On Students' Preconceptions of Speed

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Abstract. We report on the research findings on Singapore secondary one (Grade 7) students' preconception of speed: 1) The idea of someone ahead being faster than the one behind is prevalent among students when answering an open-ended question, 2) The idea becomes less prevalent when the question becomes more guided, streamlining students' thinking towards the distance apart between two moving objects, 3) While most students were able to choose the correct choice that states that two boys who are running have the same speed because they remain the same distance apart, their explanations do not invoke the concept of speed as distance moved per unit time, and 4) Many students were not aware that in the definition of the average speed of a journey, the resting time was included as part of the total time elapsed. The data were from two batches of students at a reputable school.

Keywords: speed, average speed, student understanding, student preconceptions, physics by inquiry
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INTRODUCTION

It is known to educators that students at all levels have difficulties in understanding the concept of speed [1-2]. As stated by Piaget, the concept of speed involves the relationship between space and time, which can only be understood after the operations relating to the construction of the ideas of the path travelled and of duration had been completely formed [1]. Even in higher levels of school, quantities involving ratio like speed and density are particularly difficult for students to understand [3].

Since students experience movement around them from a very young age, and hear the word 'speed' being used widely, they are bound to have preconceived ideas on the topic, which will shape significantly how they make sense of what they learn in school [4]. Thus information about students' preconceived ideas has implications for instruction as it can be used to guide the design of curricula that address problems as they actually are and not as instructors imagine them to be [2]. In this paper, we report on students' preconceived ideas on speed given three familiar scenarios, and we attempt to answer the following research questions:

1. What are the students' preconceptions of the terms 'faster' and 'speed'?
2. Are the students able to make calculations involving 'average speed'?
3. How do students understand the role of resting time in the concept of 'average speed'?

This study is part of an on-going research project to develop and validate effective inquiry-based classroom materials and instruction for secondary-grade students in Singapore classrooms.

METHODOLOGY

The participants for this study were two batches of secondary one students in Singapore. They can be described as having above average academic ability, based on the scores of their Primary School Leaving Examination taken at the end of primary education (Grade 6). They have been taught about 'speed' through the formula distance/time in their Primary 6 Mathematics lesson.

The first batch of students (N=99) sat for Pre-Test I in 2009, whereas the second batch (N=156) sat for Pre-Test II, a revised version of Pre-Test I, in 2010. They were given about 10 minutes to complete the tests at the start of the lesson.

All data for this study were collected by analysis of responses on the pre-tests constructed by a team of university professors, research associates and curriculum specialists.

PRE-TEST I AND RESULTS

Pre-Test I is an open-ended question, illustrated by Figure 1: Boys A and B are running after their school bus. Who is faster? Explain.

FIGURE 1. Diagram for Pre-Test I

Results: The students' responses may be grouped into three categories as shown in Table 1:

TABLE 1. Students' responses (Pre-Test 1, N = 99)

	A faster	B faster	Neither
No. of students	70	2	27

Explanation given for the three categories are:
1. 70 students stated that Boy A was faster, giving the reason (with a few exceptions): either *A was in front of B* or *A was closer to the bus*, implying that reaching one's destination first or the one ahead means faster. The exceptions were: One student stated that he assumed that both boys started running from the same point, another stated that B could suddenly speed up and be faster than A even though A is closer to the bus, and two students gave no explanation.
2. Only two students stated that Boy B was faster. One wrote that B is smaller and hence there would be less air resistance on him. The other wrote "since Boy B is left behind, he would run faster in order to catch up with the bus, hence he'll increase his speed."
3. 27 students gave the intended answer that one is not able to tell which boy is faster, but only 17 of them gave plausible reasons:
a) It is not a video showing actual motion. (3 students),
b)The starting positions or speeds of the boys were not given. (14 students)
For the remaining 10 students who did not give plausible reasons, five merely wrote that the two boys were running at the same speed without elaboration, except for one of them, saying that the boys being identical; Three students, who had apparently expanded the "who" to include the bus, reasoned that the bus was faster than the boys because: a) the bus had engines (1student), b) the bus was ahead of the boys (2 students), in line with the idea that the one ahead is faster. Two students did not give explanation.

PRE-TEST II AND RESULTS

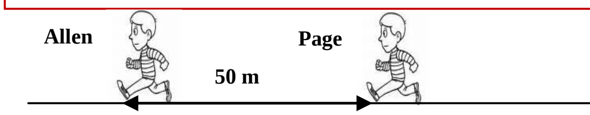
Pre-Test II consists of two questions, given in Figures 2 and 3. Question 1 is a revised version of Pre-Test I, and Question 2 has some resemblance to a typical school examination question.

In Pre-Test I, we see that most students do not know what constitute a complete explanation. For example, most students do not explain why being in front or closer to the bus means faster. They are not aware of the need to state one's assumption – only 1 in 70 students stated that he assumed that the two boys had started at the same spot.

Question 1

In Question 1, we attempted to guide students' thinking towards focusing on the distance between the two boys in deciding who was faster and also included lines of reasoning that were motivated by students' responses in Pre-Test I. The reference to the bus was removed to reduce unnecessary distraction. These considerations resulted in the revised question given in Figure 2.

Allen and his twin brother Page are running in a park for some time. Allen is 50 metres ahead and continues to be 50 metres ahead of his brother for the next five minutes.



Here are some comments made by three students observing them:
Student 1 said, "Allen is running faster than Page during the five minutes because Allen is ahead of Page."
Student 2 said, "Allen is running at the same speed as Page during the five minutes because they remain the same distance apart."
Student 3 said, "Allen is running slower than Page during the five minutes because he could be getting tired after running ahead for so long."
Which student(s) do you agree with?
☐ Student 1 ☐ Student 2 ☐ Student 3
Reason:…………………………………………...…………………

FIGURE 2. Question 1 of Pre-Test II

Results: We grouped the students' responses as "correct choice" (Student 2) and "wrong choice" (Student 1, Student 3 or any combination) in Table 2. An overwhelming majority (92%) selected the correct choice, and only 8% chose the wrong choice. We examine these two groups of students in turn.

A) *Correct choice*. Only 2 students gave the complete reasoning to support their correct choice of answer. They accurately explained that the boys remained the same distance apart because they were running the same distance for the same amount of time, thus they were running at the same speed. About 60% of them merely restated what Student 2 said in the question as their explanation, and about half as many explained by "contrast" by referring to what would happen to the distance AP (distance between Allen and Page) if the boys were not running at the same speed. The degree of details given varies from merely stating that the distance AP would change to the two situations of how it would change, namely a) if

Page was faster, then AP would get shorter, and b) if Page was slower, then AP would get longer.

Reasons grouped under "Others" include "Explanation by elimination", where students explained why they rejected the other two choices, (4 students), and "Assumptions", where a few students included information that was not mentioned in the question.

Some students in this group mentioned that Allen and Page did not change their speed throughout, thus they remain at the same speed. This response brought the team to question the students' use of the term 'same speed'. Follow up research is necessary to ascertain whether students think that for the boys to remain the same distance apart they must travel at a fixed speed throughout the 5 minutes.

TABLE 2. Pre-Test II Question 1 Results (N=156).

Category	No. of students	%
Correct choice	143	92%
- Complete reasoning	*2*	*1%*
- Restating answers	*84*	*54%*
- Explanation by contrast	*43*	*28%*
- Others	*14*	*9%*
Wrong choice	13	8%

B) *Wrong choice*. The percentage of students who thought that the boy in front is faster dropped significantly from 71% in Pre-Test I to just 6% or only 9 students. This large drop could have been due to the statement in the question that one boy "continues to be 50 m ahead" of the other -- thus no possibility of overtaking by the boy at the back and since there is no indication that the boy behind is lagging further, they must be running at the same speed.

Question 2

Ling and her brother Lung want to go to Devi's house. There is a lake between their house and Devi's house. Ling decides to walk along the lake over a distance of 1000 m and rested for 1.0 minute. The average speed of Ling's journey is 6.0 km/h. Lung decides to swim straight across the lake, which has a distance of 600 m. Lung's average swimming speed is 3.0 km/h. If both of them leave home at the same time, who will reach Devi's home first? Show clearly how you arrive at your answer.

FIGURE 3. Question 2 of Pre-Test II

Question 2 of Pre-Test II resembles a typical school examination question, except that it was designed, with appropriate choice of numerical values, to test student understanding of average speed and whether they are able to arrive at the answer through sound argument without having to carry out detailed standard calculations. For example: Ling's average speed is twice of her brother, but the distance she needs to cover is less than twice of his, so she will take a shorter time to cover the distance. Since they started their journey at the same time and place, she will arrive at Devi's home first. However, probably due to the habit cultivated in their primary school mathematics lessons where they practised solving problems on speed quantitatively, the majority of the students prefer calculations over argument to arrive at the answer.

Results: The students' performance is shown in Table 3.

TABLE 3. Calculation of arrival times (N=156)

Calculation of arrival time	Correct	Percentage
Lung's (swimming)	131	84%
Ling's (walking)	20	13%

Only 3 students attempted to solve the problem qualitatively. They were able to conclude correctly but were weak in their explanation.

Most (84%) of the students used the formula time = distance/average speed to calculate the arrival time for Lung with success. However, they have problems dealing with the resting time in Ling's journey. Only 13% of the students obtained Ling's arrival time of 10 minutes correctly. The most common mistake made was the addition of the 1 minute of resting time to Ling's 10 minutes which the students obtained correctly from Ling's average speed and the distance of 1km, yielding erroneously a total of 11 minutes for Ling's arrival time. The students failed to realize that the addition of the resting time to the time taken by Ling to arrive at her destination is redundant because in the definition of the average speed of a journey, the resting time was already included as part of the total time elapsed.

DISCUSSION

Although a significant number of previous studies have investigated student understanding of speed, there has been no comprehensive study of Singapore students' understanding and what they mean when they use terms like 'faster', 'slower', 'speed' and 'average speed'. In order to begin to address this issue, we have developed Pre-Test I, an open-ended instrument with a simple conceptual question, to elicit their understanding of these terms. Our analysis of responses revealed that most students were not able to articulate a complete explanation. In answering, students apparently had made several assumptions about the questions, but did not state them. For example, most students did not state the assumptions made when claiming that the boy in front was faster.

This made it difficult to ascertain students' line of reasoning. As a consequence, we revised Pre-Test I to make it more guided. With this change, nearly all the students of the second batch no longer thought that the boy in front was 'faster'. However, another issue surfaced: the majority ended up re-stating the reasoning and other information in the question instead of writing what they understand by 'same speed'. We had hoped to see some students attempt at explaining why the boys, in maintaining the same distance apart, had the same speed. However, only two students gave complete explanations based on the concept of distance travelled in a unit time, even though most of the students know the formula for speed and are able to make correct calculations using the formula.

A reason for this behavior could be that students' pre-conceived ideas developed through everyday experiences about speed were not being addressed when they were learning the formula for speed. This is consistent with the finding that when preconceptions are not addressed directly, students tend to just memorize formulas and rely on their experienced-based preconceptions to act in the world instead of applying what they have been taught [4].

Results of Question 2 of Pre-Test II reveal several interesting findings. First, most of the students used calculations to arrive at their answers instead of using qualitative reasoning. While most students were able to calculate the time for travel using the formula, time = distance/average speed, they encountered much difficulty when resting time was involved. Most of them added the resting time to the total time for the journey, unaware that in the definition of average speed, the resting time would already have been taken into account.

Understanding students' preconceptions of speed has important implications for instructional design. While the tests used in our study are simple, they have been able to surface some of the students' preconceptions of 'speed'. The results are useful in coming up with probing questions during facilitation of practical work and activities.

CONCLUSION

Based on research with two batches of secondary one students of above average academic ability, our findings are as follows: 1) The idea of someone ahead being faster than the one behind is prevalent among students when answering an open-ended question, 2) The idea becomes less prevalent when the question becomes more guided, streamlining students' thinking towards the distance apart between two moving objects, 3) While most students were able to choose the correct choice that states that two boys who are running have the same speed because they remain the same distance apart, their explanations do not invoke the concept of speed as distance moved per unit time, and 4) Many students were not aware that in the definition of the average speed of a journey, the resting time was included as part of the total time elapsed.

These findings are interesting enough to warrant further investigations as well as to guide the design of inquiry-based curriculum materials.

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