Impact of context on students' conceptual understanding about mechanical wave speed

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Abstract. This work analyses student understanding about propagation speed of the mechanical wave from different contexts using a model estimation of the model analysis technique. The modified version of the Mechanical Waves Conceptual Survey was administered to the first-year engineering (ENG, N = 644) and the second-year physics (PHYS, N = 37) university students. Corresponding contexts of the survey were related to yelling sounds, waves on a string, and a problem involving basic explanation without context. We identified the distribution of students' responses into four common models. The two groups showed differences and inconsistencies in the probability of using the models. Alternative conceptions become more apparent with different contexts especially for ENG students, but this is contrary to a question worded without a context. The most popular idea for ENG and PHYS students is that wave speed depends on its frequency. By applying the inner product between the primary eigenvectors of the ENG and PHYS class, we computed a projection angle of about 20 degrees. The similar trend of the class's model state vectors indicates the influence of contexts on the responses of students. These results may support researchers in designing their assessment instruments.

1. Introduction

Context is crucial in cognition because it is incorporated into the learning process [1]. In accordance with contextual constructivism, it is natural to associate context with student learning. Context does not simply constitute the conditions that inundate the student, but it also involves frames such as task, situation, and idioculture [2]. Using Mestre's definition [3], we refer to the task as the story line of a problem which may be viewed differently between the novice and expert.

A correct scientific response from a given task question is not guarantee that the content topic has been fully understood by the student. It is a common observation wherein students answer inconsistently to problems pertaining to the same physics concept. For instance, in mechanical waves, a popular alternative idea is that the propagation of the wave depends on quantities which describe wave motion rather than the medium's properties. Researchers who studied about naive conceptions with mechanical waves showed that student responses are predominantly dependent on contexts [4-6].

In this study, we aim to examine student comprehension focusing on the propagation speed of mechanical waves. By applying the model analysis technique [7-8] on students' responses to a modified version of the Mechanical Waves Conceptual Survey [9] and a supplementary question that deal with providing descriptions, the probability of using a given mental model is revealed. Moreover, the most difficult among the contexts and context-free questions, and the popular alternative concept of the samples are also reported. From our findings, we will discuss the effect of context based on the responses of students.

2. Data Collection

The sample groups were Thai first-year engineering (ENG, N = 644) and second-year physics (PHYS, N = 37) university students. Both ENG and PHYS cohorts were already taught about mechanical waves from their introductory course in university physics, as well as secondary-school physics. ENG and PHYS students took the computer-based and paper-and-pencil test, respectively. Both groups were given credit for participating in the survey. For the mechanical wave speed, we concentrated on the responses to items 2, 3, and 4 of a modified version of the Mechanical Waves Conceptual Survey (MWCSv2) by Barniol and Zavala [9] and a supplementary question taken from the test bank of Fundamentals of Physics by Halliday and Resnick [10], as shown in figure 1. All questions were carefully translated into the Thai language then validated by a group of physics professors.

The speed of a sound wave is determined by:

A. its amplitude
B. its intensity
C. its pitch
D. number of harmonics present
E. the transmitting medium

Figure 1. An additional question without a problem setting (context-free).

3. Model Analysis

We applied a model estimation of the model analysis to present the probabilities of students using the mental models. Choices of the four questions mentioned, related to the mechanical wave speed concept, were classified into 4 common mental models as follows:

Model 1 (e_1): speed depends on the medium properties (correct model)
Model 2 (e_2): speed depends on the frequency
Model 3 (e_3): speed depends on the amplitude
Model 4 (e_4): other irrelevant ideas, null model.

These common student models are represented by orthonormal vectors namely e_1, e_2, e_3, and e_4 in linear vector space. It is important to note that in choice E of item 4 in MWCSv2, wave speed depends on the property of the string medium, but it is not the correct model. In such case, the tension in the string should be increased to conform with the scientifically accepted notion.

For every student k, a model state vector u_k shows student responses to the m number of questions as given by

$$u_k = \frac{1}{\sqrt{m}}\left(\sqrt{n_1^k}\ \sqrt{n_2^k}\ \sqrt{n_3^k}\ \sqrt{n_4^k}\right)^T \tag{1}$$

where n represents the frequency of using each model and the probability amplitude is $\sqrt{q_\eta^k}$. This single student model vector is used to obtain the model density matrix D_k for an individual student, where $D_k = u_k \otimes u_k^T$. Then, D_k is averaged with other students' matrices in the whole class sample N to create the class density matrix as shown below

$$D = \frac{1}{N}\sum_{k=1}^{N} D_k = \frac{1}{N \cdot m}\begin{bmatrix} n_1^k & \sqrt{n_1^k n_2^k} & \sqrt{n_1^k n_3^k} & \sqrt{n_1^k n_4^k} \\ \sqrt{n_2^k n_1^k} & n_2^k & \sqrt{n_2^k n_3^k} & \sqrt{n_2^k n_4^k} \\ \sqrt{n_3^k n_1^k} & \sqrt{n_3^k n_2^k} & n_3^k & \sqrt{n_3^k n_4^k} \\ \sqrt{n_4^k n_1^k} & \sqrt{n_4^k n_2^k} & \sqrt{n_4^k n_3^k} & n_4^k \end{bmatrix} = \begin{bmatrix} \rho_{11} & \rho_{12} & \rho_{13} & \rho_{14} \\ \rho_{21} & \rho_{22} & \rho_{23} & \rho_{24} \\ \rho_{31} & \rho_{32} & \rho_{33} & \rho_{34} \\ \rho_{41} & \rho_{42} & \rho_{43} & \rho_{44} \end{bmatrix} \tag{2}$$

As illustrated in equation (2), the diagonal elements demonstrate the percentage of responses in corresponding models. The off-diagonal elements in the same density matrix D also indicate the

mixing of individual students' use of models. By eigenvalue decomposition, the primary eigenvector which has the largest eigenvalue (>0.65) shows the dominant features of the class model states [7-8].

4. Results and Discussion

The four questions used were categorised based on contexts as 1) context of yelling sound waves, 2) context of wave pulse on a string, and 3) no context. Percentage of students who are correct in each context was shown in figure 2. We found that although the students were correct with the context-free question, they still held a misconception of the mechanical wave speed concept. 90% of ENG and 49% of PHYS were correct with the no context question, but only 16-27% of them were correct with context 1 and 2. Context 1 involves two individuals standing 50 meters apart and yelling at each other at exactly the same time. The questions ask who will hear the other's sound first if the pitch is different and the same, respectively for the two items in context 1. Context 2 asks how a girl can produce a pulse on one end of a long string that takes less time to reach the other end fixed at the pole. Our results indicated no statistically significant difference in the percentage of responses between context 1 (yelling sounds) and context 2 (waves on a string) for both ENG and PHYS groups. However, a study of ref. [9] collected data from Mexican students reported that the responses to the wave on a string context outperformed those of the yelling sounds context.
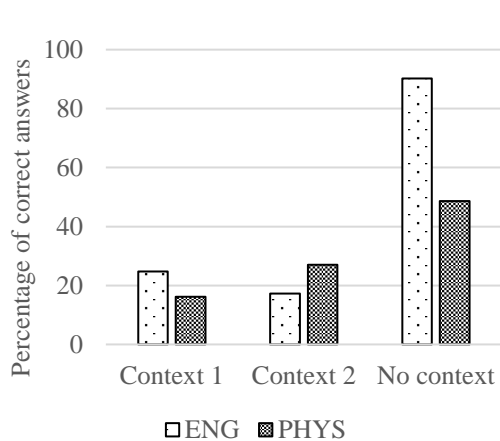
Figure 2. Percentage of students correct in each category based on with and without context
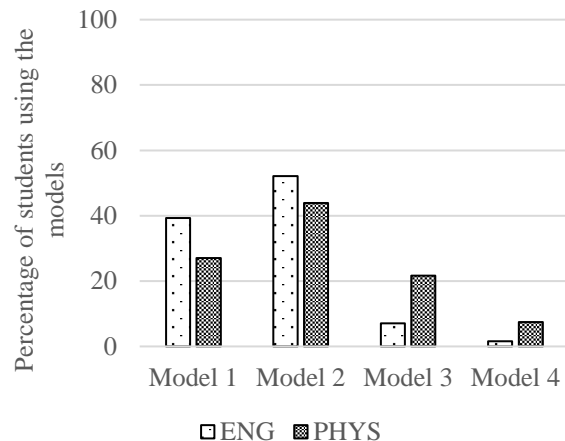
Figure 3. Percentage of students' responses using different models

The most common alternative conception that was used by 52% of ENG and 44% of PHYS students is that the speed of mechanical waves depends on frequency (model 2), as displayed in figure 3 and ρ_{22} of the class density matrices in table 1. This result is consistent with the findings of Tongchai and colleagues [6], and Barniol and Zavala [9].

There is a significant (>50%) inconsistency in the students' use of model 1 and model 2 for the PHYS ($\rho_{12} = 0.35$) and ENG ($\rho_{12} = 0.21$) groups. Students are confused on whether the propagation speed of the wave depends on the properties of the medium through which the wave moves or on the frequency of the wave itself. Moreover, the PHYS class has a larger dispersion of responses than the ENG class which is revealed through their respective eigenvalues.

In figure 3, the percentage of students using model 2, model 1, model 3, model 4 in descending order can be seen. This pattern emerges through the inner product of the primary eigenvectors between the ENG and PHYS class. The projection angle between the eigenvectors is approximately 20 degrees. These dominant eigenvectors are close to each other, indicating corresponding model states for the two class.

Table 1. Class density matrices, eigenvalues, and eigenvectors of first-year engineering (ENG) and second-year physics (PHYS) students.

	ENG (N = 644)	PHYS (N = 37)
Class density matrix	$\begin{bmatrix} 0.39 & 0.35 & 0.05 & 0.01 \\ 0.35 & 0.52 & 0.06 & 0.01 \\ 0.05 & 0.06 & 0.07 & 0.01 \\ 0.01 & 0.01 & 0.01 & 0.02 \end{bmatrix}$	$\begin{bmatrix} 0.27 & 0.21 & 0.08 & 0.02 \\ 0.21 & 0.44 & 0.19 & 0.07 \\ 0.08 & 0.19 & 0.22 & 0.04 \\ 0.02 & 0.07 & 0.04 & 0.07 \end{bmatrix}$
Eigenvalue	0.82	0.68
Primary eigenvector	$\begin{pmatrix} 0.64 & 0.76 & 0.10 & 0.02 \end{pmatrix}^T$	$\begin{pmatrix} 0.48 & 0.77 & 0.40 & 0.13 \end{pmatrix}^T$

5. Summary

The most difficult context cannot be precisely determined from the preliminary data. However, we found that students' alternative conceptions are triggered with more conceptual questions that involve different contexts. Context when presented to students has a notable impact on the items attached to them. Questions without context only test how students remember the topic and cannot classify students' ability to apply the physics concept. It is recommended that when designing test questions emphasis should be given to task problems, and not just on stored definition of terminologies. It will help instructors in diagnosing and evaluating students' complete understanding.

Students' idea drawn into the model of wave speed depends on frequency is reported as an effective distractor in the multiple-choice questions. This alternative conception should be considered in classroom instruction and the assessment of student learning. Furthermore, despite the different conditions such as mode of test administration and level of knowledge between the ENG and PHYS groups, the similarity of their primary eigenvectors indicate that students are comparably affected with the same contexts presented to them.

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