Consistency of students' conceptions about superposition and reflection of waves: findings from the development of a conceptual survey in Mechanical Waves

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Abstract

A multiple choice conceptual survey in mechanical waves was developed and evaluated with over 900 students (Tongchai et al., 2008). The survey consists of four subtopics: propagation, superposition, reflection and standing waves. In this study, we explored students' responses to the questions on the subtopics of superposition and reflection only. The objectives of this study were (1) to explore the consistency of students' conceptions, and (2) to explore the usefulness of the correlation coefficient for dichotomous data (Φ). The samples were five different groups of students with a total number of 509. Our findings support studies found in the literature in which students often use their conceptions inconsistently. Moreover, we found that the correlation coefficient for dichotomous data is useful for measuring the strength of the association between question pairs, however it has some issues which researchers need to be aware of when using it for a particular purpose.

Introduction

During the last three decades studies in science education have revealed that many students have difficulty with conceptual understanding which is important for understanding advanced topics. Moreover, many research studies have reported that students' responses to a series of questions testing the same idea are not consistent (e.g. Clough & Driver, 1986; Finegold & Gorsky, 1991; Palmer, 1992; Warnakulasooriya & Bao, 2003; Saglam & Millar, 2006). Thus suggesting that students' understanding of a particular concept is not consistent − it may depend on the context of the questions.

In our study, we have investigated the consistency of students' responses when trying to solve question pairs testing the same idea by using a statistical analysis technique, the correlation coefficient for dichotomous data (Φ).

Purpose of the study

- To investigate consistency of students' conceptions when trying to solve question pairs testing the same idea on the subtopics of superposition and reflection.
- To explore the usefulness of a statistical analysis technique, the correlation coefficient for dichotomous data (Φ).

Method

Instrument

The instrument was the Mechanical Waves Conceptual Survey (MWCS) (Tongchai, et al., 2008) which we developed recently. The survey has been trialled with over 900 students from high school to second year university. Development procedures and evaluation of the survey can be found in Tongchai et al. (2008). The survey consists of four subtopics: propagation, superposition, reflection and standing waves. Each subtopic has several questions. The full survey can be viewed at http://www.physics.usyd.edu.au/super/mwcs/mwcs.pdf. In this study, we explored students' responses to the subtopics of superposition (questions 9, 10, 11 and 12) and reflection (questions 13, 14, 15 and 16).

Participants

The participants were five different groups of students from the state of New South Wales, Australia as listed below.

1. Sydney-High school students (SydHigh): These were senior high school physics students in Sydney.
2. First year university regular physics students (1stReg): These students had studied senior high school physics, and in terms of overall high school academic achievement were ranked in the top 5% to 16% in the state of New South Wales.
3. Second year university regular physics students (2ndReg): These students had completed first year physics courses at the University of Sydney and majority of them had completed regular physics courses in 2007.
4. First year university advanced physics students (1stAdv): These students had studied senior high school physics, and in terms of overall high school academic achievement were ranked in the top 4% in the state of New South Wales.
5. Second year university advanced physics students (2ndAdv): These students had completed first year advanced physics courses at the University of Sydney in 2007.

Students groups were sorted according to the quantity of formal instruction in physics they have had. However, even with the same quantity of formal instruction, the advanced groups have had a better quality of learning experience – advanced students have considerably more mathematics background, inherent interest in the sciences and many will have participated in Physics Olympiads and similar extra-curricular experiences. Hence we have chosen to use the phrase 'previous engagement with physics learning' to refer to the mix of quantity and

quality of experiences with physics. Therefore, the groups of students are ranked as above.

Data analysis

The correlation coefficient for dichotomous data (Φ) was used to investigate the consistency of students' responses to question pairs. The correlation coefficient Φ has been widely used in the social science (e.g., Heller & Huffman, 1995; McCartney & Rosenthal, 2000; Saglam & Millar, 2006; Howell, 2006). A brief description of Φ is provided below (for more detail, see Howell, 2006).

Consider a study where students' responses to two multiple–choice questions testing the same idea are recorded. Table 1 shows the resulting contingency table.

Table 1. Contingency table of students' responses to Q1 and Q2

		Q1		
		Correct	Wrong	Total
Q2	Correct	cc	wc	*cc+wc*
	Wrong	cw	ww	*cw+ww*
	Total	*cc+cw*	*wc+ww*	n

Note: cc = correct both Q1 and Q2, ww = wrong both Q1and Q2, cw = Q1 correct and Q2 wrong, wc = Q1 wrong and Q2 correct, n = sample size

According to the data shown in Table 1, the correlation coefficient of dichotomous data (Φ) is calculated using equation 1 (Guildford, 1965).

$$\Phi = \frac{(cc \times ww) - (wc \times cw)}{\sqrt{(cc + cw) \cdot (wc + ww) \cdot (cw + ww) \cdot (cc + wc)}} \quad \text{Equation (1)}$$

The quantity Φ indicates the strength of the association between the two questions. In general, Φ ranges from -1 to +1. A positive or negative Φ denotes whether the product of the number of students who have either both correct or wrong is larger or smaller than that for having one correct and one wrong. This is counterintuitive as one is tempted to simply consider sums. A value of Φ close to zero indicates that responses to the two questions are less correlated. A value of Φ close to +1 indicates that responses to the two questions are highly correlated.

For two questions testing the same idea, we would expect a student's responses to both questions to be consistent; i.e., if a student understands the concept, he or she would answer both questions correctly, and if a student does not understand the concept, he or she would answer both questions incorrectly. If a student has an inconsistent concept, he or she may answer the two questions using different ideas, thus resulting as correct on the first question and wrong on the other. If a student has inconsistent responses, it suggests that the student does not view both situations as similar, or suggests that the student's responses might depend on the context of the questions. According to Table 1, "cc" and "ww" are considered as

consistent responses, while "cw" and "wc" are considered as inconsistent responses.

Results and discussion

Results of Superposition

Table 2 shows patterns of students' responses to the question pairs on the concept of superposition. Questions 9 and 11 are testing students' understanding of wave superposition while two pulses are overlapping. The percentage of correct responses to both questions (cc) increases as the previous engagement with physics learning increases, while the percentage of wrong responses to both questions (ww) decreases. This might suggest that students with high previous engagement with physics learning have more consistent correct concept than students with less previous engagement with physics learning. When looking at the trend of the quantity Φ, the trend is not readily identifiable; i.e., the trend seems to increase as the previous engagement increases, except for second year regular students whose responses spread out over the available cells, resulting in a small Φ value. The Φ values of all groups for this question pair suggest that students sometimes answer one question differently to the other, indicating that these two situations are, sometimes, differently understood by the students.

For questions 10 and 12, which are about the situation where two pulses have passed through one another, the trend of patterns of students' responses is similar to the previous pairs, questions 9 and 11, however these questions are seemingly easier for many students. Furthermore, the Φ values are increasing as the previous engagement with physics learning increases. Most of the Φ values are significantly high, indicating that the two questions are highly correlated. Students' responses to these questions are likely to be consistent as shown by high values in column "cc" and "ww" in Table 2.

Table 2. Patterns of students' responses to question pairs on the subtopic of superposition

Sample	n	cc (%)	cw (%)	wc (%)	ww (%)	Φ
Q9-11: while two pulses are overlapping						
SydHigh	54	19	15	26	41	0.16
1stReg	287	25	14	19	41	0.32**
2ndReg	48	27	21	21	31	0.17
1stAdv	69	49	16	14	20	0.34**
2ndAdv	51	57	16	12	16	0.34*
Q10-12: while two pulses have passed through one another						
SydHigh	54	50	9	6	35	0.70**
1stReg	287	48	22	4	26	0.52**
2ndReg	48	79	8	2	10	0.63**
1stAdv	69	77	9	0	14	0.75**

2ndAdv	51	94	6	0	0	#DIV/0!

Note: c = correct, w = wrong. *$p < 0.05$, **$p < 0.01$, and shading highlights the trend of percentage responses

Results of Reflection

Table 3 shows the results of the reflection subtopic. For this particular subtopic, it is apparently clear that the trends of correct and wrong responses to both questions depend on students' previous engagement with physics learning. However, the quantity Φ of both question pairs changes unevenly, in fact it seems to change irrespective of students' previous engagement.

When looking at the patterns of students' responses to both question pairs, we can see that students' responses spread out over available patterns, suggesting that students mostly view the two questions different from one another. This might also suggest that students' understanding of these two questions depends on the context of the questions.

Table 3. Results of students' responses to questions pairs on the reflection subtopic

Q13-14: Reflection after the pulse has finished bouncing the pole						
Sample	**n**	**cc (%)**	**cw (%)**	**wc (%)**	**ww (%)**	**Φ**
SydHigh	54	2	28	9	61	-0.10
1stReg	287	9	23	6	62	0.26**
2ndReg	48	19	21	10	50	0.32*
1stAdv	69	22	19	4	55	0.52**
2ndAdv	51	55	18	10	18	0.37**
Q15-16: Reflection while the pulse is bouncing the pulse						
SydHigh	54	4	17	22	57	-0.09
1stReg	287	9	11	19	61	0.18**
2ndReg	48	21	19	17	44	0.25
1stAdv	69	17	29	12	42	0.17
2ndAdv	51	31	24	4	41	0.50**

Note: c = correct, w = wrong. *$p < 0.05$, **$p < 0.01$, and shading highlights the trend of percentage responses

The trend of Φ values is not clear, it seems to change unevenly. Furthermore, it does not provide insight into how consistent students' responses are. To see whether students' responses are consistent, we still need to look at the patterns of students' responses in the table. In fact, this issue has been controversial, see for example, Heller and Huffman (1995), Halloun and Hestenes (n.d.). Moreover, Guilford (1965) has reported that the size of the Φ value also has limitations; i.e., Φ can vary over a range within the limits -1 to +1, but only under certain condition can Φ be as large as either of these extremes. Therefore, researchers

need to be aware of such matters when using this kind of statistical method for a particular purpose.

Conclusion

We have investigated students' consistency of their answers when trying to solve question pairs testing the same idea on the subtopics of superposition and reflection. We used the correlation coefficient for dichotomous data (Φ) to measure the consistency of students' responses. Our findings show that students often use their conceptions inconsistently. This might suggest that students' answers depend on the context of the questions, however we still need to explore this in the future. This finding supports many research studies found in literature, e.g. Clough and Driver (1986), Saglam and Millar (2006), Palmer (1992).

Further, we found that the Φ values change unevenly; i.e., they change irrespective of students' previous engagement with physics learning. It is clear that the quantity Φ tells us about the association of students' responses, but it does not tell us about the consistency of students' responses. Perhaps, exploring consistency of students' responses to a multiple-choice survey could be done by some other methods, for instant, Model Analysis (Bao, 1999).

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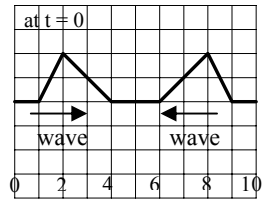
Appendix: Examples of the questions used in this study

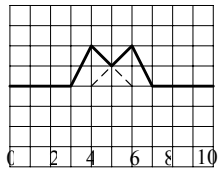
Superposition:

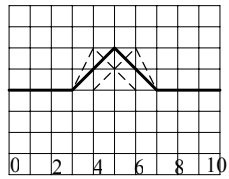
Consider the following description and answer questions 9-10.

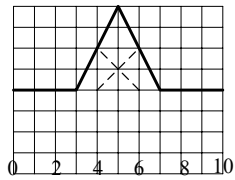
Two pulses are moving towards each other. Each pulse has a speed of 1 cm/s. The figure on the right shows the pulses at time t = 0 s. Each square width corresponds to 1 cm x 1cm. The dashed lines indicate the correct positions of the individual pulses after 2 s.

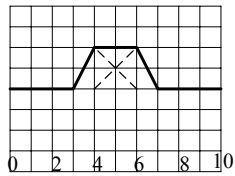


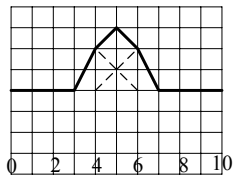
9) Select the drawing that corresponds to the shape of the resultant pulse after **2 s**.

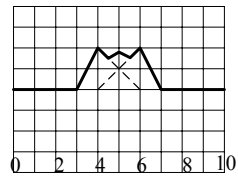
A.


B.


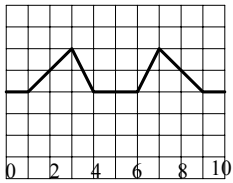
C.


D.


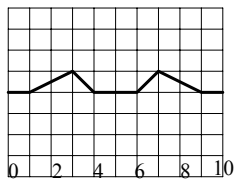
E.


F.


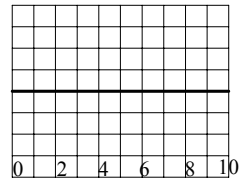
10) Select the drawing and explanation that corresponds to the shape of the resultant pulse after **5** s.



A. Waves have passed through one another and retained their shapes.



B. Waves have become smaller because they have collided and so lost energy.

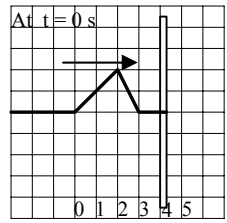


C. Waves have cancelled each other.

Reflection:

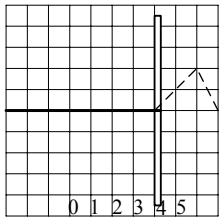
Consider the following description and answer questions 13-14.

A girl is demonstrating wave motion on a string attached to a pole. The string can be either ***firmly*** attached so that the end cannot move or tied to a ring that can move ***loosely*** up and down on the pole. The girl flicks the string creating an ***asymmetric*** pulse moving towards the pole. The pulse has a speed of 1 cm/s. Each square in the figure corresponds to 1 cm x 1 cm. The

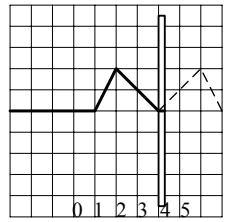


For questions 13 and 14, choose the drawing from **A** through **E** which best answers each question.

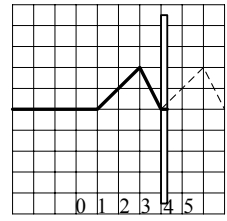
A



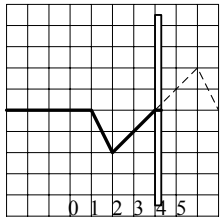
B



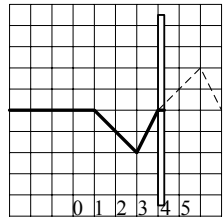
C



D



E



___ **13)** Select the drawing that corresponds to the shape of the resultant pulse after **4 s**, assuming the string is ***firmly*** attached to the pole.

___ **14)** Select the drawing that corresponds to the shape of the resultant pulse after **4 s**, assuming the string is tied to a ring that can move ***loosely*** up and down on the pole.