Consistency of students' conceptions: an important issue in assessing students' conceptions

Dr. Apisit Tongchai
The Institute for The Promotion of Teaching Science and Technology, Thailand
apisit5@hotmail.com, atong@ipst.ac.th

Abstract
Assessing students' conceptions is an important process in classroom learning. To assess students' conceptions, we can use various methods, for instance, interviews, open-ended questions, multiple-choice questions, etc. Different methods have different advantages and disadvantages. The multiple-choice test is an assessment technique frequently used in measuring students' conceptions because it is convenient to analyze and it is more affordable for testing a large number of students. Traditionally, for a multiple-choice test, different test questions measure different concepts, so students answer each question independently. However, many research studies showed that a lot of students lacked of consistency of using their own conceptions, meaning that they answer several questions testing the same concept differently from one another. This suggests that students do not really understand the concept. It is important for teachers to assess students' consistency in using their own conceptions in order to achieve learning goals. But, how can we do that? In this paper, we present various methods used in measuring the consistency of students' conceptions. We also present examples of measuring the consistency of students' conceptions as well as the results from our studies. Implications for classroom using will also be presented.

Keywords: Consistency, Multiple-choice test, Conceptual survey

Introduction

During the last three decades science educators have revealed that a lot of students have difficulty in conceptual understandings which are important for them to understand the subject at advanced levels. 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). These studies indicated that students' understandings of a concept in different contexts are different from one another. These findings also suggested that students do not really understand the concept.

In this paper, some useful methods generally used in measuring consistency of students' conceptions will be presented. Examples of findings from using these methods will be explained. Implications for classroom practice will also be provided.

Purposes of the study

1. To introduce some useful methods for measuring the consistency of students' conceptions – counting and categorizing, and Model analysis.
2. To investigate the usefulness of these methods.

Consistency of Student conception

Consistency of students' conceptions in this paper is referred to the idea that "a student is considered to have a consistent conception only if he or she answers two or more different questions testing the same concept correctly, although these questions have different contexts. But, if the student answers these questions differently from one another, he or she is considered to have an inconsistent conception". In general, the consistency of students' conceptions can be revealed by using various methods. Perhaps, interviews could be an effective technique, but it is time consuming to do so, especially with a large classroom. An affordable method that could be used in measuring the consistency of students' conceptions is to look into students' responses to multiple choice questions. There are a few methods which are usually used in analyzing students' responses to multiple choice questions. In this paper two methods; counting and categorizing, and Model analysis, are presented.

Methods for measuring the consistency of student conception

1. Counting and categorizing

This technique effectively makes the idealization that each student either:

(1) understands the concept completely (i.e. holds the orthodox conception);
(2) holds some other alternative conception; or
(3) does not understand at all, but seems to be guessing the answers.

Each of these is characterized by a specific pattern of responses to the survey questions. If any one student can be unambiguously put into one of these three classifications, on the basis of his/her pattern of answers, he/she might then be considered to be using their understanding completely consistently.

Palmer (1993) used eight multiple-choice questions testing the same concept, but in different contexts. He categorized whether students were using the correct concept or the predominant alternative conception "motion-implies-force". He then counted the number of students who used the correct conception on all eight questions, or seven questions and so on , while the number of students who invoked "motion-implies-force" were also counted on all eight questions, or seven questions and so on. The resulting table then illustrated how consistently students used either the correct conception or the predominant alternative conception. Licht and Thijs (1990) used a similar technique in two topic areas, force and electricity, allowing for several alternative conceptions depending on the contexts of the questions. This method was used in analyzing our data. The finding from using this technique will be presented in the next section.

2. Model analysis

This approach is based on the idea that when a student answers one of the questions on the test, they draw upon a knowledge schema or conceptual model. In many cases it is possible to identify which models students are using when they answer individual questions. Model Analysis does not concentrate on whether a student answer is correct or not; it is only interested in which model they are using. A brief description of Model Analysis is provided here. (For more details see: Bao & Redish, 2006)

It often happens that students' responses to a set of questions testing the same concept can be categorized into three distinct groups: (1) those employing the scientifically accepted model, (2) those employing some commonly held alternative model and (3) those using no structured model, or just guessing. Consider a set of multiple-choice questions (total number *m*), where each choice of each question can be assigned to one or other of these three "models". The response of any one student to the set of questions can be specified by a set of three numbers, which can be written as

$$n_1^k, n_2^k, n_3^k$$

where *k* is an index denoting which student it is (out of a total number *N*). Clearly, assuming that the student answered all questions in the set,

$$n_1^k + n_2^k + n_3^k = m.$$

By way of interpretation, if $n_1^k = m$ and $n_2^k = n_3^k = 0$, the kth student has answered all questions using the scientifically accepted conception (model 1). Likewise if $n_2^k = m$, that student has used model 2 (the commonly held alternative conception). And if $n_3^k = m$, the student seems not to have used any structured mental model at all (model 3). But at least, in each of these examples, the student has answered consistently. On the other hand, if any two of these numbers are non-zero, the student has not been consistent. For instance, if $n_1^k \times n_2^k \neq 0$, the student is demonstrating confusion between models 1 and 2, sometimes using one and sometimes the other.

A difficulty faced by many workers in this field is to find a representation to display these data in such a way that the interpretations described above are easy to see. The representation proposed by Bao (1999) borrows from the formalism of Quantum Statistical Mechanics. Using the three numbers, n_1^k, n_2^k, n_3^k, it constructs a (3×3) matrix, defined by,

$$D_k = \frac{1}{m}\begin{pmatrix} n_1^k & \sqrt{n_1^k n_2^k} & \sqrt{n_1^k n_3^k} \\ \sqrt{n_2^k n_1^k} & n_2^k & \sqrt{n_2^k n_3^k} \\ \sqrt{n_3^k n_1^k} & \sqrt{n_3^k n_2^k} & n_3^k \end{pmatrix} \quad \text{Equation 1}$$

This matrix represents a single student's model state; i.e., how the pattern of the student's responses to all questions spreads out over the three models. It is known as a single student model density matrix. It must be stressed that this definition contains no more information than is contained in the original three numbers themselves, which can be seen to lie along the main diagonal of the matrix. What it does do, however, is to make explicit any confusion between models, which is shown by the presence of off-diagonal elements.

The power of this representation is seen when we attempt to determine an average response to the set of questions for all students. We simply sum over all single student responses (and normalize) to obtain the model density matrix of the class.

$$D = \frac{1}{N}\sum_{k=1}^{N} D_k = \frac{1}{N\cdot m}\sum_{k=1}^{N}\begin{pmatrix} n_1^k & \sqrt{n_1^k n_2^k} & \sqrt{n_1^k n_3^k} \\ \sqrt{n_2^k n_1^k} & n_2^k & \sqrt{n_2^k n_3^k} \\ \sqrt{n_3^k n_1^k} & \sqrt{n_3^k n_2^k} & n_3^k \end{pmatrix} \quad \text{Equation 2}$$

Each element of the class model density matrix represents different aspects of the students' understanding. The diagonal elements (which range from 0 to 1) represent the average number of responses which drew upon each of the three models. The off–diagonal elements (ranging from 0 to 0.5) tell us whether or not the students drew upon those models consistently (on average) or whether they jumped around between models.

As a brief guide to interpretation, consider the following hypothetical class model density matrices.

$$\mathrm{D_I} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \quad \mathrm{D_{II}} = \begin{pmatrix} 0.5 & 0 & 0 \\ 0 & 0.3 & 0 \\ 0 & 0 & 0.2 \end{pmatrix} \quad \mathrm{D_{III}} = \begin{pmatrix} 0.5 & 0.2 & 0.1 \\ 0.2 & 0.3 & 0.1 \\ 0.1 & 0.1 & 0.2 \end{pmatrix}$$

$\mathrm{D_I}$ shows that all students in the class answered all questions using model 1. $\mathrm{D_{II}}$ shows that 50% of the class used model 1 consistently, 30% used model 2 consistently and 20% used model 3 consistently. $\mathrm{D_{III}}$ shows that students answered using all models inconsistently; i.e., they sometimes used model 1, sometimes model 2 and sometimes model 3. A comparison of $\mathrm{D_{II}}$ and $\mathrm{D_{III}}$ shows the key feature of the representation. In both cases, the average numbers for each model are the same (the diagonal elements), but the responses were consistent in $\mathrm{D_{II}}$ and inconsistent in $\mathrm{D_{III}}$.

Instrument and Data obtaining

The two methods explained above were used to analyze student conceptions. The data were obtained by using a conceptual survey called Mechanical Waves Conceptual Survey (MWCS) (Tongchai et al, 2009) to investigate student conceptions. The survey can be downloaded at http://www.physics.usyd.edu.au/super/mwcs/mwcs.pdf. In this paper we focus only on the responses to the seven questions concerned with wave propagation. Table I shows the concepts covered.

TABLE I. Concepts covered in the survey on the subtopic of propagation

Question	Concept
2, 3	Speed of sound waves
4, 5	Speed of waves on strings
6, 7, 8	Displacement of medium

Participants

The participants were seven different groups of students. They ranged from high schools both in Australia and Thailand; through three levels of first year university, fundamental, regular and advanced; to second year university. A brief overview is provided in Table II.

TABLE II. Summary of participants

Rank	Groups	n	Descriptions
1	1stFund	123	First year fundamental physics students at a university in Australia.
2	SydHigh	54	Australian senior high school students in Sydney.
3	ThaiHigh	270	Thai senior high school students in Bangkok.
4	1stReg	287	First year regular physics students at a university in Australia.
5	2ndReg	48	Second year regular physics students at a university in Australia.
6	1stAdv	69	First year advanced physics students at a university in Australia.
7	2ndAdv	51	Second year advanced physics students at a university in Australia.

The groups of students were ranked not only according to the number of years of formal studies they had done, but also taking account of other kinds of informal instruction in physics they might have experienced (like Physics-Olympiad involvement, special projects and so on). We chose to use the phrase ‘previous engagement with physics learning’ to refer to this mix of quantity and quality of education. From this perspective we ranked the groups of students as in Table II.

Results and discussion

1. Categorizing and counting

1.1 Speed of sound waves in air

Students’ responses to questions 2 and 3 on the speed of sound waves were placed into the three categories described below.

- Complete understanding (CU): The answers to both questions demonstrate that the speed of sound waves depends on the properties of the air, a consistent and correct response.
- Common alternative conception (CA): The answers to both questions demonstrate that the speed of sound waves depends on their frequency, a consistent but incorrect response. This is the predominant common alternative conception.
- Other ideas or guessing (OG): The answers are not from the patterns above. Students' responses reflect a diverse range of alternative conceptions and there is no consistency between the answers to the two questions.

The percentages of students' responses in each category were counted and plotted against previous engagement with physics learning (ranked as in Table II) as shown in Figure 1. As students' previous engagement increases, we note that the percentage of students in the category complete understanding, which represents consistently correct responses, increases to about 80 – 90 %. (There are some fluctuations about the general trend but we do not consider these to be significant.) Remember that the later year students would not have explicitly studied this material for several semesters. Therefore there seems to be a suggestion that deeper understanding of mechanical waves occurs as students cover a range of related subjects like quantum mechanics and electromagnetism. On the other hand, the common alternative conception persists at about 25% and then reduces quite sharply. The main switch going from novices to more experienced groups appears to be from other ideas (OG) to complete understanding (CU).

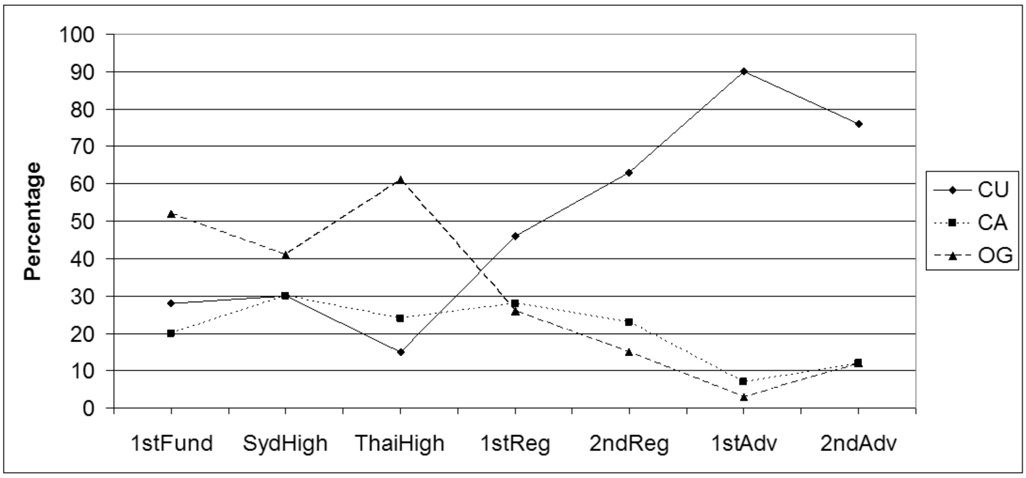

FIG. 1. The percentages of students' responses obtained using the categorizing and counting technique is plotted against previous engagement with physics learning (ranked as in Table II) for questions 2 and 3 on the speed of sound

1.2 The concept of the speed of waves on strings

Questions 4 and 5 are about the speed of wave pulses traveling along strings. The scientifically accepted concept is that the speed of waves depends on the properties of the string only. The common alternative conception was that the speed of waves on strings depends on frequency. Results using the same set of categories (CU, CA and OG) are shown in Figure 2.

This pair of questions seems to be more difficult than the previous pair, resulting in a very different looking graph. The Complete Understanding group is very small at the start. It rises steadily as previous engagement with physics increases, but it is still only 50% at second year university level. This is consistent with the fact that the scientifically accepted conception involved is actually counter-intuitive. Most naive observations of waves on strings seem to support the idea that the wave speed does not depend only on the properties of the medium, but also on how the wave is generated.

The common alternative conception, that wave speed depends on frequency, does not attract many adherents at any level. On the other hand, the Other/Guessing group is quite large at the start, about 80%. This falls steadily as previous engagement with physics learning increases, but it is still 50% at second year university level. This behavior is not characteristic of the usual mixture of ill understood ideas or guesses. Instead, it almost looks like a third, consistent but incorrect, conception. It seems to warrant more research being done to find out exactly what the conception is, and special care being taken to change it.

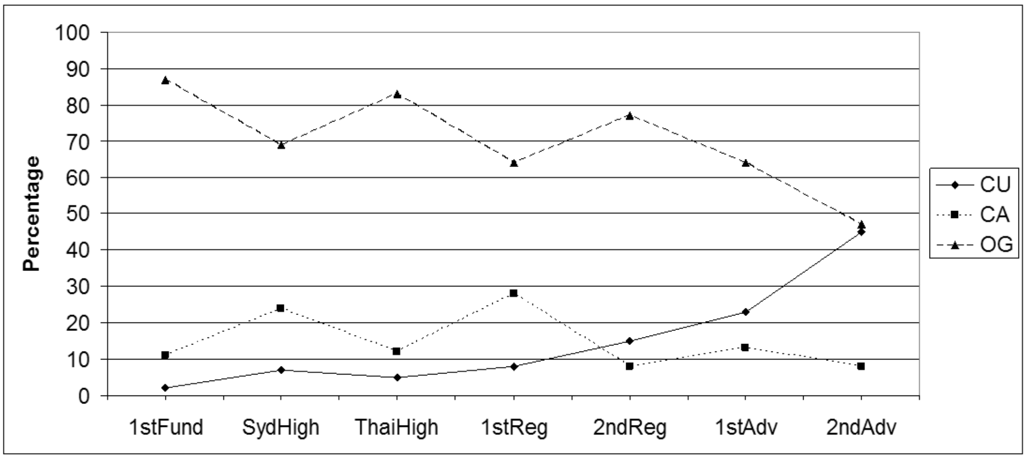

FIG. 2. The percentages of students' responses obtained using the categorizing and counting technique is plotted against previous engagement with physics learning (ranked as in Table II) for questions 4 and 5 on the speed of waves on strings

2. Model Analysis

We applied the technique model analysis to a set of questions; questions 2, 3, 4 and 5, based on one particular concept - Speed of waves. Analysis method and the results are shown below.

Students' responses to questions 2, 3, 4 and 5 can be categorized into three "models";

> *Model S1*: the answers demonstrate the understanding that the speed of waves depends on medium properties (the scientifically accepted conception),
> *Model S2*: the answers are built on the notion that the speed of waves depends directly on frequency (common alternative conception), and
> *Model S3*: other ideas or guessing.

Note, however, that there is not necessarily any one-to-one mapping between models and answers. It is perfectly possible for two or more multiple-choice options to "belong" to one model. For example, question 5 option A (use a lighter string, under the same tension, because the velocity increases as the density decreases) and option B (use a heavier string, under the same tension, because the velocity increases as the density increases) are both in accordance with model S1. The associations of multiple-choice options with each model for all questions are shown in Table III.

TABLE III. Models and multiple-choice options for questions about wave speed

Question	*Model S1*	*Model S2*	*Model S3*
2	a	B	c, d
3	c	B	a, d
4	f	B	a, c, d, e
5	a, b	D	c

Table IV shows the class model density matrices of all groups of students. The shading reflects the proportion of responses. Remember that the diagonal elements of each matrix represent the proportion of students' responses which are based on the three models. Overall, it is clear that as the previous engagement with physics learning increases, the trend of the consistent use of models (diagonal elements) shifts from other ideas (model S3) and common alternative conception (S2) to the scientifically accepted model (S1).

Further, students with low previous engagement with physics learning seem to use all models equally. Indeed, they use all models inconsistently, as shown by the high values of the off-diagonal elements. At the other end of the table, the most advanced students tend to use only the scientifically accepted model, and do so consistently.

TABLE IV**.** Class model density matrices for questions 2 to 5 on wave speed.

1stFund (n=123)			SydHigh (n=54)			ThaiHigh (n=270)			1stReg (n=287)			2ndReg (n=48)			1stAdv (n=69)			2ndAdv (n=51)		
.34	.17	.19	.38	.22	.15	.31	.22	.19	.43	.20	.14	.57	.19	.13	.75	.15	.12	.79	.12	.09
.17	.32	.17	.22	.45	.14	.22	.38	.20	.20	.41	.11	.19	.30	.07	.15	.17	.03	.12	.15	.01
.19	.17	.33	.15	.14	.17	.19	.20	.30	.14	.11	.16	.13	.07	.13	.12	.03	.08	.09	.01	.06

Note: shading highlights the trend of the numbers.

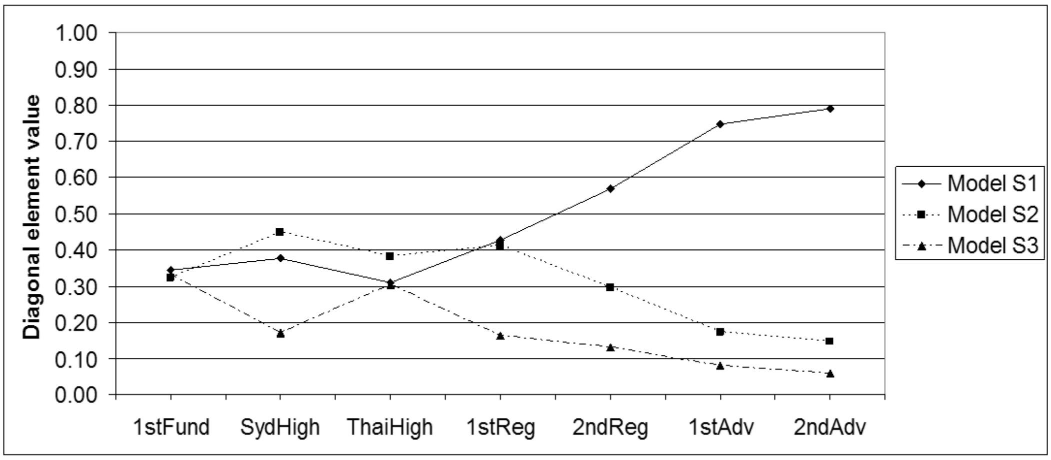

FIG. 3. Trend of the diagonal elements of all class model density matrices plotted against previous engagement with physics learning (ranked as in Table II) for questions 2 to 5 on wave speed

We also plotted the diagonal elements of all density matrices against the ranked previous physics learning, generating Figure 3. This shows that a lot more students seem to use the scientifically accepted model after they have more experience in physics learning. At a superficial level, Figures 1 and 3 look similar. However, students who showed "complete understanding" in Figures 1 and 2 (un-dotted line) can only fall into the model S1 group in Figure 3. Likewise, those who chose the "common alternative" (dotted line) fall into model S2. But the "other/guessing" (dashed line) can fall into any of the three models. Therefore it is not easy to see the relationship between these graphs, particularly Figures 2 and 3, even though they are constructed from some of the same data. To our way of thinking, the matrices in Table IV are the easiest to interpret.

Conclusion and Implications

Two useful techniques for analyzing the consistency of student conceptions were presented. Both techniques have their usefulness and were able to show that the student conceptual understanding increases as they studied more physics from high school to second year university level. The categorizing and counting technique is a simple and convenient analysis tool for evaluating students' responses and easy to use in a classroom. The model analysis technique was particularly useful in highlighting inconsistencies in the way students answered the questions. In terms of class-room practices, it is important to be careful when interpreting students' responses to this kind of survey. They may apparently get the right answers, but still be confused about the basic concepts. The more sophisticated model analysis technique gives a readily visual summary of where the students are mixing mental models.

References

D. Palmer, How consistently do students use their alternative conceptions? Research in Science Education, 23, 228 (1993)

R. Warnakulasooriya and L.Bao, Students' reasoning across contexts. Paper presented at the 2003 Physics Education Research Conference, Madison, Wisconsin, USA, 6-7 August (2003).

L. Bao and E. F. Redish, Model analysis: Representing and assessing the dynamics of student learning, Phys. Rev. ST Phys. Educ. Res. 2, 010103 (2006).

E. E. Clough and R. Driver, A study of consistency in the use of students' conceptual frameworks across different task contexts, Science Education, 70, 473 (1986).

M. Finegold and P. Gorsky, Students' concepts of force as applied to related physical systems: A search for consistency, Int. J. Sci. Educ. 13, 97 (1991).

P. Licht and G. D. Thijs, Method to trace coherence and persistence of preconceptions, Int. J. Sci. Educ. 12, 403 (1990).

A. Tongchai, M. D. Sharma, I. D. Johnston, K. Arayathanitkul, and C. Soankwan, Developing, evaluating and demonstrating the use of a conceptual survey in Mechanical Waves, Int. J. Sci. Educ. 31, 18 (2009).

A. Tongchai, M. D. Sharma, I. D. Johnston, K. Arayathanitkul. Consistency of students' conceptions about superposition and reflection of waves: findings from the development of a conceptual survey in Mechanical Waves. Paper presented at the Frontiers in Science Education Research 2009: An international conference on science and mathematics education research, Salamis Bay Hotel, Turkish Republic of Northern Cyprus, 22-24 March (2009).