Students' conceptual knowledge of mechanical waves across different backgrounds and cultures

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Abstract: *In recent years physics education researchers have focused on students' conceptual understanding, and many research papers have reported on students' alternative conceptions. Subsequently teaching strategies specifically designed to change students' conceptions to those which are scientifically accepted have been successfully implemented. A claim made in most of these research papers is that the ordinary kinds of teaching are, in general, not effective in improving conceptual understanding (Hake 1998).*

This project aims to test conceptual understanding in a cross-section of students across several years from high school to second year university levels. A conceptual survey in mechanical waves was developed and administered to seven different groups of students; 54 Australian high school, 270 Thai high school, 123 first year university non-major physics, 287 first year university regular physics, 69 first year university advanced physics, 48 second year university regular physics and 51 second year university advanced physics students. The results show that the level of student conceptual understanding depends directly on their level of previous engagement with physics learning. The more previous engagement they have had, the more conceptual understanding they demonstrate, irrespective of the kinds of teaching they have been exposed to.

Keywords: mechanical waves, conceptual survey, physics education, conceptual understanding, misconceptions

Introduction

Measuring and improving conceptual understanding has been a major goal in physics education research in recent years. Many research studies have reported that students enter the classrooms with their own conceptions which often conflict with currently accepted scientific ideas (eg Hewson and Hewson 1983; Roald and Mikalsen 2000; Tytler 2000; Voska and Heikkinen 2000). Students' understanding of basic concepts influences greatly how they will cope with higher level material when they meet it, therefore probing students' prior knowledge at introductory levels is necessary for teachers to prepare effective instruction. There are several ways of doing this, for instance one-on-one interviews or open-ended questionnaires. For large numbers of students, it is more efficient to use specially designed multiple-choice surveys because they are easier to administer and analyse. Many such have been developed and used for evaluating teaching strategies (e.g. Hestenes and Wells 1992; Thornton and Sokoloff, 1998; Wuttiprom, Sharma, Johnston, Chitaree and Soankwan 2007). Specific teaching strategies labeled 'interactive engagement' have been developed; see for instance Interactive Lecture Demonstrations (ILDs) (Thornton and Sokoloff 1997), Peer Instruction (Mazur 1997), and Just-in-Time Teaching (JiTT) (Novak, Patterson, Gavrin and Christian 1999). In a study involving 6000 students, Hake (1998) claimed that the interactive engagement strategies resulted in pronounced improvement in conceptual understanding of mechanics as measured by the Force Concept Inventory (Hestenes and Wells 1992). His data also indicated that the ordinary kinds of teaching **do not**, in general, result in pronounced improvement of conceptual understanding, a conclusion with which many researchers would agree.

Our study focused on trying to understand the trends in the development of conceptual knowledge without reference to the kinds of teaching students have been exposed to. We surveyed students' conceptual knowledge of mechanical waves, looking at groups of students with different previous engagement with physics learning and from different cultures. The phrase ‘previous engagement with physics learning’ refers largely to whether students are in different years of study or in different streams within a year of study.

Purposes of the study

Our study aims to answer the following questions:

- How does the conceptual knowledge of mechanical waves vary amongst groups of students with different previous engagement with physics learning?
- Are there significant differences in the conceptual understanding of the various subtopics of mechanical waves for these groups of students?

Methodology

Instrument

A multiple-choice conceptual survey called the Mechanical Wave Conceptual Survey (MWCS) was developed for this project, and is described elsewhere (Tongchai, Sharma, Johnston, Arayathanitkul and Soankwan 2008). The MWCS consists of 22 multiple-choice questions related to four subtopics: eight questions on propagation, four on superposition, four on reflection and six on standing waves. It takes about 30 minutes to take the survey.

Consider the following description and answer questions 2 - 3.
*Students **X** and **Y** are standing 50 meters apart and yell “Yo!” at each other at exactly the same time.*

___ ***2)*** *They yell at each other with the same loudness, but **Y** yells with a higher pitch than **X** does. Who will hear the other’s sound first?*

A. *They will hear each other at exactly the same time because the speed of sound waves depends on the properties of the air.*
B. ***X*** *will hear the sound first because the speed of sound waves depends on frequency according to* $v = f\lambda$.
C. *They will hear each other at exactly the same time because the speed of sound waves depends on amplitude.*
D. ***X*** *will hear the sound first because sound with a higher frequency is more penetrating.*

___ ***3)*** *Student **Y** yells louder than **X**, but they yell at each other with the same pitch. Who will hear the other’s sound first?*

A. ***X*** *will hear the sound first because the speed of the waves depends on the amplitude of the sound.*
B. *They will hear each other at exactly the same time because the speed of the waves depends on the frequency according to* $v = f\lambda$.
C. *They will hear each other at exactly the same time because the speed of the waves depends on the properties of the air.*
D. ***X*** *will hear the sound first because the wave with the larger amplitude travels further.*

Figure 1. Examples of the survey questions

Participants

The MWCS was administered to seven groups of students from both high school and university. Descriptions of students from each group are as follows.

1. *First year non-major physics students* (1st Non-major): These students had not studied physics in senior high school and they took the survey during their first week of university studies in 2008.
2. *Sydney high school students* (Syd-High): These were physics students from senior high schools in Sydney, who took the survey in the last term of 2007.
3. *Thai high school students* (Thai-High): These were physics students from senior high schools in Bangkok, who took the survey in January 2008.
4. *First year university regular physics students* (1st Reg): These students had studied senior high school physics, and in terms of overall high school academic achievement they were ranked in the top 5% to 16% in the state of NSW, Australia. They took the survey during their first week of university studies in 2008.
5. *Second year university regular physics students* (2nd Reg): These students had completed first year physics courses at the University of Sydney and majority of them had completed regular physics courses in 2007. They took the survey during their first week of university studies in 2008.
6. *First year university advanced physics students* (1st Adv): These students had studied senior high school physics, and in terms of overall high school academic achievement they were ranked in the top 4% in the state of NSW, Australia. They took the survey during their first week of university studies in 2008.
7. *Second year university advanced physics students* (2nd Adv): These students had completed first year advanced physics courses at the University of Sydney in 2007. They took the survey during their first week of university studies in 2008.

A summary of which topics in mechanical waves students had studied before completing the survey is shown in the table below. Teaching methods being used in the classrooms were not examined.

Table 1. Subtopics in mechanical waves which each group had covered before completing the survey

Groups	n	Mechanical waves subtopics			
		propagation	superposition	reflection	Standing waves
1st Non-major	123	-	-	-	-
Syd-High	54	√	√	√	-
Thai-High	270	√	√	√	√
1st Reg	287	√	√	√	-
2nd Reg	48	√	√	√	√
1st Adv	69	√	√	√	-
2nd Adv	51	√	√	√	√

When comparing the levels of ‘previous engagement with physics learning’, we rank the three different years of study thus: senior high school, first year university and second year university, in that order. Within first year university we again have three groupings: those who have not done senior high school physics, and amongst those who have done the subject we differentiate between the good (regular) and the high (advanced) academic achievers. In general, the high achieving advanced students have considerably more mathematics background and inherent interest in the sciences – many will have participated in Physics Olympiads and similar extra-curricular experiences. We believe that they should probably be ranked higher than the second year regular students.

Results and discussion

To measure students' conceptual understanding of mechanical waves we divided the number of students who answered a single question correctly by the total number of students who attempted the question. This measure is conventionally called the difficulty index (*P*). Since a higher value means more students answered correctly, it might be more appropriate to think of this measure as the easiness index. Conventionally, the desired value of P is in the range of $0.2 \le P \le 0.8$. If *P* is more than 0.8 then the question is too easy for discriminating between students, and if P is less than 0.2 then the question is too difficult (Ding 2006).

For this study we have averaged the difficulty indices of the 22 questions in the survey, generating the mean difficulty index ($\bar{P}$), which indicates how well each particular group of students did on the survey. Figure 2 shows the mean difficulty index for each group. The clear trend is that students with higher levels of previous engagement with physics learning show more conceptual understanding of mechanical waves.

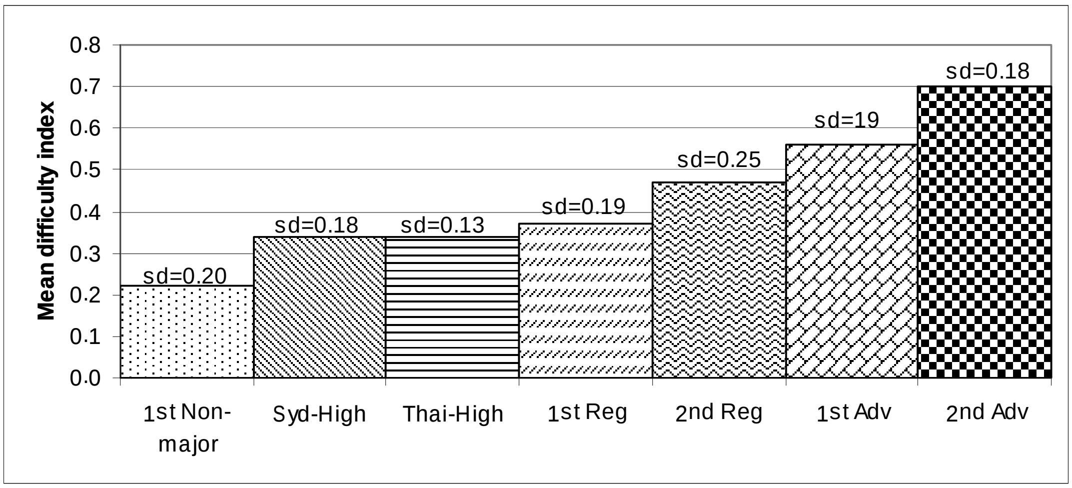

Figure 2. Mean difficulty index ($\bar{P}$) across different groups of students

From this data we note the following.

1. At university, for either regular or advanced students, second years score more highly than first years. However the first year advanced students scored higher than the second year regulars, which seems to justify, *a posteriori*, our ranking with regards to previous engagement with physics learning.
2. The first year non-major students, not having studied physics in high school, have, as would be expected, very low scores – scores which are not significantly different from random guessing.
3. The high school students, both Thai and Australian, achieved the same scores (within limits of significance).

Since the survey consists of four subtopics, we measured the mean difficulty index of each subtopic by averaging difficulty indices of all questions in the same subtopic. The results are shown in table 2.

Table 2. Mean difficulty indices ($\bar{P}$) for each subtopic across different groups
Shading criteria: 0 - 0.29 | 0.30 - 0.54 | 0.55 - 1

Subtopics	1st Non-major	Syd-High	Thai-High	1st Reg	2nd Reg	1st Adv	2nd Adv
	n=123	n=54	N=270	n=287	n=48	n=69	n=51
propagation	0.25	0.45	0.28	0.46	0.56	0.74	0.8
superposition	0.28	0.48	0.48	0.51	0.66	0.73	0.84
reflection	0.17	0.22	0.44	0.24	0.37	0.36	0.57
standing waves	0.18	0.18	0.23	0.25	0.30	0.36	0.55
Mean	**0.22**	**0.33**	**0.36**	**0.36**	**0.47**	**0.55**	**0.69**

These results show that students with different backgrounds in physics learning do indeed understand each subtopic differently. We draw attention to the following.

1. The trends in the shading show clearly that the level of each group's understanding across all subtopics depends on their previous engagement with physics. And it is clear that the later subtopics are conceptually more difficult than the earlier, and are not really mastered until second year.
2. The two groups of high school students, had the same average level of conceptual understanding, yet differ in which subtopics they understood best. Sydney students understand propagation better than Thai students, while the Thai students did better with reflection. However both groups had the same mean difficulty index for the easiest subtopic, superposition. An examination of the syllabuses from which they were taught shows that both groups had covered these topics. The data therefore suggests that different subtopics are particularly challenging for the different cultures, which need to be explored more in the future.

Conclusion

We have reported that the average level of students' conceptual knowledge in mechanical waves depends directly on their previous level of engagement with physics learning. It is worth noting that the Australian students involved in this project came from high schools all over the state of New South Wales. No effort was made to ascertain what sort of teaching they had experienced. The only two groups for which there were clear cultural differences, but who had similar levels of engagement with the subject, were the Thai and Sydney high school students. These students differed in how they understood the various subtopics of the subject, but nonetheless demonstrated very similar average levels of understanding. This suggests that a more general observation may be made, namely that students with more engagements with physics learning have greater conceptual understanding regardless of the kinds of teaching they have experienced

Our study is a reminder that there is a group of students who achieve sound conceptual knowledge quite early on, like the first year advanced students. There are others who progress gradually as their experiences in physics learning progresses irrespective of the kinds of teaching they have been exposed to. The data in Hake (1998) is often interpreted to mean that ordinary kinds of teaching do not improve students' conceptual knowledge as much as expected. Our data does not discount the possibility that conceptual development could be accelerated by interactive engagement strategies, but suggests that there is a progressive development regardless.

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