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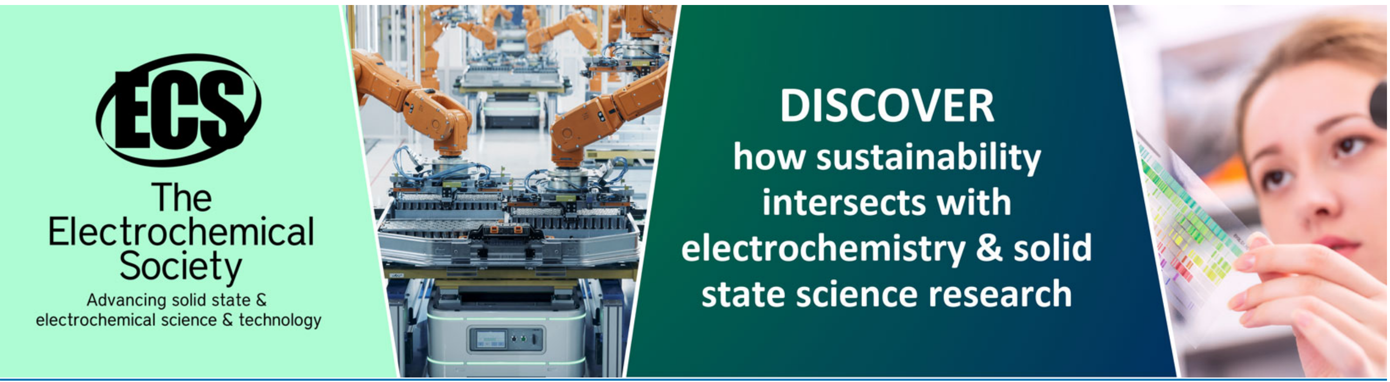

A discussion on velocity–speed and their instruction

Ali Yıldız
Atatürk University, Kazım Karabekir Faculty of Education, Erzurum, Turkey

E-mail: ayildiz@atauni.edu.tr

Abstract. This study was conducted to investigate how to teach velocity and speed effectively, with which activities and examples. Although they are different quantities, they are generally used in the same meaning. Study data and the quantities discussed were obtained from the examination of documents such as scientific articles and books about the instruction and they were examined by descriptive analysis approach. Expository instruction was supported with writing to learn activities and an approach actualized in seven stages was suggested so that velocity and speed could be understood at an anticipated level. At each stage, possible practices were explained; and especially at the fifth stage of the study, a detailed example on distance, displacement, velocity and speed promoted the understanding of presented quantities much more easily and correctly with their critical properties, thus students would be able to associate it with their prior knowledge. Moreover, it was anticipated based on these reasons that the example could be used as a tool to actualize permanent learning. At the last stage of the study, it was considered that having students write a letter and a summary to young respondents could support the practices in the previous stages, and also it would help promoting long-term retention of the learned concepts.

1. Introduction

Although speed and velocity are different quantities, they are used in the same meaning and this is something frequently encountered. It can be stated that among the individuals who receive higher education, those who use speed and velocity as synonyms or without knowing the difference or differences between them is far beyond the estimated numbers. What makes this observation more interesting is that this attitude has been identified among the university students who took mechanics course. In a qualitative study [1], science students who took mechanics course stated that "the speed of light" which is defined with the constant $c = 3\text{x}10^8\ \text{m/s}$ "is true because we were always taught like that and it is explained in that way in the sources". The percentage of the students who made this justification with that statement was 93.3% and it is really difficult to evaluate this explanation in another way. In the same study, the constant c ($c = 3\text{x}10^8\ \text{m/s}$) is called "the speed of light in vacuum" in the physics books studied in all secondary school classes, in the questions asked in the examinations (Undergraduate Placement Examination (LYS)) administered by the Measuring, Selection and Placement Center (OSYM), and in most of the national books written for the physics courses included in some higher education undergraduate programs. Similarly, some books of international level [2, 3, 4, 5] are used as a reference book for the physics course at undergraduate level. The constant c included as "Speed of light in vacuum" in the original form of these books is usually translated incorrectly into Turkish as "the speed of light in vacuum" or "the speed of light in free space" [1]. A similar misattribution is done for the speed of light. The course books, which incorrectly call the magnitude of speed of propagation of sound at 1 atmospheric pressure and 20^0C or its velocity at 343 m/s value [5] as "the speed of sound in air" and also questions asked about sound in the exams, are frequently encountered.

It was found in a study [6] that pre-service science teachers had difficulties about understanding the main principles of scalar and vector quantity, scientific definition of speed, constant speed, and the relation between speed and velocity; and they hold the views that "on the condition that numerical value does not change, the speed will be constant and the change in direction will not change the speed". In another study conducted on the primary school pre-service mathematics teachers [7], it was found that the concepts of speed and velocity were not understood fully and speed was mostly used in place of velocity. It was determined in some studies that [8, 9, 10] generally all students at every level, but mainly the students studying in high school and at university, had difficulties in understanding the concept of speed. It was emphasized in another study [11] that even students in upper grades had difficulties in understanding some common quantities like speed.

Among the reasons why speed and velocity are used in the same meaning, we can point to the spoken language, wrong documents used, translation mistakes, and not understanding the main principles of scalar and vector quantity fully [1,7]. However, although pre-service teachers took mechanics course at university, it would be more realistic not to limit their evaluation of speed and velocity as different quantities to only abovementioned reasons.

It can be stated that the same condition is true for distance and displacement (change in position). We need to explain that distance and displacement are different quantities, and clear and suitable examples should be given for their explanations. Since, explaining the difference or differences between distance and displacement clearly with appropriate examples and describing average speed as distance travelled divided by the time elapsed (Total distance / Total time) and average velocity defined ($\Delta x/\Delta t$) as the displacement (Δx) over time interval may help these quantities to be understood much more easily.

It is predicted that using documents naming the constant c, the speed of light in vacuum or the magnitude of the propagation of the speed of light in free space, as “the speed of light”, the value 343 m/s as “the velocity of sound” instead of “the speed of sound”, explaining the differences between average velocity and average speed without identifying the differences between distance and displacement or not indicating that these quantities are different with suitable examples will cause problems in the teaching of these subjects. It is inevitable that students, pre-service teachers, teachers, researchers, and instructors who use such documents mentioned above will have wrong constructions in their minds about distance and displacement, and velocity and speed or experience misconceptions.

The Purpose of the study
This study was carried out to examine how to actualize the definitions of distance-displacement, speed-velocity quantities, their crucial properties and the instruction of the formulae more effectively with appropriate examples and activities.

2. Method
Study data were obtained by analysing the relevant documents to understand the definitions of distance and displacement and speed and velocity, their critical properties, formulae related to them and the differences between them. The findings of a qualitative study are usually composed of data gathered from interviews, observation and documents [12]. During the interviews carried out, some participants can feel uncomfortable due to the existence of the researcher or the tools used for recording or they may not consider appropriate being recorded. Therefore, analysis of documents provides advantages under such circumstances. Document analysis is preferred to observations and interviews, because the information can be obtained in a very short time, it is economical and easy. Any book, journal and article found in the libraries can become an available data and information source for every researcher who loves her/his job [12]. Many documents such as columns, course books, organizational documents, annual reports, scientific study reports, and articles, which are revised, checked for their originality, organized and arranged by the experts in the field, can become a source of data, and using these documents can increase the validity and reliability of the qualitative study [13]. Documents, which include the definitions, concepts, and formulae about distance, displacement, speed and velocity, were examined with regard to descriptive analysis approach in the study so that these quantities could be taught and understood easily.

3. Findings and interpretation
Scalars are quantities that are fully described by a magnitude or a numerical value only, and vectors are quantities that are fully described by both a magnitude and a direction as physical quantities.

Distance is a scalar quantity, but displacement is a vector quantity. Displacement is referred to as the simplest vector quantity [4]. Displacement vector is defined as both the distance and direction of an imaginary motion along a straight line from the initial position to the final position of the point. Distance is the ground an object covers linearly or curvilinearly during its motion from the initial point to the final point. Speed is a scalar quantity and velocity is a vector quantity. This is not the only difference between them. Average velocity and average speed are calculated in this way. Average velocity is displacement (Δx) over total time (Δt) and average speed is distance over time. Since displacement and numerical values of the distance are usually different, the magnitude of average velocity and average speed are different.

There are quasi-experimental studies [14, 15, 16, 17] in the literature conducted on examining pre-service science teachers' level of understanding of some subjects they learned in the introduction to modern physics course and the effect of writing activities on their academic achievement. Research findings revealed that pre-service teachers had low understanding levels about the subjects, which were examined. The views of the participating pre-service teachers about writing activities were gathered with the follow-up questions given with the post-test in written form. 87.5% of the pre-service teachers stated that they understood the Compton Effect, which they wrote letters about, 91.7% of them understood the photoelectric effect, 91.4% of them understood the uncertainty principle and 87.2% of them stated that they understood the special theory of relativity, about which they wrote a summary. They said that writing activities, which they used, were effective in learning the subjects, about which they wrote a letter and a summary.

Moreover, the use of writing activities, which facilitate materializing conceptual change within students [18], enable retention of knowledge [19, 20] and help designing student-centred learning, in which students discover and construct knowledge, can be beneficial. The use of these activities for the teaching of difficult subjects of the modern physics, which are difficult to understand and have effects on increasing academic achievement [14, 15, 16, 17], also reveal that they can be used for teaching quantities such as distance, displacement, velocity, and speed.

Teaching of distance, displacement, speed and velocity, the definitions of quantities, critical properties and equations can be actualized by following the stages suggested for the instruction of uncertainty principle [21], dimensional analysis, [22], and $E = mc^2$ paradigm.

I) At the first stage, students will be informed about the gains and operations that will be performed, so they will get prepared for learning [24]. As stated in a research study [21], students are informed about the subject to be presented, its importance, and the gains. Considering and discussing the student responses to the question "Suppose that there is an athlete who gets prepared for a race in a circular race track with a length of 600 m. He completes one lap around the track at the same pace in 300 s (returns to his starting point). In that condition, what is the athlete's distance travelled displacement, and average velocity and average speed?", finding the correct answer can raise students' interest and curiosity in the subject in the first stage.

II) Students can be given suitable and necessary explanations or suggestions about the quantities in the formulae related to average speed and average velocity, concepts and symbols (Δ, Δx, $\Delta t, v_{average}$).

III) "What are distance, displacement, speed, and velocity?" The names of these quantities are written on the board with their symbols in order and they are defined clearly and directly.

IV) The formulae for average speed and average velocity are written on the board and the quantities in each formulae and the relation between them are explained.

V) Appropriate examples and non-examples related to distance, average speed and average velocity must be given. It must be considered that appropriate examples must be used as well as using lecturing and talk in expository instruction [26].

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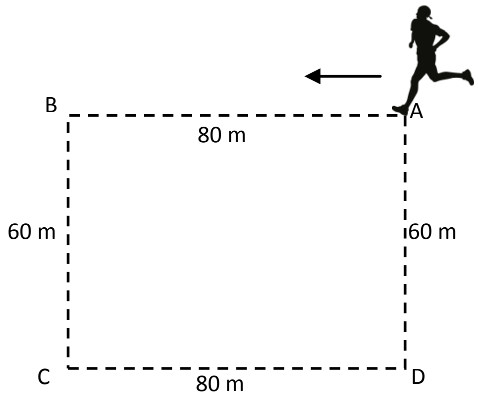
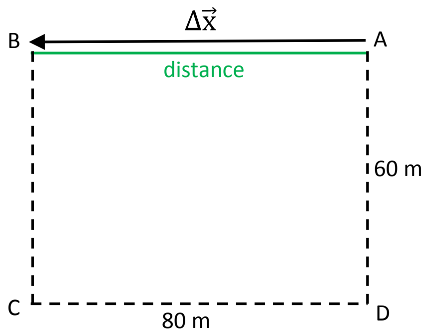
Example:

Suppose that an athlete runs in a rectangular racetrack with a 60 m width and 80 m length. He begins running from the point A and he runs at the same pace (2 metres in 1 second) only one lap and he completes this one lap in 140 seconds.
What is the distance taken, displacement, average speed and velocity when
a) the athlete reaches the point B.
b) the athlete reaches the point C.
c) the athlete reaches the point D.
d) the athlete reaches the point A.
Please calculate.



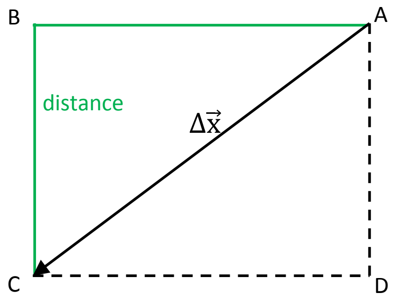
Solution:

a)



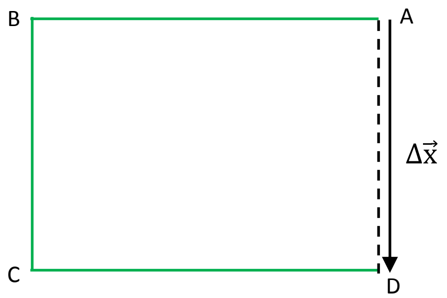
Distance travelled (length of the green line) = 80 m
The size of the displacement (Δx), Δx=80 m
Average speed= Total distance / Total time
$= \frac{80\text{m}}{40\text{s}} = 2\ \text{m/s}$
The value of average velocity is calculated as,
$\text{v}_{\text{average}} = \frac{\Delta\text{x}}{\Delta\text{t}} = \frac{80\text{m}}{40\text{s}} = 2\ \text{m/s}$

b)



Distance travelled (length of the green line) = 80 m + 60 m = 140 m
The size of the displacement (Δx),
$(\Delta\text{x})^2 = (80)^2 + (60)^2 = 6400 + 3600$
$(\Delta\text{x})^2 = 10000\ \text{m}^2 \rightarrow \Delta\text{x} = 100\ \text{m}$
Average speed= Total distance / Total time
$= \frac{140\ \text{m}}{70\ \text{s}} = 2\ \text{m/s}$ because he runs at the same pace.
The value of average velocity is calculated as
$\text{v}_{\text{average}} = \frac{\Delta\text{x}}{\Delta\text{t}} = \frac{100\ \text{m}}{70\ \text{s}} = 1.42\ \text{m/s}$

c)



Distance travelled (length of the green line) = 80 m + 60 m + 80 m= 220 m
The size of the displacement (Δx), Δx= 60 m
Average speed= Total distance / Total time
$= \frac{220\ \text{m}}{110\ \text{s}} = 2\ \text{m/s}$ because he runs at the same pace.
The value of average velocity is calculated as
$\text{v}_{\text{average}} = \frac{\Delta\text{x}}{\Delta\text{t}} = \frac{60\ \text{m}}{110\ \text{s}} = 0.545\ \text{m/s}$

d)

Distance travelled (length of running track) = 80 m + 60 m + 80 m+ 60 m = 280 m
The size of the displacement (Δx) is zero ($\Delta x= 0$). Because the athlete is at point (A) where he begins to run, his first and last positions are at the same point $(x_1 = x_2)$. $\Delta x = x_2 - x_1 = 0$
Average speed= Total distance / Total time $= \frac{280\ \mathrm{m}}{140\ \mathrm{s}} = 2\ \mathrm{m/s}$
When the athlete reaches point A (he completed one lapse), the average velocity is zero for displacement $(\Delta x = 0)$. Because there is no displacement, we cannot mention average velocity, in other words, average velocity is zero ($v_{average} = 0$).

As it is viewed in the above example, the only difference between distance and displacement is not the fact that distance is a scalar quantity and displacement is a vector quantity. Only in the option a of the example, the magnitudes of distance and displacement are equal. It can be seen in the other options (b, c, and d) that the calculated values of distance and displacement are completely different. Especially in the last option, although displacement is zero, the distance travelled is 280 m., and this proves that distance and displacement are different quantities. Similarly, the only difference between speed and velocity is not the fact that speed is a scalar quantity and velocity is a vector quantity. Only in the option a, while average velocity and average speed have an equal value (2 m/s), in other options (b, c, and d), while the value for the average speed is the same, different values are calculated for average velocity. In the last three options, the calculated values demonstrate that speed and velocity are different quantities. It can be more useful if the examples solved are supported with appropriate visuals, then the concepts of distance and displacement, velocity and speed and the relation between the quantities related to them in the formulae would be understood much better.

VI) Appropriate examples and problems about distance, displacement, average speed, and average velocity are solved by the teacher clearly and concisely. Immediately after, students are asked to solve different examples and problems.

VII) In the final stage, writing activities (letter, summary, diary, journal, poster, banner, essay and so on) can be used. Summaries or letters written to younger respondents [26] can enable students to understand crucial properties of quantities and concepts such as distance, displacement, average speed and average velocity, and the formulae about them in a meaningful and permanent way.

4. Results and discussion

Regarding the documents examined [1, 7, 8, 27], it can be considered that although velocity and speed are different quantities or concepts, using them in the same meaning may be attributed to such reasons as the spoken language, wrong definitions in the documents, wrong translations, not understanding the fundamentals of scalar and vector quantities and the thought that distance and displacement are the same quantities. It would be effective to teach speed, velocity, and their crucial properties via inclusive, simple, and clear examples, which include the differences between distance and displacement.

According to the findings of the studies carried out about the writing activities [14-20, 26], after the lessons in which speed and velocity are explained, students can be asked to write a letter or a summary to the students who are younger as writing activities. These activities can help these students to construct the difference (s) between distance and displacement, and speed and velocity in their minds correctly and make their learning permanent.

If there are wrong descriptions in the course books or documents used as reference about speed and velocity such as $c = 3x10^8\ \mathrm{m/s}$ constant is “speed of light” and “343 m/s” is “speed of sound in air”, teachers or instructors must certainly point out that they are wrong. In other words, warnings or explanations must be made by the experts or people in charge on time about the wrong descriptions in the reference documents.

As stated in a study [27], sometimes it may not be enough for the person who is going to translate, speak and write the language, which the original book was written in. If the work which is going to be translated is about physics and the person who knows, speaks, and writes in both languages is not a physicist, he will not know the differences between speed and velocity, so his translation will be probably faulty. Ethically, although people translate, speak and write in a language very well, they should not make an attempt to translate a topic, which they are not experts at or they should work with and consult to an expert of the field.

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