is particularly significant as math and science education are the only items on the domestic agenda explicitly defined as national priorities (WhiteHouse 2009). In his radio address on 20 December 2008, the President-elect beckoned science educators stating,

> "Today, more than ever before, science holds the key to our survival as a planet and our security and prosperity as a nation. It's time we once again put science at the top of our agenda and worked to restore America's place as the world leader in science and technology." (WhiteHouse 2009)

Each of the aforementioned issues poses unique obstacles that greatly hinder students' ability to succeed in physics on both the individual and institutional level and need to be addressed. In the discussion of solutions to these challenges, I also relate these as a solution to meeting the tasks presented by the Obama administration.

While many of my arguments are not necessarily new to the science education community, I offer them through a first-person perspective as a recent graduate with five years of studying physics and has engaged in education as a tutor and student teacher. My experience working as a teacher intern while receiving my education at UC Santa Cruz has allowed me to also study, critique, and apply different pedagogies specifically as they apply to physics. In this thesis, I share some of my observations and offer suggestions through the perspective of my personal experience before presenting their implementation in a sample lesson plan modeling how physics instruction can be improved to include more students in both secondary school and universities. While this overview considers a familiar subject in physics, it includes many subtleties that distinguish it from many other physics lessons; the most prominent being the broad range of demonstrated applications. To better recognize these subtleties, I first introduce the rationale for them in the following.

II. A Reevaluation of the California State Standards

As a freshman entering the physics department at UC Santa Cruz, the discontinuity between high school advanced (college) placement courses and actual college courses quickly became a reality. Although I had successfully passed the advanced placement examination for physics, I had received no such advanced placement at the university and was still required to enroll in the year-long introductory physics series. At the very least, one might assume this year became one of review, but that was not the case. While I was familiar with many of the equations and concepts, their associated manipulations and applications were a different matter.

I was later surprised to learn that this story was not unique to myself, but rather was one shared amongst my fellow classmates who had come to the university from throughout the state. This was my first indication that a problem existed not with the students, but rather the California education system as a whole. While there are many arguments regarding the cause of such a disconnect, I believe the relevance of the disconnect lies within the more general sphere of priorities in learning.

Fortunately, the priorities for secondary learning in California are clearly outlined by the State Standards. The California Department of Education, CDE, describes the standards as being "designed to encourage the highest achievement of every student by defining the knowledge, concepts, and skills that students should acquire at each grade level" (CDE 2009). Unfortunately however, standardized tests often undermine the very goal for which these content standards were created to accomplish.

As the California state standards for physics are currently written, students are required to *understand* very few physical concepts. Instead, students are required to know approximately 30 facts of physics trivia and execute 18 computations. The state standards even explicitly dictate that students know how to utilize five specific equations (CDE 2003). While these are not exceptionally unreasonable expectations for high school students, they fail to correspond to learning, or rather, doing physics.

I do not contest that students should know these facts or be able to make these calculations, nor do I intend to marginalize their importance. In fact, I do agree with the standards that knowledge of these facts is indeed an important, though not complete, measure of student intelligence. Furthermore, it is imperative that we maintain these shared values of the rising Eastern countries (Oakes & Lipton 2003) such as Japan, Taiwan, and Singapore if we wish to remain competitive (Stigler & Stevenson 2001). However, I do not believe these should be the primary focus of a high school physics class. Whether a student is required to multiply *m* times *a*, *k* times *x*, or *I* times *R*, they are still only multiplying. Procedurally, nothing changes and thus there is no reason to test a student's ability to multiply and divide in a physics class. Similar problems have similar solutions, which is why calculations are inherently the same, regardless of the field in which they are being used. This is why tests with such problems should be dealt with in their arithmetic and algebra classes.

Currently, the state standards dictate the curriculum for physics instruction. Given my experience and studies, I am convinced that this relationship should be reversed. In order for this to happen, we must first understand that physics is a science; but what is science? In an interview, Richard Feynman described science as "the result of the discovery that it is worthwhile rechecking by new direct experience, and not necessarily trusting the [human] race['s] experience from the past" and more succinctly, "the belief in the ignorance of experts" (Feynman 1966). More specifically, science is the study and understanding of phenomena, not simply knowing that it exists. Consequently, I believe the purpose of scientific instruction is to provoke cogitation and questioning such that a student may reason their knowledge rather than simply regurgitate facts disbursed by some authority so they understand the nature and process of science.

This is precisely where the discontinuity arises between secondary and higher education. While the syllabus and curriculum for my high school advanced placement physics and university introductory physics, which are supposed to be equivalent, match almost verbatim, the directions of their respective lessons diverge greatly. Physics professors are not restricted or obligated by such political standards and tend to teach physics in accordance with Feynman's emphasis on scientific principles.

If we want our students to learn physics, we need to teach it to them as the science itself is actually done. While I agree with the standards as an outline of the facts that a student should be expected to know upon completing a physics class, I maintain that they are incomplete as they fail to address what skills a student should acquire and what they understand. For example, a student can know that energy and momentum are different, SSSP 2e (CDE 2003), but they should understand that this results from energy being a **scalar** measure of capacity to perform work, while momentum is a **vector** "quantity of motion" (Halliday & Resnick 2004). Additionally, while students are required by the standards to know equations, they should instead be acquiring skills and understandings of relationships to express equalities.

It is this very point that physical equations are built upon relationships that our physics students should be learning. However, I reiterate that to understand these relationships unilaterally necessitates the understanding and knowledge of the equations. While it takes more initial effort and time to review so that students may have this level of understanding, because of the aforementioned principle of similar problems, I have found that less time and effort is spent throughout the year teaching students how to manipulate individual equations and understand distantly analogous concepts

In summary, the state standards serve well as a content checklist, but through standardized tests, undermine the goals of scientific process and contradict the presidential call for higher order thinking (WhiteHouse 2009). This lack of demand for and assessment of argumentative reasoning –i.e. justification process for one's conclusion, on state testing by the California Department of Education in lieu of testing their capacity for facts is most disconcerting. This has, for me as well as many of my colleagues, resulted in a disillusionment of our abilities to succeed in physics upon entering the university.

Additionally, as a teacher intern, I often observed my host teachers having to compromise a lesson in the interest of state standards rather than that of the students, which I have learned is now part of the job description for most California teachers. Fortunately, as a teacher intern I was granted a little more freedom with what and how I taught (such as that mentioned in the previous paragraph) and found the students significantly more engaged and receptive. Based on the research of Ginsburg (1996), Stevenson & Stigler (2001), and others, in conjunction with my own experiences in the classroom, I confidently conclude that by shifting to a more student-centric system from the current standard-centric, an appreciable increase in recruitment and retention of students in physics will be observed.

III. Phobia and Disinterest of Physics

A strange unwarranted phenomenon currently plagues our schools and universities: a phobia of math and physical sciences. As a five-year physics student, I personally experience this fearing culture every time one inquires about my studies. My response is invariably followed with a revering wince as they reply “oooh, that sounds painful” or “wow, you must be really smart, I could never do that” or some other synonymous lines. With an increasing demand for graduates of math and science backgrounds, such as that stated in the executive agenda for technology (WhiteHouse 2009), this is especially worrisome. Before I can present some possible remedies to this epidemic, it is first important to understand some of the causes and effects of math/science phobias.

Math and (physical) science are unique among disciplines in that students can generally be assessed with questions that have definitively correct and incorrect answers; or for specificity, I will call these: conclusions. What fails to be addressed here is that the answer is not simply the part written after the last equality symbol. Rather, we should define an answer to be the process by which the student engages to arrive at their conclusion –i.e. the value at the end of their equation. Currently, this is problematic as it is the conclusion by which students are usually evaluated. This is especially true of standardized tests that are used to assess both student and school proficiency.

Naturally, as students are evaluated and assessed, some arrive at the correct conclusion while others do not. Usually however, the processes used to acquire their conclusions are in fact, correct. The question now becomes “how can so many students who use the same process for the same problem have different conclusions?” As a grader for both high school and university math and physics classes, the answer to this question is rather trivial. After grading hundreds of papers and problems, I have observed that this generally results from two common deviations. In most cases, the error results from little more than simple arithmetic or algebraic mistakes usually due to lack of attention to detail –e.g. misplacement of a parenthesis, dropped a negative sign or coefficient, etc. Other times, students simply answer correctly the wrong question (Ginsburg 1996). Unfortunately, the students in our elementary and secondary schools do not seem to enjoy the prerogative of partial credit to the same degree as in the university.

Consequently, rudimentary mistakes are not addressed and the students become divided into those who arrived at the correct conclusion, and those who did not –especially on standardized tests. From the student's perspective, the labeling of their conclusion as wrong, with no evaluation of the process used, implies their method must have been invalid as well. Over time, comparing their apparent mistakes with others leads these students to gauge that they belong in the "did not" category and conclude they cannot do math or science; whence the phobia spawns.

To avoid this with my own students, I usually try to provide feedback on their work. Or, when asked by a student, I have them tell me if it's right or wrong and why. In doing so, the students usually are able to introspectively discover the answer themselves, correct any errors, and gain confident autonomy on future assignments.

Another unfortunate plague spreading throughout the education system is a disinterest of math and physics. While similar to the math and science phobia, it differs fundamentally in how it affects a student's capability to succeed in these fields. Students with a disinterest in subjects such as physics usually avoid these classes in lieu of subjects that more relevantly connect to their passions. Thus, the question posed by disinterest is how can we motivate and inspire students to take a personal interest in the subject.

Too often classes are filled with questions of "when am I ever going to use this?" or "how is this even relevant to real life?" My conviction is that it is the inability to effectively answer these questions that results in the disinterest of physics. I have encountered this plenty as a Cal-Teach intern throughout Santa Cruz County schools. I have also observed this at the university where many of my classmates have left the physics department in favor of peripheral disciplines[1]. Building on my argument from the previous section, one effective solution to curtailing disinterest is quite simple and straightforward: answer their questions and show them why/how this new information they are being presented is relevant to them.

Students become more engaged and interested when they are allowed to pursue their innate drive to construct new meanings (Oakes & Lipton 2003) and connections from the lessons than having significance dictated at them. Unfortunately, mandated standards and hidden curriculum restrain such freedom of constructive learning, which I will discuss in the next section.

[1] This is an important distinction that these students transferring to departments such as earth & planetary sciences, chemistry, and biology which have several applications of physics as opposed to disciplines such as history, literature, sociology, etc which share less in common.

IV. Embracing and Utilizing Diversity

Diversity transcends skin color and encompasses language, socioeconomic class, age, religion, gender, sexuality, ability, and even cognition (Stigler & Stevenson 2001, 232). Furthermore, diversity is the *intermixing* of these groups within a community; as opposed to segregation, which is the systematic and/or coincidental *polarization* of these groups in that community. However, it is also important to understand what these elements of diversity are and how they influence a student's experience in the classroom, as they carry a strong innate potential for positive contributions to the classroom experience once embraced.

In a recent lecture I presented for an audience of senior university-physics students, I conducted a brief informal survey. In a class of approximately fifty students, its demographics consisted of only five females (consistent with the disproportionate science work force demographic (WhiteHouse 2009)) and seven minority students. In discussing the relevance of this brief survey, a series of interesting events ensued that ultimately reinforced the point I was trying to make.

Studying physics, we have learned about the great physicists of history: Galileo, Newton, Faraday, Maxwell, Planck, Einstein, Tesla[2], Feynman, and many more. In my presentation however, none of these faces were represented. Instead, I asked my audience to indicate who they recognized as they saw the faces of [in order]:

Slide 1: George Washington Carver, Edward Alexander Bouchet,
Daniel Tsui, Granville Woods, Onottom Narayan*, Gey-Hong

[2] Though technically not a physicist, his contributions to the field were significant enough for him to be included in this list

Gweon*, Lewis Latimer, Steven Chu, and Garret Morgan.
Slide 2: Jocelyn Burnell, Sally Ride, Sandra Faber*, Rosalind Franklin, Marie Curie, and Jane Goodall.
Slide 3: Unknown, Kalpana Chawla, Jane Wright, Chien Shiung Wu, and Shirley Jackson.

Slide 1 consisted of only minority male scientists, Slide 2 of only female scientists, and Slide 3 of only female minority scientists. Now, I was very specific to request that they raise their hand only if they recognized the scientists on the slides, not necessarily be able to identify them. With the exception of the UCSC professors (denoted by an asterisk) I had included for the purposes of esteem and engagement, very few of these scientists were recognized, and even those that were, were only recognized by a handful. Even physics historian, Professor Michael Riordon was unable to recognize the majority of these scientists; most of whom were in fact physicists and/or inventors with notable contributions to physics.

This activity was an illustration of the hidden, or inadvertent curriculum in physics –the curriculum that very disproportionately includes women and people of color in its course of studies. As a result, the physics profession is saturated with euro-male-normativity[3]; particularly at the higher levels. As of 2008 for example, of 183 Nobel laureates in physics, only two were women –half the percentage for total science laureates[4] (Nobel 2009). Additionally, women hold only 12% of all science and engineering jobs contrasted with 45% of the American general workforce (WhiteHouse 2009). By exposing and

[3] Although many argue that there is a large and growing Asian representation in the physical sciences, it is important to note that this generally follows a model minority mentality (the idea that because one minority group shares the success of their euro-descent counterparts dismisses claims that the others are disadvantaged) that fails to acknowledge the diversity of color even within that specific community (Ong 2005).
[4] Nobel Prizes in science are only awarded for physics, chemistry, and medicine

understanding the hidden curriculum, physics educators can begin to investigate answers to such provocative questions as, "Why do we have so few females and people of color in the discipline?" "How can we equilibrate the demographics?" and "How can we close the achievement/opportunity gaps in this field?"

As noted at the beginning of this section, some very notable events followed shortly after my presentation on the subject of diversity; specifically, one female student shared her and other's experiences as women in physics. "The professors aren't even aware," she noted in reference to how they treat women students differently from their male counterparts. She supported her comment citing the use of course evaluations[5] explaining that male students are more likely to receive evaluations reflecting their intellect (e.g. "he is a really bright student with a clear grasp on the material and shows great potential for future studies") rather than their personality (e.g. "she maintained a very positive attitude, was pleasant in office hours, and did well in the course") as is a common case for women.

Her uncontested disclosure of this seemingly minute but significant injustice was the very quintessence of the point I was trying to make. If we are to close opportunity and achievement gaps in physics and balance the demographics to represent those of the greater population, it is imperative that stories like this one not be dismissed. While true, it *shouldn't* matter if we have a textbook that presents a hypothetical investigation of some phenomenon by Jamal and Guadalupe or Mark and Ben, when there is a consistent theme throughout the instruction, it does. This is the so-called hidden curriculum that

[5] At UC Santa Cruz, students are given written evaluations in addition to letter grades

inadvertently informs students who should be studying physics, and who does not. Ultimately, the effects of the hidden agenda are best summarized by the following testimony of a Chicana college senior:

> "You never see someone that looks like me as a scientist. No matter how long I stay here. When I walk through the campus, no one's ever gonna look at me and just think that I'm a physicist . . . I guess the things that have made other people find it hard to see me as a scientist are making it hard for me to see myself as a scientist, too." (Ong 2005)

Another arm of the hidden curriculum is the marginalization of secondary languages. Susan Baker and Kenji Hakuta (2009) describe popular reaction to challenges created by linguistically diverse communities as being "combated by assimilating immigrants into the American mainstream by teaching them English, and mandating its use, starting in school."

In my placements as a teacher intern, I have found that it is often helpful to defer English in favor of the student's native language. Being proficiently bilingual in Spanish allowed both my host teacher and me to support students to better understand mathematical and scientific concepts using Spanish[6] as a bridge rather than a barrier. However, cognates are not the only benefits of multi-lingualism. It also provides students with the advantage of alternative and advanced cognition (Baker & Hakuta 2009). This results from bilingual students having to make connections across disciplines at an earlier age than their monolingual counterparts as they attempt to combine and process information acquired in differing languages.

Another particular form of diversity in the classroom that holds less popularity but was hinted at in the previous section, is that of cognitive

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[6] Spanish is a language derived from Latin, so too is much scientific terminology.

processes. It is common for students to use various approaches to problems and interpret information differently from one another. However, introspection is often not greatly emphasized in the United States and as a result; an error in the execution of one's method may lead to the false conclusion that the method itself is flawed as demonstrated by Ginsburg (1996).

This concept was epitomized by an assignment for my math education class. In this assignment, 20 math majors were challenged to divide fractions with the catch that their expressions must be executed visually/pictorially, not with equations. While it would suffice to say that no one successfully divided the fractions, this is not the point because what we later realized is that no one divided the fractions at all. In the midst of trying to solve the problem pictorially, each group effectively multiplied the fractions rather than dividing them, or in other words, correctly answered the wrong question.

As demonstrated by the examples of this section, diversity in the classroom helps expand a student's zone of proximal development[7] on all levels. With a greater zone of proximal development, students in physics (as well as all other subjects) are given the advantage of exposure to more opportunities to learn concepts and retain them for future knowledge (AAAS 1990). This contrast in cognition and problem solving processes leads to increased introspection, the reflection of one's own understanding also known as "meta-cognition", and allows students to improve their thought processes (Ginsburg 188).

[7] Lev Vygotsky introduced the zone of proximal development in the early 20th century as the difference between an individual's potential working alone and interacting with others (Roschelle 1995)

V. A Lesson Overview with Application

To demonstrate how a lesson might serve to better recruit and retain students into the physics discipline, I offer a sample lesson plan overview that incorporates solutions to some of the issues described above. I have chosen the topic of waves for this discussion out of personal interest. This lesson is designed specifically for a secondary school physics class but lends itself to higher education as well. By the end of the lesson, students will have learned about waves and transcend their knowledge beyond simply learning the topic at hand by crossing disciplines and adding application to modern technology and current issues. Before engaging in the discussion of instruction, some background information on waves is needed first.

Introduction to Waves

Waves are a topic familiar to most students by the time they reach high school physics. In addition to informal learning outside of the classroom, students will have also formally learned about waves in grade 3, SSS 1D; grade 6, SSS 2c and 3a; grade seven, SSS 6e; and high school trigonometry, SMS 2. However, the degree of their familiarity with and understanding of waves will vary greatly amongst the class (Stigler & Stevenson 2001). To optimize both the efficiency and effectiveness of this lesson, I have divided it into three primary sections with associated subsections:

1. Mathematical Background
    a. Sines and Cosines
    b. Graphs
    c. Properties, behavior, implications
2. Physical Phenomena
    a. Reflection
    b. Refraction
        i. Total Internal Reflection

c. Interference[8]
    i. Diffraction
3. Application to nature and technology.
    a. Soap bubbles/Rainbows
    b. Fiber optics
    c. Open ocean whale communication
    d. CD/DVDs
    e. Mineralogy and crystallography
    f. Cell phone reception

Plane propagating waves (e.g. light) are expressed mathematically as functions of two variables: position *x*, and time *t*, and assume the form:

$$y(z,t) = A^{*}\cos(kz-\omega t)\ \boldsymbol{\varepsilon}_x \qquad 1$$

where *A* is the amplitude of the wave, k is the wave number, *z* is the position, *ω* is the angular frequency, *t* is the time, and $\boldsymbol{\varepsilon}_x$ is the polarization in the x-plane. This equation, and its subsequent graph are composed of six primary characteristics: period, frequency, wavelength, amplitude, phase (shift), and (group) velocity.

Since period *T* is measured as time per cycle and frequency *f* is a measurement of cycles per unit time, these quantities share an inverse relationship of

$$f = 1/T \qquad 2$$

For sinusoidal functions however, we are interested in the angular frequency *ω*, which differs only by a factor of 2π

[8] Interference results from the superposition (addition) of two or more waves and is usually described as either constructive or destructive; constructive being the combination of waves resulting in a net increase in the magnitude of the resultant wave amplitude. Destructive yields a net decrease in the magnitude of the resultant wave amplitude. The magnitude of the resultant wave amplitude may range between a minimum of 0 and a maximum of *nA*; with *n* being the (integer) number of waves and *A* being the amplitude.

$$\omega = 2\pi f \qquad 3$$

The spatial analog of period and angular frequency is the wavelength **λ** and associated wave number **k** respectively, where

$$k = 2\pi / \lambda \qquad 4$$

Because period and wavelength are analogous, they are also directly proportional to each other as indicated by the equation

$$\lambda = \mathbf{v}T \qquad 5$$

where **v** is the velocity of the wave. However this is not the only advantageous analogy for learning this relationship. Eq. 5 is presented in the familiar fashion in which most students learn algebraic relationships: $y=mx+b$; in this case b is equal to zero and **v**, like m, is just a constant[9]. Additionally, a change in the right hand side of the equation yields a change in the left as expected from previous lessons in algebra. By contrast, one could just as well substitute Eq. 2 into Eq. 5 to obtain

$$\mathbf{v} = \lambda f \text{ [10]} \qquad 6$$

However, the advantage of cause and effect (i.e. the change on one side, results in the change on the other side) is lost.

From this relationship, a few others readily emerge. By substituting equations 3 and 4 into equation 5, we have that

$$\mathbf{v} = \omega / k \qquad 7$$

With these equations, the effects of manipulating one variable can more easily be readily observed. For example, a decrease in the value of ω would result

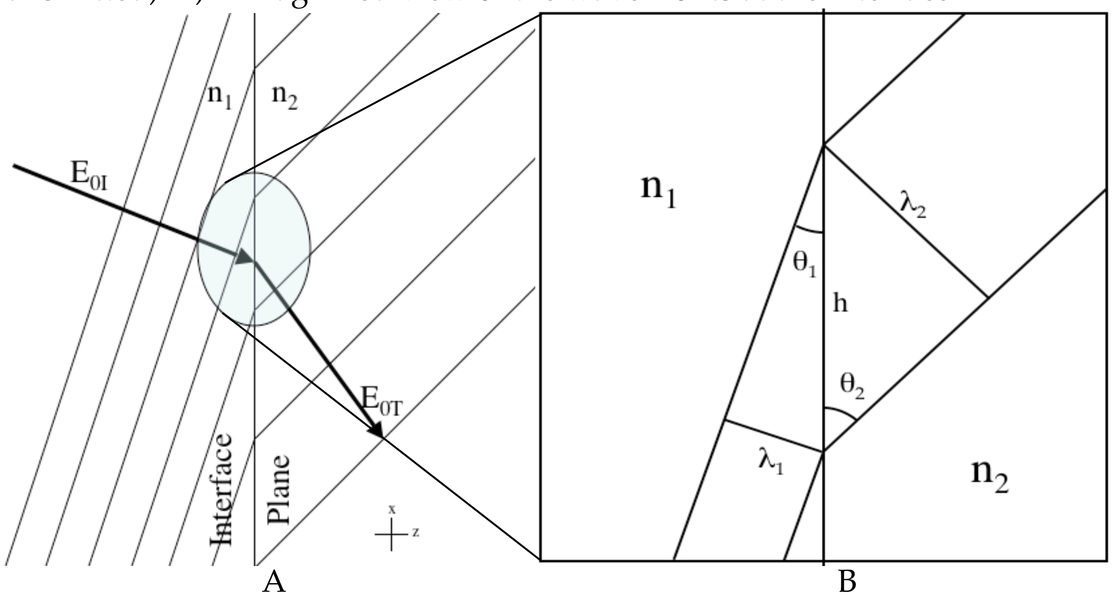
[9] The velocity of any given wave is always constant within a given medium
[10] Although the same effect could be achieved by rewriting Eq. 5 as v=λ/T, computing the product of two variables is easier to manipulate than the quotient as demonstrated by the visual math exercise described in the previous section.

in an increase in the wavelength or an increase in the period and velocity of the wave. In essence, this is the mathematical foundation for waves.

With an establishment of what waves and their fundamental properties are, the next step is to investigate wave phenomena. The prominent phenomena for young adult students to learn about are reflection, refraction, superposition (includes interference and resonance), diffraction, and Doppler shift.

Beginning with refraction; one might describe it as the apparent bending of an object when viewed simultaneously from differing media. That would be an example of a literary explanation of the phenomena. In physics however, there is also an associated mathematical explanation, which derives from the observation of the phenomena. In the case of refraction, it is first important to remember that what is being observed is not the object itself, but rather the light, or electromagnetic waves being emitted (reflected) from the object at the interface between the media. Fig. 1 demonstrates the phenomena we will now try to explain mathematically.

Figure 1: A) Wave fronts passing from one medium with an index of refraction n1 across an interface into a medium with a lower index of refraction n_2. The directions of wave propagation are denoted by vectors E_{0I} (incident) and E_{0T} (transmitted). B) A magnified view of the wave fronts at the interface.



The lines regions represent wave crests; the distance between them is the wavelength λ. For the purpose of deriving a mathematical relationship, we are going to focus on an area surrounding only two wave crests where they cross the medium interface. By dropping a line perpendicular to the wave front from the intersection point of the front wave crest and interface down to the following wave crest we have constructed a triangle. The hypotenuse h, is the intersecting interface plane between these two crests. Doing the same on the other side of the interface will create another triangle with a shared hypotenuse but differing angles.

Using trigonometry, we see the relationship

$$h\sin\theta_1 = \lambda_1; h\sin\theta_2 = \lambda_2 \qquad 8$$

or by substituting Eq. 5:

$$h\sin\theta_1 = Tv_1;\ h\sin\theta_2 = Tv_2 \qquad 9$$

Solving for h, we find that

$$Tv_1/\sin\theta_1 = h = Tv_2/\sin\theta_2 \qquad 10$$

We can then rewrite this equation as

$$v_2\sin\theta_1 = v_1\sin\theta_2 \qquad 11$$

Since the index of refraction *n*, for a given medium is defined to be

$$n = c/v \qquad 12$$

where **c** is the speed of light in a vacuum and **v** is the speed of light in a medium

$$n_1\sin\theta_1 = n_2\sin\theta_2 \qquad 13$$

This mathematical expression is known as Snell's Law and is the governing equation for explaining refraction. As the incident wave approaches the critical angle –i.e. the angle at which the refracted angle is in the plane of the interface such that

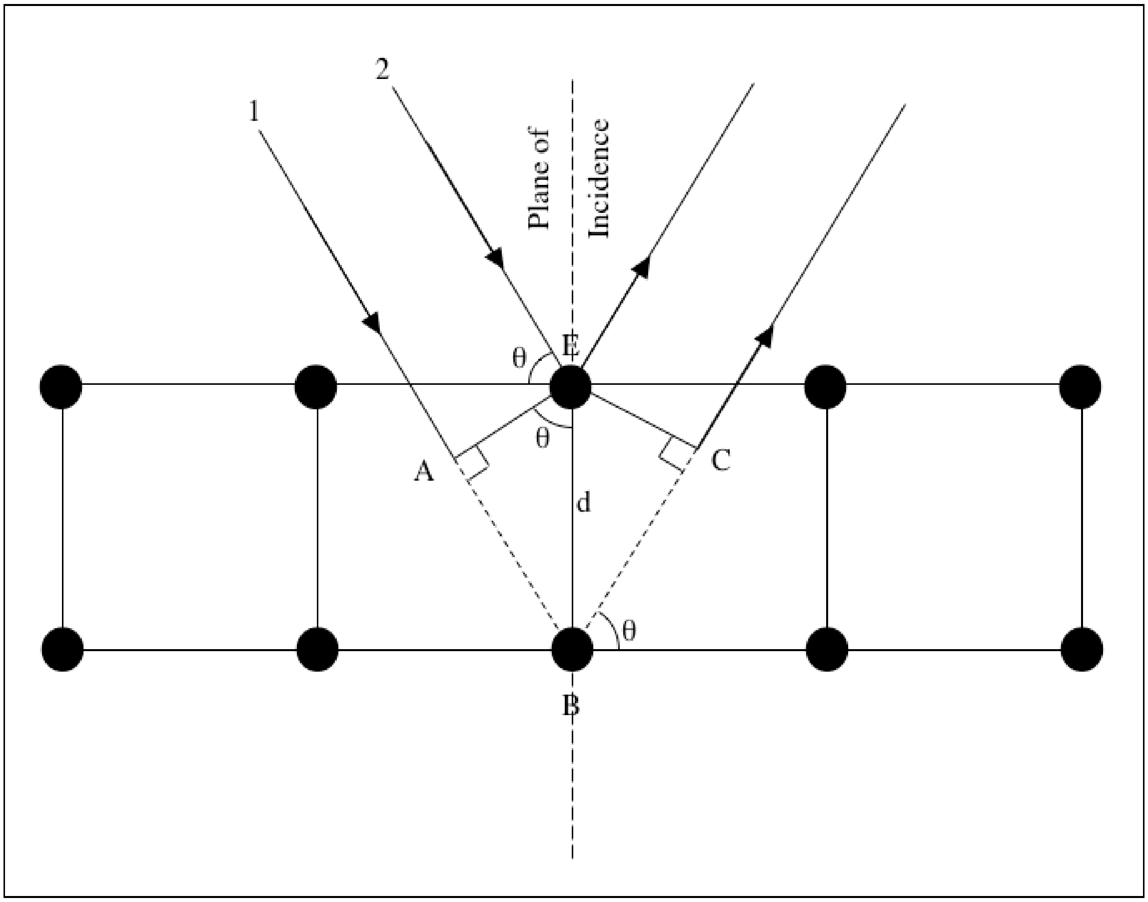
$$\sin\theta_1 = \sin\theta_c = (n_2/n_1)\sin 90° = (n_2/n_1)\sin\theta_2 \qquad 14$$

the refracted wave vanishes as required by energy conservation, continuity, and the law of reflection[11]. Consequently, Snell's law has no (real) solutions for incident angles greater than this critical angle since n_1 and n_2 are constants and $\sin\theta$ is a maximum at 90° ($\pi/2$).

A similar method can be used to derive Bragg's law, which in conjunction with the principle of superposition, is used to describe diffraction phenomena in three dimensions such as that used in mineralogy/crystallography. Fig. 2 shows a two-dimensional cross section of simple crystal lattice where the large dots represent individual atoms and light beams.

[11] A well written and detailed mathematical explanation of this phenomena using Euler's formula and the Fresnel equations can be found in Griffiths' Introduction to Electrodynamics (1998) 7.3 and 9.3.2

Figure 2: A simple crystal lattice cross-section with two beams of light.



Beam 1 travels a distance greater than beam 2 that is equal to AB+BC. In order for constructive interference to occur, this distance needs to be an integer number of wavelengths so that the two beams remain in phase –i.e.

$$n\lambda = AB+BC \qquad 15$$

By symmetry, triangles ABE and CBE are congruent and thus AB = BC yielding:

$$n\lambda = 2AB \qquad 16$$

Acquiring AB = dsinθ from Eq. 6 and plugging it into Eq 13, we obtain

$$n\lambda = 2d\sin\theta \qquad 17$$

which we know to be Bragg's law.

I conclude here on this subject as this is usually the extent of which wave phenomena are studied by students at the introductory levels. Moving now into the realm of instruction, this should serve as a reference for the perspective of my suggestions in the following sections.

Getting Started

Before beginning any new unit or topic, I have found it useful to first assess the students' general familiarity and understanding of the unit subject. I have had most of my success by engaging in the following way. First designate a couple of minutes, two to five, for students to reflect on their prior knowledge and write down everything they know about waves. In favor of acting as an educational facilitator, I defer to the students to discuss in small groups what they wrote before having them share their knowledge about waves with the class. To ensure that they address the key ideas pertinent to the lesson, I interrupt them periodically throughout this process with pointed questions such as "what are waves?" "where have you seen waves before?" "what are different types of waves?" and "what do you want to know about waves?"

This KWL[12] approach accomplishes a number of goals. First, the students are engaged from the lesson's inception through a process of introspection with respect to the topic at hand. Second, they are given the opportunity to share their knowledge without having to fear being wrong; something likely to discourage them from future participation and lower their confidence in their abilities as discussed earlier in this paper. Third, it provides the teacher with formative

[12] An acronym commonly used amongst teachers to reflect what students Know, what they Want to know, and what they have Learned

assessment to determine a foundation on which to build the rest of the lesson without assuming too much, or too little on the students' part. The final question, "what do you want to know about waves?" and variations thereof, is included specifically to allow the instructor to modify the lesson if possible to include more relevant topics to the students' interest and thus more conducive to their learning.

While this lesson is designed with secondary school primarily in mind, many of the principles I propose in this paper can (and should) be adopted among introductory or undergraduate courses at the university level. Sadly however, in my experience, this has not yet been the case. Instructors tend to utilize institutional assumptions resulting in a pseudo-foundation upon which they begin building the framework for the class. While some students are in fact able to transition seamlessly using this method, many deviate from this assumed level of proficiency. This causes students whose prior knowledge is below the instructor's assumed proficiency level to feel inferior and forlorn while students advanced beyond this mark are left unchallenged, unengaged, and even patronized.

With an established foundation through formative assessment, the instructor, whether high school or university, can move forward with the lesson. It is likely that in the exchange of knowledge during the opening discussion, some information may not have been entirely correct. In such cases the instructor should address, correct, and learn the source of the misinformation as an effort to end its perpetuation. Alternatively, minimal review may be necessary and students with advanced understandings can be utilized to aid or even lead discussion/explanations.

As a follow-up to this introduction, some review should still be administered, the depth of which should be decided based on the outcome of the discussion. In accordance with the structure I specified at the beginning of this lesson plan, this review should transition into or encompass the mathematical background associated with (sinusoidal) waves if any discrepancy in their familiarity and understanding is evident from their initial discussion. To instill the underlying mathematical principles of waves, a variety of approaches can be used here, but they should all remain student-centric. Ideally this section should be constrained to one or two days to cover the properties of waves such as: period, frequency, amplitude, wavelength, phase shift, etc.

Whichever student-centered approach the instructor chooses to use, the properties of waves are little more than scientific vocabulary that serve as an axiomatic foundation upon which the rest of the unit builds. As such, rote memorization of these properties is actually useful at this point. While these properties of waves are essential to understanding waves, phenomena such as refraction, diffraction, and interference can still be learned without directly connecting the two. However, continued use of this method will result in teaching *about* physics, rather than the teaching *of* physics.

Instead, the students should be learning about the new phenomena in terms of their prior knowledge; irrespective of how recently that knowledge was acquired. Consequently, the wave properties should be explicitly defined and integrated to describe further phenomena and their behavior throughout the rest of the unit. This is demonstrated in the example below by the blue and green text respectively.

Beginning Worksheet: Wave Properties

1. Period – the amount of time elapsed for a wave to complete one cycle at a fixed point
2. Frequency – the number of cycles completed in a given amount of time (the inverse of the period) at a fixed point
3. Amplitude – half the height between the crest and trough of the wave
4. Wavelength – the distance between two crests/troughs at a fixed moment in time
5. Phase shift – a lateral translation of the wave
6. (Group) velocity – the speed at which the wave propagates

Concluding Worksheet: Wave Phenomena

1. Reflection –the bouncing back of all or part of a wave (or particles) at the boundary between dis-similar media (Oxford 2005). Reflected waves maintain the same **frequency** (and period), **wavelength**, and **velocity**.
    a. Total Internal Reflection – the transmitted refracted wave **amplitude** vanishes while the reflected internal wave **amplitude** assumes full strength of the incident wave.
2. Refraction – change in **velocity** causes bending of waves as they change mediums. Refracted waves result in altered **wavelength** and **amplitude**, but preserve **phase** and **frequency** (period)
3. Diffraction – spreading or bending of waves as they pass through an aperture or round the edge of a barrier (Oxford 2005). The effect is marked when the size of the object is of the same order as the **wavelength** of the waves (Walker 1995).
4. Interference – superposition (addition) of coexisting waves with different **frequencies** and **phase** differences

With a student-centric approach and utilization of constant formative assessment in place, I leave the details for actual instruction and discussion for the instructor and students to determine.

<u>Labs and Demonstrations</u>

Laboratory experiments and demonstrations are potentially the greatest learning tool any science teacher can use when it comes to creating deeper understandings of natural phenomena and how they work. However, another problem that is plaguing many public schools is the apparent lack of application of these concepts. Physics teachers should be well rehearsed in their fields enough to understand the significance of the contributions physics has made to other disciplines. Living in a "seeing is believing" world, lab demonstrations are prime opportunities to convert young minds to the world of science by showing them exactly how these topics are relevant to their everyday lives.

Continuing with the example of waves, the students have learned about various phenomena. Of these phenomena, I have fashioned a set of laboratory experiments and demonstrations that incorporate various learning styles and provide answers to attract interest with special regard to the more abstract concepts of diffraction and total internal reflection. This is achieved by directly applying the concepts learned thus far in the lesson to examples in the technological-, earth-, ocean-, and atmospheric-sciences.

Traditionally, students observe interference patterns by directing a monochromatic light (laser) through a grating. The resultant diffraction pattern is caused by the gratings being spaced on an order of magnitude comparable to that of the light's wavelength. While this lab clearly demonstrates the concept of diffraction and use of the grating equation for an incident angle perpendicular to the grating plane, it fails to accomplish much else; no connections are directly drawn between subject and application or discipline. As a result, the student has little incentive to assume ownership of this information and maintain further interest.

MODERN DEMONSTRATIONS: INTERFERENCE

Instead, the following series of modernized demonstrations and laboratory experiment on interference expands upon and applies this traditional approach to other disciplines and more importantly, their daily lives.

1. Cell Phone Reception

For many, it is a mystery as to why when we stand in one spot we seem to get perfect reception on our cell phones, but when we move only a couple of feet, there is none. The answer is simple: interference. Cell phones work by emitting and receiving information via electromagnetic waves. These waves are in the radio/microwave band. This means their wavelength is on the order of 10^0 meters, or approximately the same scale of buildings, windows, streets, walls, and doors; what we as scientists would call obstacles and openings (“slits”). Since these “obstacles” and “slits” are of the same scale as the cell phone waves, the cell phone waves are susceptible to reflection *and* diffraction by these obstacles and slits respectively. As they disperse and are reflected and diffracted, they separate and intersect causing interference patterns throughout the metropolitan grid.

By arranging various blocks in a water tank with a wave generator, a small-scale horizontal cross-sectional silhouette of such a city can be simulated. By projecting the image with an overhead projector lamp, the students can actually see the waves diffract through the slits, bend around and reflect off the obstacles and as electromagnetic signals do for cell phones in the city. It is worth noting that the shading effect displaying the waves in the projected image is actually a result of the light refracting through differing thicknesses of the water.

While this demonstration is relatively simple, brief, and qualitative, the students were explicitly exposed to four of the five wave phenomena outlined above. More importantly, a direct connection between the realm of physics, their daily lives, and technology was established in the process. Lastly, this demonstration encompasses three of six physics content standards for waves (CDE 2003).

2. Mineralogy/Crystallography

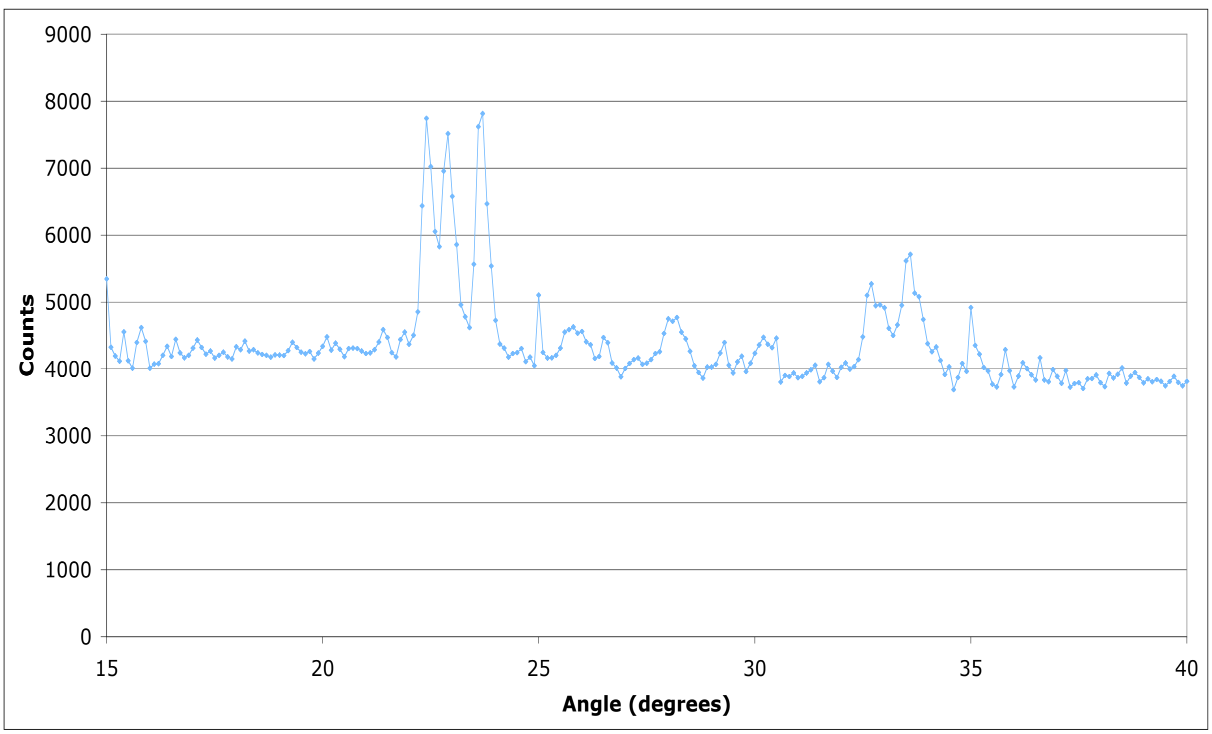
Interference is more than just a strange phenomenon of waves that we can use to understand inconveniences in our technologically advanced lives. Interference is also applied to investigating and discovering properties of various matter by using the process of diffraction. Clinton Davisson and Lester Germer (1927) used diffraction to discover the wavelength of electrons. In 1912, the discovery of crystal X-Ray diffraction by Max von Laue (Nobel 2009) was used by W. H. Bragg and W.L. Bragg as a means to investigate the atomic structure of crystals (Bragg 1915) for which they later won a Nobel prize (Nobel 2009). It is this latter discovery that we can replicate with the assistance of a local university geology department, or for convenience, the internet.

To determine the mineral composition of a rock sample, geologists utilize x-ray diffraction (XRD). The consistent arrangement and spacing on the order of 10^{-10}m between atoms in minerals and crystals effectively act as a three dimensional atomic grating. Because various minerals and crystals have distinctly different atomic structures, they will also diffract x-rays at distinctly different angles creating a unique pattern by which they can be identified and used to calculate atomic spacings.

To demonstrate this application, students can look at diffraction patterns and graphs of diffracted x-rays for a set of minerals/crystals. While the students themselves would not be participating in the actual diffracting of x-rays, they would nonetheless be able to observe its effects. With time permitting, this discussion can then be further expanded to a lab similar to the problem based learning activity described below.

Given only the information in various graphs for an unknown sample found in rocks from a local geological site (similar to the one shown in Fig. 3), knowledge of Bragg's law –i.e. $n\lambda=2d\sin\theta$, the frequency of the x-rays used in the experiment, and the "wave relationship" $\lambda=c/\nu$, students can be directed to identify an unknown substance. The students would execute this investigation by first determining the wavelength from the wave relationship and then using that value to solve for the atomic spacing in Bragg's equation. Lastly, the students would match the calculated spacing with its associated mineral/crystal from a table of known atomic spacings for given materials.

Figure 3: A graph of diffracted X-Ray Intensity vs. Angles for Tungsten Oxide between 15 and 40 degrees –also known as the "crystal fingerprint" for WO_3



The accomplishments of this demonstration and laboratory experiment include: instruction of diffraction and Bragg's law, practice of physics investigation, and applying physics in another discipline. Additionally, seven of the fourteen investigation and experimentation state science standards (CDE 2003) will be covered in the process.

3. CD/DVDs

This final lab on interference allows the students the opportunity to finally do a quantitative lab on diffraction. As noted in the previous demonstration, diffraction is used to investigate the properties of matter. In this lab, the students will do exactly that with the matter being CDs and DVDs. The students will quantitatively use diffraction and Bragg's law to determine the spacing between grooves on a CD and contrast them with those of a DVD and DVD Blue Ray.

The only materials needed to conduct this lab are: laser pointers, CD/DVD's (which the students could actually bring themselves), meter sticks, clamps, a wall, and an old LP (for comparison). All of these supplies are relatively inexpensive and abundant.

This lab will focus on directed inquiry[13] to provide students with an insight as to how CDs and DVDs work, not including encoding, and how CD's differ from DVD's with particular regard to their difference in track pitch, or groove spacing. The students will be "required" to investigate: the effect the incident angle has on the diffraction pattern; the effect the color (wavelength) of the light has on the diffraction pattern; and the difference in spacing between CDs, DVDs, and DVD Blue Ray, as well as their effect on the diffraction pattern.

While this lab will require quantitative results and is a *directed* inquiry, it can also be elevated to include open inquiry in which the students formulate

[13] Directed inquiry allows the students to discover relationships for themselves while still being guided by the teacher as opposed to the students being told by the instructor what the relationships are and why they are important.

their own questions and investigative processes. By the end of this lab, the students will have explored three properties that yield variations in diffraction, gained an insight into the workings of compact discs, learned how to recognize the occurrence of diffraction, how it is used along with the grating equation, and how it can be applied in technology.

REFRACTION

Standard instruction has students observe refraction by bending light through prisms, sticks in water, and jouncing a slinky[14] connected to another slinky of different material or thickness. In this last demonstration, students observe the change in wavelength and velocity (refraction) as it propagates across the interface (joint) of two mediums. What they may notice is that a wave is also reflected from the joint. A similar effect can also be observed using lasers and translucent materials. As the angle of incidence is adjusted, this reflected wave becomes stronger while the transferred wave refracts at a greater angle and weakens in intensity until it finally fades to zero intensity as it refracts parallel to the interface plane. At angles greater than this "critical angle", only a reflected beam is observed and the interface acts effectively as a mirror.

Although mathematically intricate and beyond the scope of a regular high school physics class as demonstrated by Griffiths (1998) –see footnote 10, students are still capable of understanding some of the underlying principles responsible for this phenomenon (Oakes & Lipton 2003). One such concept that the students can understand is that this behavior actually manifests conservation of energy and is quantitatively represented by T+R=I, where R is the reflection

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[14] Slinkies are preferred for this exercise as they can be used to demonstrate both transverse and longitudinal waves.

coefficient, T is the transmission coefficient, and I is the incident coefficient, which is generally taken to be unity (Griffiths 1999).

1. Fiber Optics

The index of refraction for various materials can be quantitatively measured using a laser, various mediums (glass, plastic, air, water, etc.), and a protractor. In this lab students will be given directions for tracking the path of the laser through the two mediums (or more should they feel so inspired) and measuring the refracted angle. For some mediums, the students will be required to use Snell's law –i.e. $n_1 \sin\theta_1 = n_2 \sin\theta_2$, to calculate the index of refraction; for others they will be given the indices of refraction and instructed to compare predicted/calculated refraction angles with actual/measured refraction angles.

The last component of this lab will consist of directed inquiry and problem based learning. The students will be given a challenge to determine the incident angle at which the light is refracted along the plane of the interface. As a bonus activity (possible extra credit), the students could be challenged to generate the formula that represents this situation –i.e. $\theta_c = \sin^{-1}(n_2/n_1)$. They will then be directed to investigate and describe what happens as the incident angle increases beyond this "critical" angle. Assuming proper materials, the students should see two laser rays of varying intensities opposite the incident plane prior to passing the critical angle -one refracted and one reflected and only one ray after passing the critical angle –the angle at which the light waves are totally internally reflected.

Ideally, this will be a newly discovered concept for most of the students that will lead to a class discussion of what is happening and why. At this point the instructor can formally introduce the concept of total internal reflection and explain the remaining physics involved and expand upon the significance of the critical angle, which the students themselves had just discovered.

Although the heart of the lab is refraction, total internal reflection is the soul that will stay with the students long after they leave the class. Especially after the "bending of light with water" demonstration in which a laser is aimed through a hole poked in a two liter bottle filled with water and the light seems to flow down the spout. It is at this point where the significance of this bizarre phenomenon can fully be revealed. "What if we had some sort of pliable translucent material that we could use to direct light down some sort of tube?" Thus would begin a follow-up demonstration with lasers being totally internally reflected down plastic tubes that would lead into the discussion of fiber optics: an important element in modern communications and electronics. With an understanding of fiber optic cables, the students should then be able to relate the significance of Snell's law to their daily lives through communication lines.

Open Ocean Whale Communication

Refraction is responsible for a few other fascinating phenomena. One such phenomenon is that of desert mirages. The temperature gradient caused by the intense heat convection in the desert acts as a continuum of varying indices of refraction that constantly bend the light until it actually bends back upward. The mathematics[15] involved in this process is fairly advanced even for even university physics students. However, most secondary school students understand that water follows the path of least resistance. Analogously, light can

[15] The mathematics referenced here are the Lagrange equations of motion:
i.e. $\partial L/\partial x_i$ - $(d/dt)(\partial L/\partial x_i dot) = 0$, i = 1,2,3

also be thought of as taking the path of least resistance, which results in least time; mathematically speaking, this is described by the Lagrangian[16] (Thorton & Marion 2004). The students do not necessarily need to know mathematically what the Lagrangian is exactly, but can use this association with the principle of least time as a working definition on which they can build further understandings.

Another similar phenomenon is that of open ocean whale communication. Whales are actually able to communicate across thousands of miles of open-ocean using infrasonic frequencies ranging from 15-35Hz (Curtis et. al. 1999). Maurice Ewing and Lamar Worzel (1948) first replicated this phenomenon in an experiment involving explosive discharges at a depth of about 1200 meters in what is known as the SOFAR[17] or "deep sound" channel that effectively acts as a wave guide. The pulses from the discharges were detected 3100 miles away and were extrapolated to be detectable from as far as 10000 miles away (Ewing & Worzel 1948). Based on their data shown in Fig. 4, low frequency sound waves were not only found to be contained in the wave guide through the process of continuous refraction, but in conjunction with total internal reflection as well.

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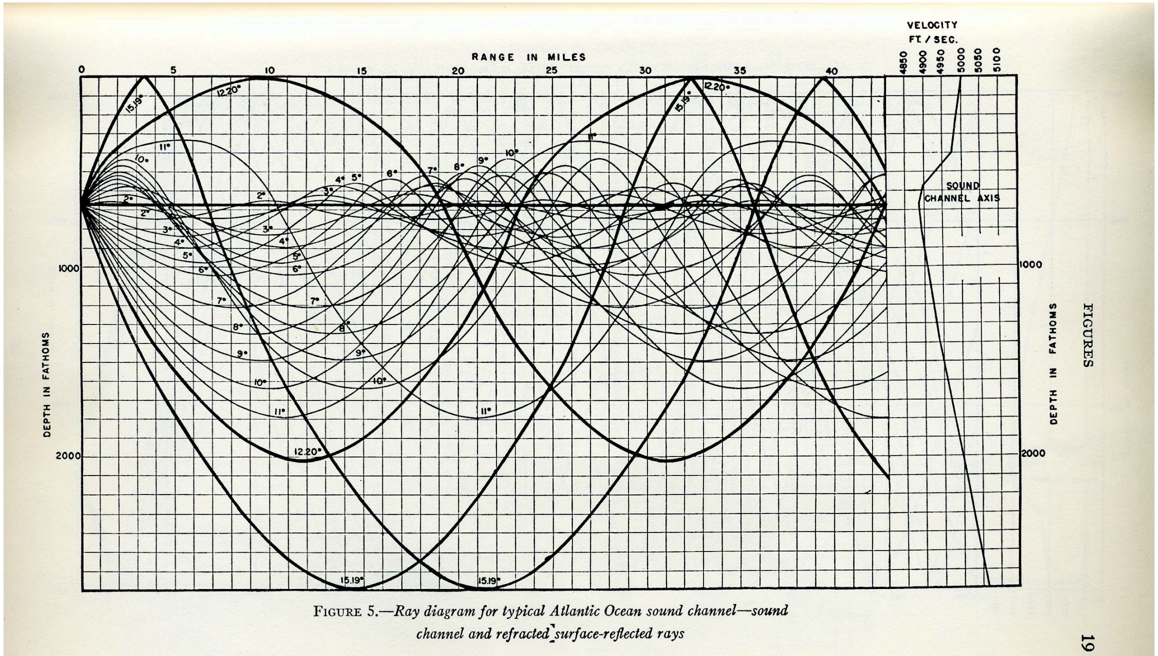
[16] The Lagrangian, L, is equal to T-U where T is kinetic energy and U is potential energy (Thorton & Marion 2004)

[17] SOund Fixing And Ranging

Figure 4: A graph of sound waves as they propagate through the SoFAR channel in the Atlantic Ocean according to the findings of Ewing & Worzel (1948)



Just in case students were not particularly grasped by the previous example of desert mirages, this will provide another opportunity to provoke student interest. This time however, some of the students at least, will now know how the phenomenon works and should be able to contribute to a discussion about how refraction, the Lagrangian, and whale communication might be related.

Keeping in mind that sound, like light, is made up of waves, it also behaves in a manner similar to light as can be expected of all other waves as well (Griffiths 1998). While the purpose of this discussion is to exhibit the principle that phenomena with similar properties also have similar behavior, it also provides another hook on which to attract student interest toward physics.

Though subtle, I have used this simple fact to stimulate student interest on the subject of total internal reflection many times with great success. Even students in higher education who are familiar with the concept of total internal reflection, refraction, and even the Lagrangian, became suddenly intensely engaged upon mentioning this application and began asking numerous questions about the whales, total internal reflection, and other wave properties.

VI. Conclusions and Recommendations

The American Association for the Advancement of Science's Project 2061 (1990) argues that, "concepts are learned best when they are encountered in a variety of contexts and expressed in a variety of ways." When asked, Richard Feynman (1981) suggested that the best way to teach is by using every possible way of teaching so as to hook every student at one point or another. It is with this idea in mind that I had crafted the above lesson plan. By shifting emphasis from summative to formative assessments, students can work in confidence of their learning without compromising knowledge and content. More importantly, by employing inquiry-based teaching with constructivist learning, students will have more opportunities to enjoy the pleasure of finding things out for themselves.

Furthermore, university physics classes should no longer be filled with the students who are left after the high school "weeding" process, but rather with those who were given sufficient support to thrive. This means creating an environment where all students not only succeed, but also feel they have a place in the sciences. The challenge here becomes integrating discussions that break away from euro-male-normativity, such as the discovery of pulsars by Jocelyn Burnell (Beyers 2006) or current US Secretary of Energy, Steven Chu

(WhiteHouse 2009), which could include concerns regarding other modern issues.

However, the only way teachers can have this freedom for instruction is to not be burdened with high stakes exams such as standardized tests that fail to evaluate skills and knowledge essential to physics such as logic, inference, or data analysis (WhiteHouse 2009). While I did not discuss formal summative assessment, it is another subject that needs much reform with consideration of the topics discussed in this paper.

In light of the research on constructivist (Roschelle 1995) and problem based learning through inquiry instruction supported with much of my own experience presenting physics to young people as well as my peers, I maintain that in order to meet the need for increased recruitment and retention in physics and science in general (WhiteHouse 2009), I offer the following suggestions:

(1) *Make physics relevant.* Understanding how physics influences other aspects of our lives not only fosters an invested interest in the physics being taught, but also aids understanding of the physics itself. Providing multiple examples of physical concepts as they apply to other disciplines increases the number of opportunities for students to seize interest in physics.

(2) *Make physics attainable.* Physics is currently viewed as being reserved for the "math and science" people. By utilizing more formative assessments in favor of high stakes summative exams, students will not only receive better feedback for themselves, but will be left feeling more capable of gasping the concepts and solving the problems presented in physics.

(3) *Make Physics inclusive.* Awareness of who is currently represented within the discipline is the first step toward actively supporting peoples whose

backgrounds differ from the traditional physicist stereotype. Including more discussions about such physicists as Steven Chu, Shirley Jackson, and Chien Shieng Wu will help compensate for the centuries of under representation while also providing a bridge to advanced topics.

Adjust pedagogy to meet the needs of all students; this is particularly applicable to university level physics where there is an apparent assumption of cognitive homogeneity as evidenced by invariable teacher-to-class style of lecturing used to diffuse information amongst the students.

(4) *Scientists, teach science*. In order to teach a subject, the instructor should have at least one more level of deeper understanding of the content being taught. With slumping 40% of US physics (and chemistry) teachers actually having expertise in their subject (WhiteHouse 2009), student resources for help are increasingly scarce.

My hope is that as a (soon to be) recent graduate of physics stepping into the role of teaching, my shared perspective in conjunction with the research provided above will contribute to the movement for better physics education. I wish to pursue this line of work so that the field of physics may continue thrive in the coming years at an exponential rate by not only recruiting more students into the discipline, but more importantly, retaining a greater percentage of those recruits.

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VIII. Appendix A

Ms. Meraz Interview

Background

1. Name: Carolina Meraz
2. Number of years as teacher: 3
3. Where and what do they teach: H. A. Hyde Elementary School
4. Involvement in any school activism/outreach programs and/or groups: A little involved in union

Interview Questions

1. What are the basic demographics of the school?

~90% Mejicano ~10% other

2. Does the school have bilingual education or an emersion program?

It is a bi-literacy program –means they learn how to read in both languages. My class is 50/50

3. How effective is this program?

I think it's very effective. I've seen the children be at higher levels of English with the 50/50 than my first year when it was more of an emersion program. The 50/50 is very effective for their English.

4. What are the strengths and weaknesses of the program?

Strength: equal exposure to both languages. Weakness: demographics; don't have good English models because most students are Spanish speaker –no Spanish learners, all English learners. Students are pushed into learning subjects in English when they are lacking the necessary vocabulary.

5. What are some suggested reforms?

Would love to get English models. Have 50% percent English portion be English Language Development rather than English Language Arts

How might they deal with:

6. A classroom in which a group of students had a common language that was different of the teacher and other students.

First check to see if I have support such as an aide or a teacher who knows the language as far as teaching is concerned. And encourage all languages and emphasize that when with a larger group of people try to use the common language out of common courtesy.

7. A classroom in which a single student does not speak a common language with anyone.

Some teachers put them in front of a computer with headphones to learn English. Simplify some assignments if they are language arts related and try to find some materials in their native language.

8. In either of these situations how does the teacher engage and include the students and effectively teach the lesson?

Visuals Visuals Visuals! And hands on activities so they can see what other students are doing so they can imitate and so language doesn't block them from knowledge.

Personal

9. How do you think students could benefit from a bi-lingual education program?

It benefits them so many ways I don't know how to explain it. It benefits them because they can be literate in their native language. It also benefits them because it opens up opportunities for jobs and traveling. It also benefits them in their way of learning because when you speak more than one language, you are making more connections, which helps them become better critical thinkers.

10. How do you think a bi-lingual education program would hinder your students?

It could hinder them if the program is not organized or an established program because they could end up not knowing both languages competently (only a little English and a little Spanish).

11. Do you feel that such a program should be designed to help non-English speakers continue to learn other subjects such as math, science, and social studies or should it be expanded into a dual-language emersion program?

In upper grades it needs to be structured so that they are receiving instruction in their native language because language should not restrain them from learning other subjects.

12. How do you encourage or react to bi-lingual students who use another language that you do not understand

I encourage them. Reassures them that they should practice their language at home and even asks a few words. Only other languages at my school are Mixteco and Hebrew.

IX. Appendix B

Selected Lab/Demo Layouts:

I. CD Diffraction

Materials:

- Laser pointer
- CD/DVD
- Tape measure
- Protractor
- Stands with clamps, vices, or tape

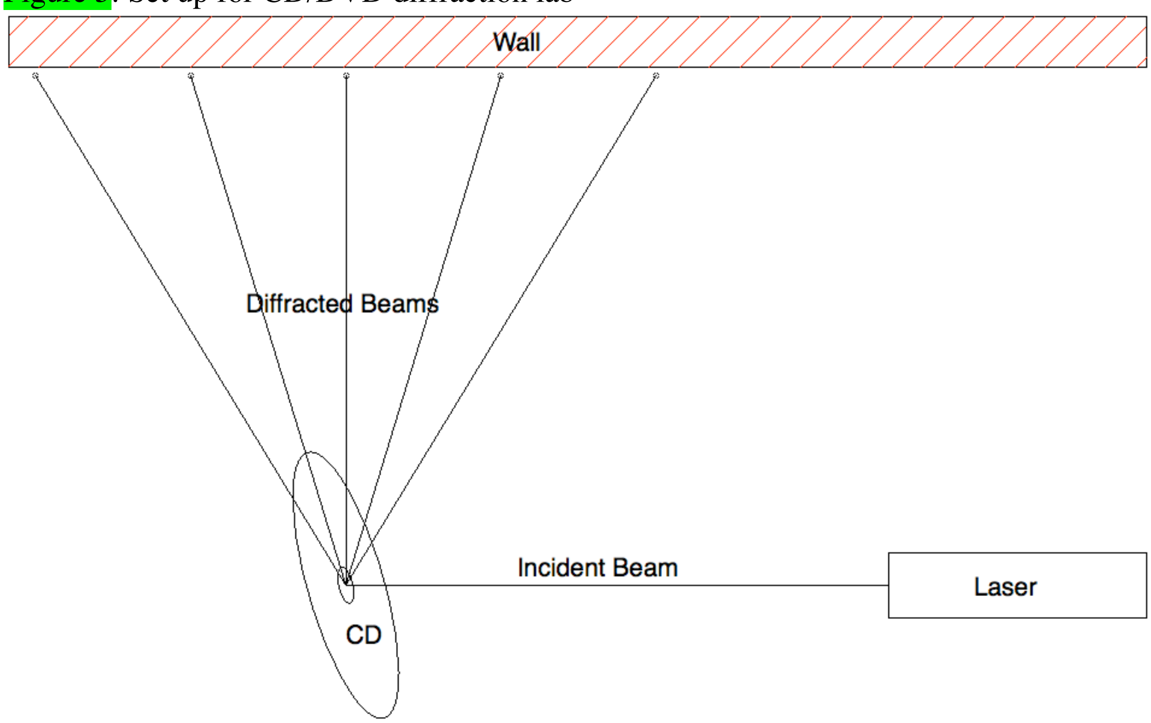
Procedure:

1. Set up equipment similar to Fig. 5
2. Arrange CD/DVD so that it is vertical and the reflective side of the CD/DVD is directed toward the laser but angled about its vertical axis (between 30 and 60 degrees)
3. Measure distance between CD/DVD and wall
4. Recalling the relationship $m\lambda = d\sin\theta$, record the following:

$\lambda \sim 7x10^{-7}$m	r	X	$\theta = r/x$	$d = \lambda^{*}r/x$

Where r is the distance between the CD/DVD and the first order diffracted beam; x is the distance between the first order diffracted beam and the bright central reflected beam; θ is the resultant angle between the two beams; and d is the spacing between the grooves of the CD/DVD to be determined

Figure 5: Set up for CD/DVD diffraction lab



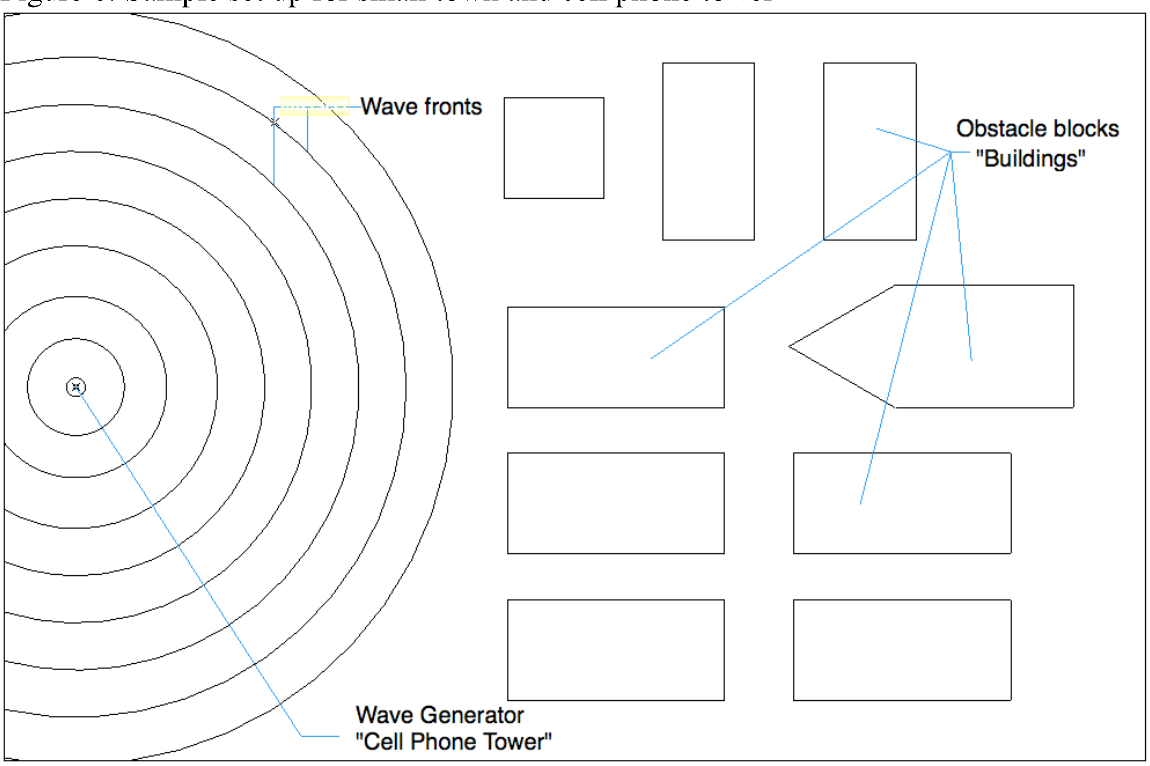
Suggested inquiry:
1. Observe what happens as the incident beam moves around the disc.
2. Observe what happens as you adjust the incident angle of the beam.
3. Is there a difference between CDs and DVDs?
4. What do you think is the cause of the behavior you observed?

II. Cell Phone Reception

Materials
- Transparent tub approx 12" x 12" x 4"
- Overhead projector
- Small wave generator
- Various blocks
- Water

Procedure
1. Place tub on top of overhead projector and add water
2. Set up equipment within tub similar to Fig. 6
3. Turn on overhead and wave generator

Figure 6: Sample set up for small town and cell phone tower



Suggested Inquiry:
1. What happens if the objects are farther apart? closer together?
2. What do you notice away from the objects? near the edges?
3. What might happen if another generator ("tower") were added to the "city"?

III. Mineralogy/Crystallography

Materials
- List of atomic spacings for various materials
- Mineral/Crystal XRD "fingerprints" (see Fig. 3)

- Worksheet

Procedure

1. Identify the frequency of the x-rays used (should be given)[18]
2. Determine the wavelength of the x-ray from the wave relationship
3. Identify scattered angles from the mineral/crystal fingerprint provided
4. Use these values with Bragg's law to calculate the atomic spacing
5. Use atomic spacing key to identify the mineral/crystal (see Table 1)

Table 1: Sample identification key for atomic spacings

Atomic Spacing	Substance
2.61^{-10}m	KCl
3.82^{-10}m	WO_3

Suggested Inquiry:

1. Were there any substances that had similar fingerprints? If so, why do you think that was; what did you notice about them?
2. How might have California immigrants in the late 1840s have benefited from this knowledge and technology?
3. Discuss with your group some possible explanations for the extra signals (spikes) in the fingerprints

IV. Diversity Assignment[19]

Select one of the following physicists*

1. Jocelyn Burnell
2. Steven Chu
3. Shirley Jackson
4. Maria Sklodowska (Curie)
5. Nicola Tesla
6. Chien Shiung Wu

*See instructor about choosing a physicist not on this list

Write a brief biography that should include their personal, educational, and professional background. Then research their greatest accomplishments and contributions to science and try to explain in your own words, what they did and how they did it. Be prepared to present your findings to the class.

[18] Usually about $1.54056*10^{-10}$m = 15.4056nm

[19] This would be a supplemental assignment that would also help keep physics relevant in a social and historical context. Such assignments like this one could be dispersed throughout the year as they do not necessarily have to directly reflect the course material.