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Radio Wave Errors: Students Mistaking Radio Transverse Electromagnetic Light Waves as Longitudinal Sound Waves

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Abstract. Commonly anecdotally noted among physics instructors is that students often misidentify radio-waves as sound waves, not as part of the electromagnetic light-energy spectrum. To highlight the prevalence of this error, a pilot survey, whose results are presented here, was made of a total of 225 high school physics students from four high schools in New Jersey in the USA, taken immediately after students had covered both sound and electromagnetic radiation. Note that although the study is made in one locality, there is likelihood that the same data would be obtained in any introductory physics classroom and future studies are suggested. This survey suggests that a majority of students appear to still incorrectly conclude that 'radio waves' are sound, even after instruction otherwise. This is perhaps reinforced by students' sensory illusion interpretation which might be articulated as: "I hear a radio, I experience 'radio broadcasts' as sound, so if 'radio signals' are 'radio waves', they are hence sound waves". The survey results were also sought to see if students who responded that "radio waves are sound" in this study, more consistently answered other related questions that used that assumption - that is, once they made that decision, did they stick with it, even when not consecutively asked the questions in the survey? Or is it possible that aspects of questioning or syllabi can mislead students? To help teachers assist students in properly identifying radio waves some ideas are suggested, particularly directly challenging students to realize that this is a frequent misunderstanding.

Keywords: Radio Waves; Physics Education; Astronomy Education.

Introduction

'Are radio waves sound waves or part of the electromagnetic spectrum?' and 'are they hence longitudinal or transverse waves?' These are common questions from physics teachers to their students when studying radio waves. Yet, anecdotally, students often get these questions wrong. Why do physics teachers on both the secondary level and in higher education often refer to difficulties in teaching the electromagnetic spectrum with a sense of frustration, especially regarding students' frequent misidentification of radio waves as longitudinal sound waves and not as transverse electromagnetic waves after being taught otherwise? Are there conceptualizations that students are making regarding the physical phenomenon of radio transmissions that make it difficult to communicate the correct physics of radio signals to students? Are more stringent warnings to students of difficulties needed when teaching sound waves and electromagnetism?

The purpose here is to document the prevalence of the existence of this difficulty and possible implications of students' misidentification of radio waves as sound instead of as electromagnetic waves in the radio frequency range, an invisible portion of the light spectrum. For this pilot study, the students completed a paper-pencil instrument to show their understanding of this material. Also, how strong is the possibility that students may carry through their conclusions that radio waves as sound or light to other questions? It is also the first published study to attempt to quantify the prevalence of this error, and also to point out the difficulty of producing testing questions that do not mislead students via pointing out the weakness of the survey tool used.

Note that due to its fundamental nature, we use the term light (as is done in many physics textbooks) to mean both the visible portion of the electromagnetic spectrum and also invisible portions of the electromagnetic spectrum such as radio waves, microwaves, infrared, ultraviolet rays, X-rays, and gamma rays. The choice to confine the definition of light to just visible light appears to be increasingly viewed as abstruse and unusual, hence the terminology choice made here.

Background

The need for, and difficulties of, students to understand the nature of radiation, radio waves, sound waves and radio signals is noted in both the physics and astronomy communities (Berger, 2015; Barder et al., 2005; Landt, 2015; McGuinnes & Oliver, 1998; Plotz & Hopf, 2016; Newmann & Hopf, 2012; Rego & Peralta, 2006). Radio waves are introduced in most physics textbooks during the discussion of waves and then again after sound when electromagnetic radiation is introduced. Astronomy textbooks do so when they introduce the concept of light. Physics textbook author Paul Hewitt generated a thought problem on this important misunderstanding in his "Figuring Physics" series available as a Next Time Question (Hewitt, 2007). Other suggestions and helps in addressing teaching radio waves are available in Perkins et al. (2006), Wise (2006), DeVries (2001), and Finkelstein et al. (2006). The question remains of why would students think of radio waves, transmissions from one radio to another radio tower as sound waves?

It should be noted that when one thinks of a radio, one thinks of the sound it produces – such as listening to a car radio or a radio station on one's cell phone. Students might then easily misinterpret radio waves as being the same as radio signals. A radio signal does change forms: from sound to electrical signal inputted to a transmitting antenna, to electromagnetic (EM) 'radio waves' that travel to a detecting radio antenna, which in turn produces electrical signals that are converted to sound output that is heard, where the receiving 'radio' itself is acting like a translator box and producing a sound wave. If one is simply considering the beginning and end product, it only makes sense to consider radio signals as sound waves. In that sense, physics learning that asks the question – does the physics make sense in everyday life based on what is sensed and are students naïvely putting in a situation of observation to be deceived by sensory illusions and correlation to everyday experiences (Tabor-Morris, 2015; Caramazza et al., 1981) which can mislead if all aspects of the radio signal are not considered? Also the intricacy of signal changing forms may be only briefly addressed in class, perhaps because physics teachers tend to try to stick to the basics – such as saying 'radio waves transmit signal' and ignore the other aspects of radio signals such as signals through electronics before and after the radio waves are sent, and the fact that the original signal was a sound wave and the final product is a sound wave, such as music listened to on a radio (Lazebnik, 2002).

In addition, other examples given in class may lend to the misconception. For example, some radio telescope dishes, even in current astronomy, have been construed to resemble ears and are sometimes even referred to as "listening to outer-space". Others, perhaps unfortunately, have been identified by the colloquial term of "horns", such as the "horn antenna" used by Penzias and Wilson in the 1960s to map radio signals from the Milky Way leading to the discovery of the Cosmic Microwave Background.(APS website online). However, is it possible that some other explanations and demonstrations are reinforcing this misinterpretation rather than clarifying it?

Education research indicates also that errors are often actualized not only from direct input but by organizing and reorganizing which initially may be fragmented ("knowledge in pieces") and re-evaluating misconceptions such as "naïve theories" (Tuminaro & Redish, 2007; Bao & Redish, 2006; Disessa & Sherin, 1998, Carmazza et al., 1981; Etkina & Ruibal-Villasenor, 2008). Wave types might be considered in class in different contexts (such as a discussion of sound and then later light) that are never fully connected for students.

Purpose and methodology of survey

The source, nature, and consequence of the described errors is explored in this article, which reports on a pilot study (via a paper survey) to physics students in several high schools. A short seven question multiple choice survey of students was prepared and distributed in the classroom by the high school physics teacher. The reasoning for the questions in the pilot survey was based on frequent multiple-choice questions types similar to those often asked/tested on light and sound to high school physics students with the goal to obtain data on student responses on this subject, following physics education research models (Ding & Liu, 2012). The objective was to test the idea that students may have trends in how they answer these multiple-choice questions.

The survey was reviewed and approved by the University's six-scientist Institutional Research Review Board (IRRB) prior to dissemination and was also evaluated by an outside evaluator from the Social Work Department and one from the School of Education (with pre-college teaching experience) at our University for face and content validity in addition to bias. This study was intended as a first look at this problem and outside expertise was not sought in this initial study but future survey tools will be subject to more rigorous scrutiny. Methodology in the selection of the high school students taking physics was based on availability of the test subjects via the cooperation of local high schools which included parental permission as all test subjects were minors.

The high schools were surveyed after students had covered electromagnetic radiation in their spring semester (April), as verified by a survey to their teachers. Data was collected with a total of 225 students (that is, N=225, where N is a variable equal to the number of subjects) participating from 4 high schools (mix of public and private institutions) with a total of 7 different classes who participated in this survey. No record of who the teachers of these classes was made, nor if any of these teachers taught multiple courses that were surveyed. All the students in this study were from the same age group strata (high school juniors and seniors of ages 16-18 years old) with the data taken in only one particular year, in 2012; hence, this study is only representative of a single cohort based on age, year, and demographic location. Distribution to other cohorts was never initiated due to inherent concerns in the study as will be highlighted.

The demographics of the students in the study were such that all were from central/southern New Jersey and were in basically the same economic strata: the average student was from a middle-class family not under financial stress. The students were taking a physics course from one of all levels of physics including general, college preparatory, honors and advanced placement (AP) and all were juniors or seniors in high school; no Physics First (freshman) classes were surveyed as these schools did not have that program. Students were not asked personal questions regarding family, wealth, gender identity, ethnicity, minority status or whether or not their parents were college graduates.

Each student completed a paper survey in their physics classroom. The survey was administered in the selected high school physics classrooms by the high school physics teachers. These surveys were returned to the researchers and tabulated. This study could not be further stratified since the surveys were delivered back from the schools bundled without differentiation between classes; hence, the experiences due to a variety of physics class levels or teachers (who might teach various levels) could not be segregated for further analysis, although individual class sizes were small; and hence, statistically insignificant as stand-alone units.

This survey's results are presented mostly in a qualitatively-descriptive manner and the discussion of the survey study is meant to serve as a pilot for a possible larger group sampling, although the sample size was adequate, within common and appropriate *apriori* parameters (Apriori Calculator online). Even given the limitations of this study, some interesting trends can be noted. Details of the survey instrument are given in the next section along with the results.

Survey and results

Table 1 is a summary presentation of all the results obtained in this study. Note that consideration of whether high school students would take such a survey seriously should be made (Kalat, 2010). We did make this consideration. Firstly, the survey was distributed in students' physics class by their physics teacher, a place where students would be expected to answer questions thoughtfully, being in the classroom or laboratory where they had learned the material. Secondly, all students answered all the questions in the survey, indicating that they took it seriously. Thirdly, Question #5, an easy stand-alone question, had a high percentage of correct answers. It was a question embedded deep in the survey so unlikely to be prompted by a teacher, and had an overall 92% correct percentage and only one class (High School 3) with only one notable lower percentage (72%), possibly not having covered this or emphasizing it less. Conclusions likely can be drawn that students took the survey seriously, noting that distractor answers in that question – an energon is a make-believe particle, a pion likely would not (yet) have been discussed in a high school physics class, nor would a phonon.

Table 1: Physics questions asked high school students (with percentages normalized to N=225)
Note: numbers may not add to 100% as numbers were rounded.

#	Question Text (*correct answer is underlined*)	Overall Percentage Correct (N=225)	High School 1 Percentage Correct (N=104)	High School 2 Percentage Correct (N=43)	High School 3 Percentage Correct (N=11)	High School 4 Percentage Correct (N=67)
1	Light is a ___ wave.					
	a.) longitudinal	**33%**	41%	41%	45%	12%
	b.) transverse	**67%**	59%	59%	55%	**88%**
2	Radio waves are a form of sound waves.					
	a.) true	**60%**	57%	48%	64%	70%
	b.) false	**40%**	43%	51%	36%	30%
3	Electromagnetic waves have zero __.					
	a.) mass	**83%**	77%	88%	63%	91%
	b.) wavelength	**4%**	5%	5%	0	3%
	c.) energy	**3%**	5%	2%	9%	0
	d.) frequency	**10%**	13%	5%	27%	6%
	e.) velocity	**0**	1%	0	0	0
4	The electromagnetic spectrum, in order from lowest energy to highest.					
	a.) x-ray,microwave, infrared, visible, ultraviolet	**14%**	18%	16%	9%	8%
	b.) visible, infrared, ultraviolet, microwave, x-ray	**21%**	25%	30%	27%	9%
	c.) x-ray, infrared, microwave,	**11%**	14%	16%	18%	0

ultraviolet, visible					
d.) microwave, infrared, visible, ultraviolet, x-ray	**46%**	37%	25%	9%	**80%**
e.) microwave, x-ray, ultraviolet, visible, infrared	**7%**	6%	9%	36%	3%
5 Another name for a bundle of light is a					
a.) phonon	**1%**	0	2%	0%	0
b.) photon	**92%**	92%	93%	**72%**	**95%**
c.) proton	**3%**	2%	2%	9%	5%
d.) pion	**2%**	2%	2%	9%	0
e.) energon	**2%**	4%	0	0	0
6 Radio waves travel in air at a speed that is __ the speed of **SOUND**.					
a.) slower than	**20%**	22%	25%	27%	13%
b.) the same as	**44%**	39%	35%	36%	57%
c.) faster than	**36%**	39%	40%	36%	30%
7 Radio waves travel in air at a speed that is __ the speed of **LIGHT**.					
a.) slower than	**71%**	71%	65%	72%	70%
b.) the same as	**21%**	18%	25%	18%	22%
c.) faster than	**8%**	11%	5%	9%	8%

Note that a glaring 8% of the population surveyed said incorrectly that radio waves could travel faster than the speed of light, when in most high school classes, the speed of light is expected to be proclaimed to new learners as the universal speed limit. However, it should be noted that no collection of syllabi of the students was collected and hence no correlation made to what students were presented with which may have missing items from those usually expected, at least in this study.

The introductory survey question and implications

It was desirable that the survey be short since the aim was to sample students' knowledge and not have them realize that their answers were incorrect and to go back and change them. The survey was meant as an expression of student knowledge, and not a learning experience. The first question was considered a 'control question', to see if students remembered light was a transverse wave, and to determine what the overall rate of student correct answers would be to a technical course-based question.

1.) Light is a ________ wave.
    A) longitudinal –INCORRECT
    B) transverse - CORRECT

Overall average results in student responses was tabulated with 32% incorrect and 68% answering correctly. However, before proceeding, let us also take a look at the performance of individual schools (See Fig. 1).

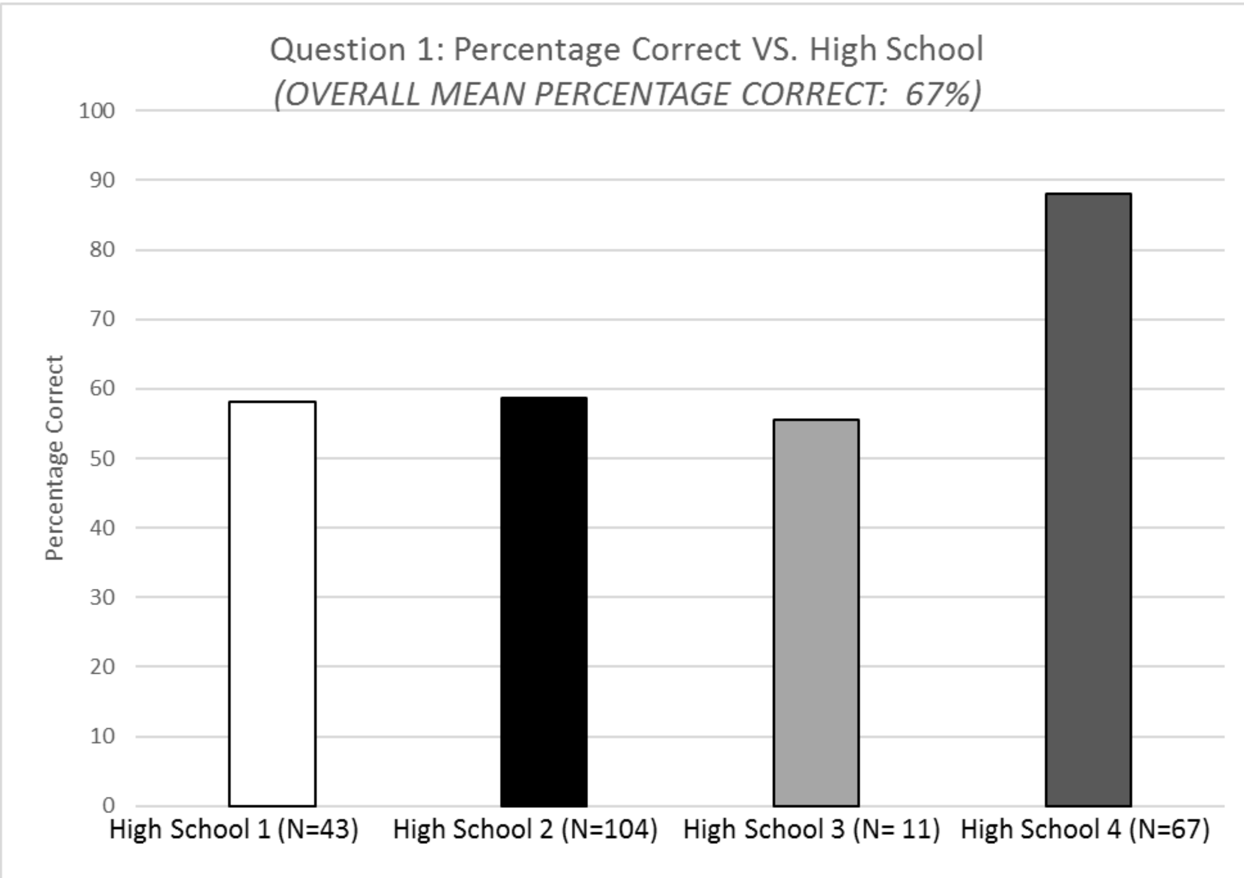

Figure 1: Question #1 results ("Light is a longitudinal/transverse wave"): Percentage correct vs. high schools surveyed.

Except for one school, the spread of answers was similar. The glaringly large percentage correct (at nearly 90%) on Question #1 for High School 4 (likely two classes but maybe more, at N=67), but lower scores on later questions may indicate that possibilities:

1.) topic of light had possibly just recently been covered; but possibly radio waves were not covered or at least not in much depth,
2.) possibly that the teacher(s) at this school is (are) doing a better job overall in achieving better results in student learning on that topic, and/or
3.) teacher(s) may have prompted the answer to Question #1 to the students, for example, such as by saying "doing this survey

remember how we covered…," or some other similar, even more outright, prompting. However, if the answer had 'just been given', the return rate would likely have been 100%. It is a topic for future studies.

Having an initial question to buffer was not intentional but in retrospect seemed good practice, especially as teachers would be unlikely to prompt more than one question. Note that it might be difficult to get a third party to administer the survey.

Excluding the results from High School 4, the percentage rate of correct answers was a more moderate 58% correct and more consistent, within ±3 percentage points. Still this is a discouraging statistic, considering that all students in this study would have recently covered this topic. However, the unfamiliarity of the words ('longitudinal' and 'transverse') and students only recently being introduced to them, and not seeing them often might lend to less accuracy in answering the question.

Rate of students incorrectly identifying radio waves as sound

The questions of most interest for this article in which physics students incorrectly identify radio waves as sound are Questions 2, 6, and 7. Logically, a percentage of students answering Questions 2 incorrectly might also tend to answer Question #6, and Question #7 incorrectly but consistently (that radio waves were sound). Figure 2 highlights these answers per high school.

Question #2: Radio waves are a form of sound waves.

True: N=134 (60%) incorrect
False: N=91 (40%) correct

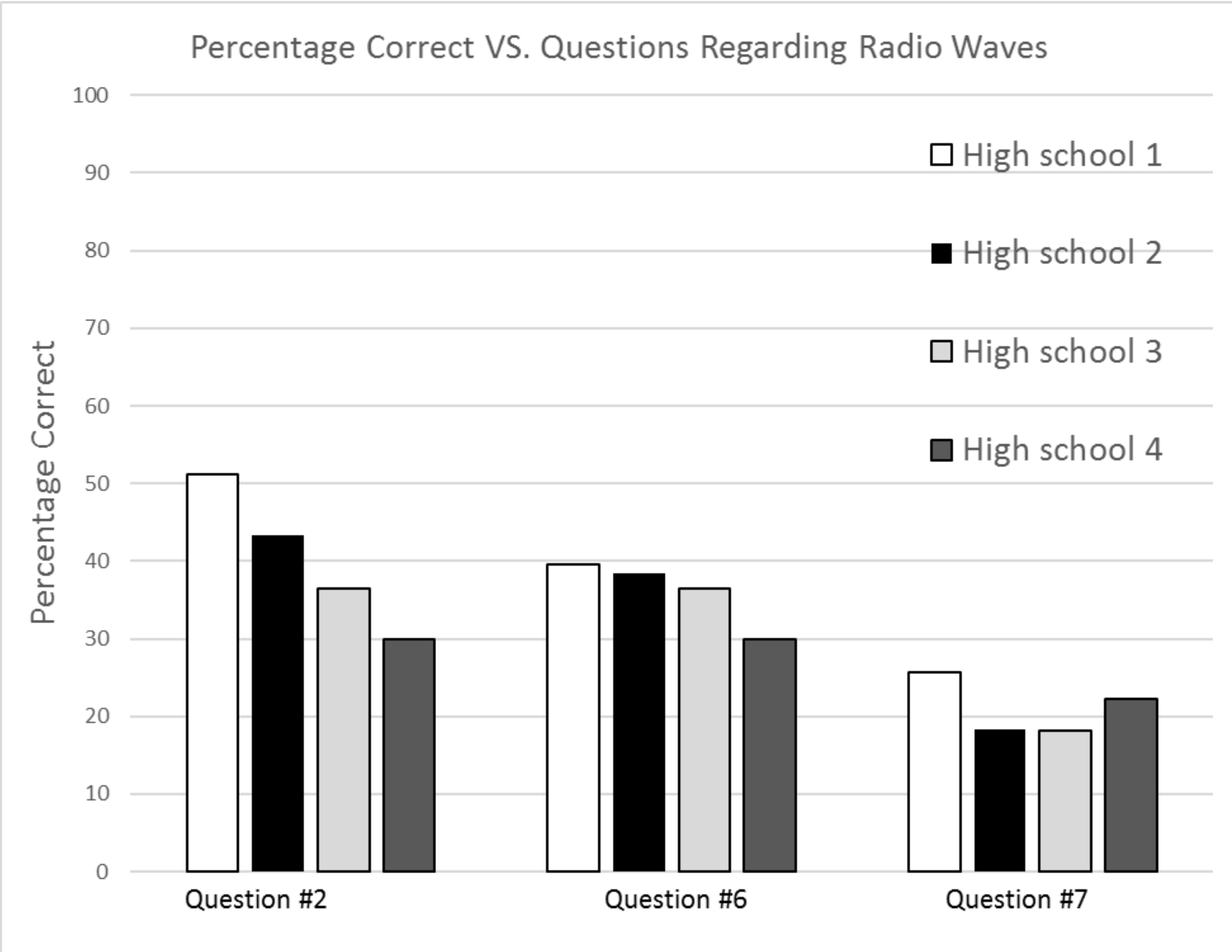

Figure 2: Percentage correct VS. Questions regarding Radio Waves (as light)

Averaged results showed 60% of these high school physics students were identifying radio waves as sound. However, there also exists the possibility that students are mistaking "radio waves" for "radio signal", as mentioned previously, which would, as heard from a radio, indeed be sound (Lazebnik, 2002).

Also, out of those 134 incorrect answers, 82 also answered Question #6 that "radio waves travel at the same speed as sound" – a percentage rate of 82/134X100= 61% of those students who specifically answered Question #2 that 'radio waves were sound' who were sticking with that idea that radio waves travel at the speed of sound in Question #6, higher than the overall percentage at 44%.

Of the 82 who answered that radio waves were sound in Question #2 and Question #6, there were 73 who answered in Question #7 that "radio waves travelled less than the speed of light". Hence 89% of those seemed to be sticking to the idea that radio is sound. That is 32% of the entire population (N=225) surveyed, a possible indication that this portion of the students were again following through on the idea that radio is sound. This seems to be defined as a "naïve theories" as discussed in the background section (Tuminaro & Redish, 2007; Bao & Redish, 2006; Disessa & Sherin, 1998, Carmazza et al., 1981; Etkina & Ruibal-Villasenor, 2008). Students may, once committed, not realize that they are being deceived by what could be termed a sensory illusion (Tabor-Morris, 2015) and/or be over-correlating their experience of everyday experiences in a way that is not physical (Caramazza et al., 1981).

Students correctly answering and following though that radio waves are light

Of the 91 students who answered Question #2 correctly that radio waves were light, 34 also correctly answered Question #7 that "radio waves travel at the speed equal to the speed of light". So, it appears 34/91X100= 37% of those students followed through with their idea that radio waves are light into that question.

The index of refraction effect on the speed of light would be negligible, something some students might (or might not) have considered, in which then, assuming students follow through, would raise the percentage of correct answers to – that is, including a and b as correct – from 37% to (89 answering either a or b) a total of 97%. However, it is unclear that students would be thinking along those lines. This is clearly an area for future research and survey modification.

Correlating this back to Question #6, if students were following the logic that radio is light, they would have answered that radio waves travel faster than sound. Of the students who answered that radio waves travel at the speed of light (only), 28 or 82% indicated that radio waves travel faster than sound (assumedly at the speed of light, as they answer in the next question). This is 12% of the entire student population surveyed, a lower overall percentage of those who appeared to follow through on the logic for radio waves as sound.

Possible changes to questions in survey in future research

Question 6 and 7 might have the "in air" portion of the phrase also put at the end of the sentence in both cases so that any confusion regarding the effects of index of refraction could be eliminated. There also exists the unexplored possibility that some students may be identifying radio waves, instead of electromagnetic waves, but instead as AC-type electrical signals. Question #2 could be expanded to include (c.) electrical signal and/or a Question #8 could be added that distinguishes students' thoughts about which is fastest could be added:

Which is fastest? Speed of a.) sound in air, b.) light in vacuum, c.) electricity in metal, expounding on past problems seeking to be addressed.

Noting that electricity travels faster than sound but slower than light in vacuum (Halliday, 2007), this question might allow students to better qualify radio waves or at least distinguish them from other phenomenon. Student attitudes among a particular cohort, with participants representing a single strata and age but inspires the research question whether the results could be applied more broadly to physics, such as on the undergraduate level. Giving the same tests to the same class twice within a short period of time is used to judge the stability of the testing (Engelhardt, 2009). This was not completed in this case as this was always intended to be a pilot study and questions were not Leichardt gray-scale, and therefore less likely to be answered differently if asked consecutively to the same audience, with the assumption being that learning is stable, which would be a separate study. Cohort and longitudinal studies with pre- and post-tests are also suggested for the future.

In addition, the responses of students in southern New Jersey (mostly suburban) may or may not be representative of all students nationally or internationally. There is also less racial and/or economic diversity than in many other populations in the United States and elsewhere. However, given that the survey was taken in a region of the country that was somewhat culturally homogenous and overall non-stressed financially, these stressors and differentiators most likely were not any significant factor in, for example, student-to-student interactions.

For this study, a cross-sectional sampling across many age groups could not be made since most people take a physics class in a short period/time of their life only, although college students could also be studied in the future and may be of interest due to their further maturity and possibility of having taken a physics course in high school. A longitudinal study was also not possible for this group to investigate if their knowledge and attitudes carried though to future classwork. This was due to the fact that the students were not identified as individuals and are in high school only a short period of time before graduation. Hence after high school graduation students and their responses would not be traceable as either individuals or a unit, since limited communication is maintained by high school graduates with their alumni schools. In the future, a larger sampling of students could be made and several years of data from students who are juniors/seniors in those years. Also, students on the college level were not tested but would be of interest.

Conclusion and Suggestions

Many students have difficulty correctly identifying radio waves as transverse light waves. The primary purpose of this study was to highlight that the problem exists on a statistically significant level and is worthy of further study and active remediation by teachers. Based on the results of the survey-tool in this pilot study, a large percentage of students appear to conclude that, since they experience radio broadcasts as sound, then sound waves are the actual transmission of radio signals, at least more so than that for light. That “things are not always what they seem” is something scientists are used to analyzing. How can teachers prepare students for conditions when what seems initially obvious is more subtle?

Teachers’ awareness and addressing this problem directly may be essential to assisting student learning. Note that it could be easy to see that students might interpret the term "radio waves" as waves emitted by a (hand-held) radio - which would be sound, but would be more concerning is if the misconception extended to students believing that radio broadcasts (from base) are transmitted as sound (and somehow amplified by a radio). A future survey could address this issue. For the purposes here, it is suggested that teachers alert students to this often made error is one possible method to help remediate student confusion.

Can teachers better identify to students that a radio is a "translator box" that translates radio signals into sound? Questioning students on the steps for radio communication might also be helpful in sorting out their understanding of the process. Also helpful may be identifying to students that radio waves are electromagnetic radiation in a range invisible to the eye, in a sense, "invisible light" with better distinction between radio signals and radio waves? Radio stations are continually broadcasting radio waves on many frequencies ("We are now awash in radio waves but do you hear anything? No."). Cosmic sources such as the sun create what is interpreted by radios as static. People simply cannot sense the radio waves using our bodily senses.

In addition, there are also indications that students need to take in physics terms multiple times for physics jargon to be absorbed into the students' vocabulary and understanding. In addition, repetition of phrasing may be necessary for students to be able to distinguish scientific and everyday meanings for the same words. For example, the survey results suggest that terms such as 'longitudinal' and 'transverse' need to be reviewed multiple times by teachers for students, but that term-sticking is achievable as seen in the survey with the term 'photon', not a term used in everyday language. Fragmenting of knowledge, as addressed in the background (Tuminaro & Redish, 2007; Bao & Redish, 2006; Disessa & Sherin, 1998, Carmazza et al., 1981; Etkina & Ruibal-Villasenor, 2008), may also be occurring from the time students are first presented with wave types until they study light. Frequent quizzes that keep students on track might be very valuable during the study of sound and light, including questions that tie past concepts with present instruction. Future studies beyond this pilot study are suggested. This would entail revaluating the questions for possible bias as well as content. Another item for future studies would be to check syllabi between classes data was taken for to assure consistency of topics.

Another issue may lie in the fact that students may not even be able to identify radio transmission towers. Why? Many may not even experience "radio" except streaming over the internet. While examples of transmission of cell phones and cell phone towers, might be more effective for this current younger generation, as many are cellular phone device users, most of these transmissions fall into the microwave region. Microwaves constitute another invisible portion of light's electromagnetic spectrum and are perhaps difficult to address without discussing microwave ovens, another common appliance to students. Confusion can ensue regarding applications of these as well: relaying communications versus heating of food. This would merit another study. Confusions in astronomy and physics with sound and light, such as the use of terms 'horn telescopes' mentioned in the background should also be considered with care. Consequences of not understanding the nature of radio waves would also include students being unable to ascertain secondary effects such as absorption and polarization as well as applications of communications such as AM and FM. While some important questions were addressed in this study, a number of others are still unanswered, such as the construction of questions that will not "lead" students to answers, but also will not confuse them.

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