Alternative conceptions held by first year physics students at a South African university of technology concerning interference and diffraction of waves

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ABSTRACT

Many researchers have reported the incidence and prevalence of alternative conceptions concerning many concepts and principles in science. This was a case study aimed at identifying the most prevalent alternative conceptions relating to interference and diffraction of waves amongst first year physics students at a University of Technology in South Africa. The research sample comprised 133 students. A questionnaire and a test were used to collect the required data. Although quantitative data were collected, the main thrust of data analysis for this paper was on the qualitative data generated. The results showed that the students held many alternative conceptions concerning interference and diffraction of waves including the notions that (a) the principle of superposition applies along both the y and x axes, (b) interference is associated with reinforcement and not destructive interference, (c) interference results in the average effect – hence two identical waves won't have any effect on one another, (d) waves have mass, exert force and occupy space, (e) waves have positive or negative charges, which result in attractive and repulsive forces, (f) amplitude is directly proportional to period, and (g) sound and electromagnetic waves are the same concept. It was further established that students were confused by the different meanings and interpretations of the concepts of in phase, out of phase, constructive and destructive interference, given in literature and different text books. It was noted that these could have led to the incidence and prevalence of alternative conceptions. These findings are discussed, and recommendations made.

Keywords: Alternative conceptions, first year university students, physics, interference, diffraction, waves

INTRODUCTION

Many researchers have reported the incidence and prevalence of alternative conceptions concerning many concepts and principles in science (Boyes, 1988; Coetzee, 1998; Driver, 1983; McDermott, 1993; Rowell, Dawson & Lyndon, 1990; Treagust, 1988; Veiga, 1989; Wandersee, Mintzes & Novak, 1994). Indeed it is now well established that learners do not come to the classroom with empty minds, because they develop beliefs about things that happen in their surroundings from the very earliest days of their lives from any previous life experience or observation, not necessarily arising out of formal education. In this regard, learners come to science lessons with a wide range of some already strongly held ideas, which may differ from the theories the educator may wish to develop. In this study, these ideas are referred to as alternative conceptions (Kyle, Family & Shymansky, 1989; McDermott, 1993; Wandersee, Mintzes & Novak, 1994).
These conceptions, once formed, influence the sense learners make of further learning, are resistant to change and make a considerable number of learners hold on to certain intuitive notions despite formal science education they receive (Driver, 1983).
According to Driver and Head (1986), the origins of alternative conceptions bear their roots in the individual's previous experience and observation, language, cultural influence, and the way teachers and textbooks present information.

A study done by Imenda (2005) revealed the presence of alternative conceptions due to religious and cultural beliefs – thereby posing very difficult challenges for teachers. For instance, Imenda (2005) asks the moral and philosophical question as to whether or not teachers have a moral obligation to change their students' cultural and religious beliefs in order to align them with modern scientific thinking. In some countries, like South Africa, teachers are not allowed to touch on issues of religion in their classrooms. It is felt that because formal schooling is based on logic and scientific rationality, religious education is, in principle, seen as being incompatible with formal schooling. The apparent contradiction, however, is that according to the National Curriculum Statement Grades 10-12 (General) (2003:4) indigenous knowledge systems, which include African religion and culture, should be respected and valued.

Considering that textbooks are the dominant teaching tool in colleges and secondary schools (Ennis & Schlipf, 1966, as cited by Deighton, 1971:214), they deserve a special mention as a possible source of students' alternative conceptions. Indeed, a number of studies reveal that science textbooks, in particular, have a major influence on students and teachers (Dall'Alba, Walsh, Bowden, Martin, Masters, Ramsden & Stephanou, 1993; Potter, 1992, as cited by Whiteley, 1996:169; Whiteley, 1996:173). In cases where students rely substantially on a single textbook in developing their understanding, misleading or inaccurate statements in those textbooks may have a considerable impact on their conceptual understanding of the subject, presently and in future. In their study on acceleration, Dall'Alba *et al* (1993) found that some students' understandings were incomplete in ways that paralleled misleading or inaccurate textbook treatments. Coetzee (1998) investigated alternative conceptions concerning the interference and diffraction of waves amongst first year technikon students and had the same findings that textbooks were a major contributor to the existence of alternative conceptions.

The meaning ascribed to a textbook definition, for instance, depends on the interpretation of the author or the reader. It follows, therefore, that when a student relies on a single text in developing understanding, misleading or inaccurate statements may have a considerable impact on learning. This calls for the use of supplemental materials, current journals, magazines and reports to update, add and support textbook content.

Whatever the source, however, alternative conceptions that learners hold can hinder experimentation. These conceptions may be so firmly held by learners that, instead of acting as a source of ideas to test, they restrict empirical observations (Driver, 1983).

Wessel (1999) distinguishes between two types of knowledge students have, and emphasizes that science requires both types of knowledge. Experiential knowledge, i.e. the knowledge that students bring to class as a result of their life experiences. This knowledge includes all experiences they have had during their lives and the thinking that they have done to organize this knowledge to help them operate in their world. On the other hand, conceptual knowledge is theoretical in nature. This knowledge is formed in the mind as a result of reflection about experiences and generally has principles that can be used to explain a number of experiences. Conceptual knowledge is the abstract part of science which serves to organize knowledge using laws and theories, and in turn influencing the content of such laws and theories. Quite often, however, students struggle with conceptual knowledge, its use and development.

It is the discrepancy between the alternative conceptions constructed by learners (mainly from experiential knowledge), on one hand, and those held by the community of scientists (conceptual knowledge), on another, which educators seek to address (Imenda, 2005). One needs to hasten to add, however, that there is an active interaction that exists (at least, there ought to be) between experiential and conceptual knowledge in every individual – resulting in a steady state of equilibrium between the two for the individual not to experience dissonance.

Wandersee, Mintzes and Novak (1994:195) summarize existing research literature on alternative conceptions in 8 knowledge claims:

(i) Learners come to formal science instruction with a diverse set of alternative conceptions concerning natural objects and events.
(ii) The alternative conceptions that learners bring to formal science instruction cut across age, ability, gender and cultural boundaries.
(iii) Alternative conceptions are tenacious and resistant to extinction by conventional teaching strategies.
(iv) Alternative conceptions offer parallel explanations of natural phenomena offered by previous generations of scientists and philosophers.
(v) Alternative conceptions have their origins in a diverse set of personal experiences including direct observation and perception, peer culture and language, as well as in teachers' explanations and instructional materials.
(vi) Teachers often subscribe to the same alternative conceptions as their students.
(vii) Learners' prior knowledge interacts with knowledge presented in formal instruction, resulting in a diverse set of unintended learning outcomes.
(viii) Instructional approaches that facilitate conceptual change can be effective classroom tools.

These attributes of learners provided the understanding upon which this study was based.

PROBLEM STATEMENT

Many of the sources of confusion in science classes are not identified in the classroom as instruction occurs. Students may be aware of some conceptual blockages, especially those that stop learning completely, but may remain unaware of other blockages, because knowledge construction continues, but in a wrong direction, leading to some forms of alternative conceptions. It is, therefore, important to systematically investigate students' alternative conceptions concerning specific scientific concepts, as a first step, so that subsequently appropriate instructional interventions can be made.

Studies suggest that there is much in common in students' alternative conceptions, although there are indications that different social and cultural influences have an effect on the development of these conceptions. Therefore, documenting all the alternative conceptions held by students could contribute to lecturers' ability to effect conceptual change, as well as benefit and inform science curriculum planning, generally (Driver, 1989:484).

In her many years of teaching first year physics at the participating institution, the first author has observed that many students experience difficulties with the part of the first year physics module dealing with interference and diffraction of waves. Over the years she has tried to be alert to some of the learning difficulties presented by the students, *albeit* in a non-formal way, in order to assist them to better understand the many concepts and principles covered in the module. This study was, therefore, an attempt to formally and systematically investigate the most common alternative conceptions presented by first year physics students concerning interference and diffraction of waves. This was done as a first step of a bigger project which would then go further and design instructional interventions to ameliorate the identified alternative conceptions regarding the topic.

RESEARCH OBJECTIVE

This research sought to identify and document the most prevalent alternative conceptions relating to interference and diffraction of waves amongst first year physics students.

RESEARCH METHODS

The research methods are presented under several sub-headings as indicated below.

Research Sample

The study involved 133 first year physics students at a University of Technology in the Republic of South Africa. The students were enrolled for different qualifications within the Science Faculty, but all taking the same first year physics module.

Instrumentation

A questionnaire was designed to obtain the participants' biographical information, as well as determine their understanding of, and knowledge about, waves, in general, and interference and diffraction, in particular. The questionnaire had both structured and open-ended sections. The structured section focused on biographical information, whereas the open-ended section sought to elicit the students' views regarding waves and wave properties. Therefore, the open-ended section sought to elicit more original responses than would have been the case had the students been asked to respond to already pre-conceived statements regarding interference and diffraction. The responses from the questionnaire were complimented by responses on a test given to the research sample, comprising multiple-choice items. Each question was followed by an open-ended question where the answer had to be motivated. This test targeted alternative conceptions from the literature review, as well as potential alternative conceptions which had emerged from students' responses and problematic notions, from the first author's experience as a physics lecturer.

Data Analysis

Although quantitative data were collected and processed mainly in terms of frequencies of the different multiple choice options, the main thrust of data analysis for this study centered around the qualitative data generated from the students' motivations for their answers. Consequently, the analysis of the students' responses did not focus on the knowledge, *per se*, but the underlying conceptions behind the respondents' answers.

With regard to qualitative data analysis, a researcher frees him/herself from his/her ways of perceiving the world, so that he/she is able to "see" things from the point of view of the respondents (Imenda, 2005). This way, the researcher places him/herself in a neutral position to be able to present the original data/views with minimum distortion and adulteration – thereby understand the experiences of the respondents better within the context of their lived world. So, in this regard, the researchers searched for patterns of meanings from the statements and explanation given by the students. From there, descriptions and interpretations of the students' experiences were constructed and categorized. These categories emerged progressively from the data as the analysis proceeded.

RESULTS

The results are presented and discussed below under various sub-headings.

Demographics

The majority of students were 19 years of age; females outnumbered the males and most of the students were *not* repeaters of Physics I, but were taking it for the first time; over 50% of the students had attended township (generally poorly resourced) schools prior to their admission to the University; 26% had attended Model C schools (relatively well-resourced); and a small percentage had attended private schools; the majority had taken science as a subject until grade 12, and had had access to textbooks (87%).

Students' familiarity with basic concepts on waves indicated that most of them were familiar with the concepts of wavelength (92%), amplitude (97%) and frequency (98%). The familiarity on constructive interference (46%) was lower than destructive interference (53%). A lower familiarity with superposition (28%), the underlying principle of interference, was strange.

Most Prevalent Alternative Conceptions:

The research objective of this study was to identify and document the most prevalent alternative conceptions held by first year physics students. Table 1 (Appendix) presents a categorized summary of the most prevalent alternative conceptions identified in this study. Under each category, selected quotations from the students' motivations are presented to illustrate the point. Each category was assigned a symbol (AC1 to AC10), in no specific order of significance. These findings are discussed briefly.

AC1: Superposition along X-axis

The principle of superposition was not well understood. The alternative conception identified was that superposition was applied along both axes, which implied that not only the amplitudes were added along the y-axis, but also the wavelengths (or time) along the x-axis. The following were quotes from students to explain and support the alternative conception:

- "The two waves are similar thus the combination will be double the effect of the original wave i.e. it will be 2x the amplitudes and wavelength."
- "As the pulses meet the amplitude on the Y-axis and the wavelength on the X-axis will enlarge."
- "When two crests meet (in phase) the smaller crest will be inside the larger crest, but the distance will be twice the distance."

AC2: Interference is associated with reinforcement

A second alternative conception relating to the principle of superposition was that interference is associated with reinforcement. So, essentially, the students were of the view that interference was associated only with constructive interference and not destructive interference. Therefore, another wave would always increase, and never decrease, an existing wave.

The following were quotes from students, which illustrated this alternative conception:

- "It will create more noise than before as this wave will meet with another wave and have more wave length."
- "When a car plays loud music and another one parks near it and plays loud music too, the noise will now be bigger."
- "Because of their combination they will not get weak, but they will be strong – like team work."

AC3: Interference is an average effect

The students were of the view that identical waves would have no effect on each other. When two pulses interfere the result is an average pulse, or the bigger pulse will be dominant. The following quote bears this out: "When two pulses meet the final crest will be the average of both crests and the final point where pulses will be will be the average of the x-axis."

AC4: Waves have mass and collide according to the law of momentum

Another alternative conception was that waves collided and adhered to the law of conservation of momentum. In this regard, a view was held that two identical waves propagating from opposite directions would cancel each other when they met in phase. Therefore, the direction in which a pulse is propagating, as well as the propagating velocities, influences the interference pattern. In the case of pulses propagating towards each other, they collide and come to a complete standstill or move backwards. Motivations like the following have their origin from the viewpoint that waves collide:

- "Two crests will cancel and form a straight line."
- "Two pulses moving towards each other will collide and form one big pulse. The direction will depend on the pulse with the greater speed."

- "When two waves meet (in phase) they will move like two cars with same mass and traveling at the same velocity. When they collide they will stop one another there and then."
- "Two pulses (crests) moving towards each other will collide and turn back to different directions with different amplitudes…"
- "Two equal crests moving in opposite directions cancel, because the direction of the one is positive and the direction of the other is negative. The resultant would be zero."
- When two single crests meet …." depending on their speed they are moving as they collide, they go in opposite directions with either the same amplitude or a greater one."

AC5: Waves are charges

Waves were seen as having positive and negative charges with repulsive or attractive forces - therefore, crests which are identical would have a repulsive effect on one another and move backwards. The following quotes of students reflected this alternative conception:

- "When two single pulses (crests) are moving in opposite directions towards each other along a rope, it is like bringing two positive charges together. They will repel each other even if the directions differ."
- "Identical pulses will repel. Therefore they will move in opposite directions."

AC6: Waves occupy space and exert forces

All kinds of properties of matter were associated with waves, e.g. that waves have mass and occupy space. A reference like "the force of the wave" instead of the "energy of the wave" contributes to this alternative conception that waves consist of matter.

From the quote: "Sea waves carry energy and sand to pull you away" it is clear that students associate waves with particles, e.g. water particles form the water wave and even additional particles like sand in the water, which exert (a pulling) force.

From the quote: "Waves carry both energy and matter, e.g. light waves carry photons of light as well as light energy" it is clear that a photon is associated with matter and not energy.

AC7: Amplitude is directly proportional to period

A shorter amplitude was associated with a shorter period. This is reflected in the following quote from one of the students: "The periods of the waves are not the same because their amplitudes are not the same. The wave with amplitude A has a period half the time than the wave with amplitude 2A, because it doesn't occupy a large space."

AC8: The Nature of Sound

The nature of waves, especially sound waves, was misunderstood. The properties of sound were confused with electromagnetic waves. In this regard, the alternative conception was that sound was more versatile, faster and stronger than light. Furthermore, The third alternative conception was that waves consisted of matter with mass, and therefore waves were moving particles. In particular, water waves were seen as particulate in nature – perhaps because of the visibility of water.

From the students' responses, two alternative conceptions were identified. The first was that sound was an electromagnetic wave. Therefore, sound and electromagnetic waves interfere. The second was that sound propagated easier, faster, stronger and was more flexible than light.

The following were quotes from students indicating the alternative conception around the nature of sound:

- "Sound is more flexible than light, light moves straight to the point, but sound can bend…"
- "Because sound is also an electromagnetic wave, the sound waves cause interference…"
- "Sound waves move with more ease than light waves."
- "Sound waves travel in different ways and take different paths. Light waves move from one point to another as directed by the source of the light."

AC9: The meaning of out of phase and in phase is confusing

In this study, the meaning of out of phase and in phase was not clear. The following quotes from students confirm this confusion:

- "Waves in phase will reinforce each other. Waves out of phase will not reinforce each other."
- "Two waves (nearly in phase) will have no effect on each other since they are moving with different speeds and they might strengthen each other's speed."
- "The two waves are traveling in the same direction, same amplitude, they are not in phase, and they won't reinforce or diminish each other."

AC10: The definitions of constructive and destructive interference

In this study, the definitions of constructive and destructive interference were not clear. This is also a result of the confusion of in phase and out of phase. Other identified alternative conceptions are also related. The following quotes from students confirm this confusion:

- "Constructive interference results when two identical waves having the same amplitude and frequency overlap."
- "Constructive interference is when two waves are moving in different directions…" (This illustrates AC4 as well.)
- "Destructive interference is the cancellation of two waves having the same phase which meet crest-to-trough." (This illustrates AC9 as well.)
- "Destructive interference results when two waves meet and the effect is lesser than the wavelength and amplitude of the individual wave." (This illustrates AC1 as well.)

DISCUSSION

Three of the identified alternative conceptions (AC1, AC2, AC3) related to the principle of superposition. Results from the questionnaire indicated that the superposition concept ranked by far the lowest in the familiarity of wave concepts, even lower than constructive and destructive interference. In the light that superposition is a fundamental concept to understand constructive and destructive interference, it is clear that the principles of constructivism, which contribute to meaningful learning, was not adhered to.

Three of the identified alternative conceptions (AC4, AC5, AC6) relate to the fact that students give physical properties of matter to waves: waves have mass, occupy space, are charged particles, and exert forces. This explains the alternative conception that waves collide and adhere to the law of conservation of momentum – destructive interference will occur when they meet in phase from different directions. Especially water waves are seen as particles which propagate, because of the visibility of the water wave. Two crests (or troughs) are seen as two "positive" (or "negative") waves which will have a repulsive force on one another, change direction and move backwards.

The nature and properties of waves are not well understood, according to two of the identified alternative conceptions (AC7, AC8). Sound is seen as an electromagnetic wave and sound is stronger, faster and more versatile than light. This is the explanation for the question on diffraction: "Why can you hear around an open door, but not see around the open door?". Basic properties of waves, involving specifically amplitude and period in this case, where amplitude and period are directly proportional, are totally misunderstood.

Textbook related confusion is clear from the last two identified alternative conceptions (AC9, AC10). The meaning of out of phase and in phase**,** as well as the definitions of constructive and destructive interference are treated and interpreted differently by literature reviewed. Although definitions are associated more with knowledge than understanding, it is worth mentioning them under possible alternative conceptions, because of the confusion it causes, e.g.:

- Out of phase: "Two waves are out of phase when their maximum, zero and minimum displacements are not at the same place." (Nolan, 1995:337). "Out of phase waves arrive a half-cycle out of step at a point." (Jones & Childers, 1993:422; Sears *et al*, 1991:508).
- Constructive and destructive interference are often explained and defined when identical waves are overlapping (Mulligan, 1991:288). Giancoli (1980:298) describes partial destructive interference and Halliday, Resnick and Walker (1993:496) describe fully constructive interference. Beiser (1986:290) describes complete and partial cancellation. According to Cutnell and Johnson (2004:488) two waves partially reinforce or partially cancel at locations where neither constructive nor destructive interference occurs. Sears *et al* (1991:891) associate constructive interference with reinforcement and Serway (1985:615) associates destructive interference with diminishment. From the above the question arises whether it is possible for waves with different amplitudes to experience constructive interference.

To date little research on students' ideas of physical optics has been done. Driver (1983) investigated the well known ripple tank experiment, which demonstrates wave patterns with water waves. A simple task with the ripple tank experiment is to observe the reflection of plane waves from a straight barrier. When the wave strikes the barrier at an angle, the wave pattern produced is quite complex. In recording their observations, some children showed the reflected wave at right angles to the incident wave for all angles of incidence. Coetzee (1998) did a comprehensive research on students' alternative ideas of interference and diffraction of light. The study revealed that there were many inconsistencies and contradictions in the way interference and diffraction were defined and treated in South African secondary level textbooks, as well as international tertiary level non-calculus textbooks – thereby leading to alternative conceptions amongst both students and teachers.

Examples of *in phase* and *out of phase*, as well as constructive and destructive interference, have already been discussed. Diffraction was defined as an interference effect (Cutnell, 2004:832) and as the bending or spreading out of light around obstacles or small openings (Cutnell & Johnson, 2004:831; Giancoli, 1980:299) – thereby possibly leading to the following alternative conceptions or confusions:

- Light does not diffract through a wide opening like an open door. Therefore Huygens' Principle is not understood as a continuous action that occurs at all wave fronts.
- Diffraction disobeys the rectilinear propagation of light.

At a practical level, ripple tank interference patterns on an overhead projector, projected on a vertical screen, could lead to alternative conceptions. The difference in the interpretation of the dark fringes produced by water waves, due to constructive interference of two troughs, in a shallow ripple tank (Heyns, de Villiers, Gibbon, Jordaan, Naidoo & Fowler, 1987:21) and the dark fringes produced by Young's double slit experiment, due to destructive interference of a crest and a trough, could be confusing. During secondary education, children meet interference patterns for the first time, usually illustrated with the ripple tank, in which the dark fringes represent the troughs. Interference of two troughs leads to constructive interference and is indicated by a dark fringe. At the tertiary level of education, students are confused when constructive interference is associated with the bright fringes of an interference pattern, due to the interference of two crests or two troughs of light waves (Nolan, 1995:338). Although many students in South Africa enter Higher Education from schools without electricity, where the ripple tank experiment cannot be done, the textbook illustrations are good enough for students to understand this experiment. Consequently, statements like these commonly found in school textbooks would need some attention and the use and interpretation of textbooks should be addressed. As already stated, in cases where students rely substantially on a single textbook in developing their understanding, misleading or inaccurate statements in textbooks may have a considerable impact on their conceptual understanding of the subject. Some students' understandings are incomplete because of misleading or inaccurate textbook treatments. The meaning ascribed to a textbook definition, depends on the interpretation of the author or the reader (Dall'Alba *et al*, 1993).

Constructive interference should be associated with reinforcement (Sears *et al*, 1991:891) and destructive interference should be associated with diminishment (Serway & Faughn, 1985:615) or partial or complete cancellation (Beiser, 1986:290), when waves meet. The meaning of *in* and *out of phase* should be cleared out.

Interference and diffraction are two phenomena which are not really different. The pattern that results from diffraction by a single slit is due to self-interference of light passing through the slit. In double-slit interference, the light is diffracted at each slit and the pattern describes both interference and diffraction at the same time (Giancoli, 1980:566,570; Jones & Childers, 1993:671).

One of the central tasks of the educator is to alleviate the alternative conceptions which are not in line with the intended learning. From the literature a view is expressed that every instructional intervention has conditions to make learning effective. In particular, Gagné (1977) summarizes nine instructional events to promote learning, which are applicable in any instructional situation. The sequence of these events is: gain attention, inform learner of objective (i.e. intended learning outcome), recall prior knowledge (i.e. making the relevant prior knowledge available to the learner), present material, provide guided learning, elicit performance (i.e. provide opportunity for the learner to try out /

practice the acts – in stages and/or as a whole, the competences that lead / amount to the expected goal), provide feedback, assess performance (i.e. assess the effectiveness of the teaching/learning process)and enhance retention and transfer.

Therefore, it is quite important to realize that one very important factor that can really make a difference to instruction are good teachers who practice intuitively many of the above stages in their teaching approaches. For the thousands of less intuitive educators the theory of constructivism may provide a successful way to improve their methods of instruction.

By using students' questions, comments, responses on tests and quizzes, and work at the 'board', it is possible to build models of their knowledge construction and conceptual development. To develop such models, interactions among students and lecturers have to occur openly. Accordingly, classrooms have to be student-centered (Wessel, 1999), thereby affording students an opportunity to freely express themselves regarding their understanding of the subject. Driver (1983) encourages that learners' thinking be probed in some detail, in order to investigate alternative conceptions. In certain instances, it is the reasons learners give for their answers, not necessarily the answers themselves that may be important.

Lecturers have to be aware of alternative conceptions and the complex network of interdependent concepts that students are usually expected to navigate. Students' ideas are not random bits of wrong information that can be simply exchanged for correct bits (Roth, 1990:156). It is very difficult for students to make sense of scientific explanations when these explanations are not part of their everyday life experiences.

RECOMMENDATION

Because there is much in common in students' alternative conceptions, documenting the identified alternative conceptions held by students could contribute to effective and meaningful learning. Accordingly, other researchers in this field are encouraged to contribute to this exercise by sharing their findings in future publications, or by communicating directly with the authors of this article.

CONCLUSION

Regarding the main results of the study, qualitative analysis revealed the following ten most prevalent alternative conceptions related to the interference and diffraction of waves amongst first-year university students: (a) superposition along x-axis; (b) interference being associated with reinforcement; (c) the "average" effect of interference; (d) waves have mass and collide according to the law of momentum; (e) waves are charges; (f) waves occupy space and exert forces; (g) amplitude as being directly proportional to period ; (h) the nature of sound; (i) the definitions of in phase and out of phase as well as (j) constructive and destructive interference.

To the extent that the main object of this study was to identify and document alternative conceptions held by first year students, this study has fulfilled its objective.

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APPENDIX

Table 1: Most Prevalent Alternative Conceptions

Symbol	ALTERNATIVE CONCEPTION	HIGHEST FREQUENCY PER QUESTION (n = 133)
AC1	**Superposition along x-axis**. Superposition results in an increased wavelength, and not necessarily a change in amplitude.	68
AC2	**Interference is associated with reinforcement**. Interference is associated only with constructive interference and not destructive interference as well.	68
AC3	**Interference is an average effect**. Identical waves have no effect on each other when they interfere.	21
AC4	**Waves have mass and collide according to the law of conservation of momentum.** Two identical waves cancel when they propagate from opposite directions – therefore, the direction in which a pulse is propagating, as well as the propagating velocities, will influence the interference pattern.	107
AC5	**Waves are charges.** Attractive and repulsive forces result.	2
AC6	**Waves occupy space and exert forces.** All kinds of properties of matter are associated with waves, like waves have mass, occupy space and exert a force.	41
AC7	**Amplitude is directly proportional to period.** A shorter amplitude is associated with a shorter period.	23
AC8	**The nature of sound**. Sound is an electromagnetic (em) wave. Sound propagates easier, faster, stronger and more flexible than light.	80
AC9	**The meaning of out of phase and in phase is confusing.** Only waves that were **in phase** would reinforce each other and that those **out of phase** would not.	55
AC10	**The definitions of constructive and destructive interference**	10 (determined after an appropriate intervention)