Visualizing Physics Questions

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ABSTRACT

Physics is an essential subject for most fields of study within science and engineering. Students cannot master it by simply watching their lecturer solving the problems at the end of each chapter, they must fully engage in solving these problems. However, in order to solve these problems students must be able to extract the information from the problems necessary for setting up the equations. This often requires that they visualize the problem, and that skill can present quite a challenge for some, and especially students who are studying physics in a second language. The aim of this study was to investigate the effects of the ability to visualize physics problem on students' success in answering physics exam questions. Twenty-eight undergraduate and 10 preparatory students were randomly assigned to participate in this study and asked to solve physics problems related to their mechanic's physics course. These problems contained a few sentences of English text which described a situation or image, and students were asked to draw the scenario or image described in the text. The result of the study highlights the difficulty in solving physics questions faced by students who lack the ability to visualize and the importance of training students to visualize physics problems in order to help them solve problems and to enhance their understanding of the physics concepts.

Keywords: Physics, visualization, mental image, spatial resonance skills

Introduction

The ability to visualize thoughts, stories and explanations is central to the human experience. Spoken or written language is our medium of communication, but visualization of those words and phrases is essential to the basic process of communication [1, 2]. However, in some cases, people may find difficulty in correctly perceiving what is being described. This difficulty becomes especially apparent in the physics classroom as students encounter complex problems that require visualization in order to solve them. Often in physics, a diagram or a figure is given and students must imagine and draw additional elements in order to solve the problem.

Visualization plays a central role in the conceptualization process of physics and other science subjects [1,3].

Good problem-solvers will read a problem carefully and make an effort to visualize the physical situation. Physics problems typically begin as word problems that lead to mathematical exercises and equations. Before the mathematics portion of a problem begins, a student must translate the written information into mathematical variables. Many errors, if not most, in a physics assessment can be traced back to mistakes made during this translation process. These errors are usually the result of either a failure to visualize the physical situation described in the statement of the problem or some missed strategic information during reading.

Generally speaking, difficult problems in physics are multistep problems and the path from known information to unknown quantity is often not immediately obvious. The problem can become like a jigsaw puzzle; the assembly of all the pieces into the whole can only occur after careful inspection, analysis and perhaps some wrong turns.

For the vast majority of students in the United Arab Emirates (UAE) English is their second language and their secondary education does not adequately prepare them for university level science courses. The teaching approach followed in many of their primary and secondary schools follows a more traditional model, where students are not required to search for information outside the classroom; instead they must rely on simply memorizing the information given by their teachers or the textbook [4]. This practice can have adverse effects on students' understanding and learning in physics because the principles of physics cannot be truly understood by memorization. Teaching methods that focus on memorization for any subject can affect students' attitude and motivation in learning physics and directly impact their achievement in the physics classroom. According to recent studies, UAE students have a negative association with or attitude toward physics learning and many of them choose not to pursue physics at the university level. Findings of this nature are also reported by other researchers who point out that students' physics achievement is negatively affected by low interest in classroom activities [4]. It is possible that this attitude toward physics is not wholly related to the way the subject is being taught, presented or delivered but instead is more related to the way physics questions for exams have been written because it can seem confusing to students as they lack the ability to determine what is required of them by the wording of the question and that would in turn affect their ability to answer the question. This frustration could be a major contributing factor to a student's belief that physics is a difficult subject and that they should avoid it.

There have been many studies that investigate students' attitude toward physics in schools and universities in recent years. Examines factors associated with changes in attitude toward science. Researchers found that motivated behavior is connected to a positive attitude while a negative attitude is related to less motivated behavior [5, 6]. Positive or negative attitudes of students affect the physics learning process [6, 7], and in their work, as well as in this paper, the

researcher uses the definition of "attitude" from [8, 9]. Students normally describe their attitudes towards a course by expressing likes or dislikes with regard to the subject. A positive attitude towards physics indicates that students are confident in learning physics and they enjoy the learning process. It is believed that attitudes have an effect on physics achievement; the more positive the attitude of students, the better their achievement [10-13]. The focus of this study was to increase the confidence of the students and generate more positive attitudes in students by changing the wording of physics questions in order to increase their ability to understand, visualize and extract information. This was accomplished by asking students to read and solve several higher-level physics questions which required visualization and then analyzing their responses to determine both their ability to correctly sketch an image and the confidence with which they completed the task. The questions were then reworded to simplify the language and make the language more accessible to students. Students were then asked to complete the task using the reworded questions and those responses were then compared to the responses from the first set of questions.

Physics is an important subject but unfortunately, many students consider it to be very difficult. Physics courses tend to have a high failing rate and are sometimes reported as having a lower than desired or expected achievement of learners. Many students struggle with physics in both the secondary and the university level and beyond and are especially likely to withdraw from or perform poorly in the foundation program or the first year general physics courses [2, 11-13]. In Khalifa University (KU), more than one third of students get a grade "C" or below in the preparatory physics subject and results are similar in the mandatory introductory undergraduate level physics courses (mechanics and electromagnetism).

Procedure

1 Participants

The participants of this study were a group of Khalifa University students. Group one was comprised of 26 male students and 12 female students. The students came from mainly two levels; 10 students from the preparatory program, and 28 students from the first year undergraduate course. Group two included 10 male students and 16 female students. Of those, 10 students were from the preparatory program and 16 students from the undergraduate courses. Each of these students had taken physics courses in high school, and in one or both of the preparatory program and undergraduate level.

2 Materials

In this study students were given a group of mechanics questions covering a variety of topics such as forces, incline surface, 2D projectile motion, collision and equilibrium.

For group one: questions were taken from a fundamental physics text, that we do not use in our course, and which were written in plain English text using "passive voice." Students were asked to draw the diagram or sketch the figure to represent the scenario described in the question.

Group two was given two types of questions:

- Type A: The same physics questions used with group one but using more simplified language and having changed the structure to active voice. Students were asked to draw the diagram or sketch the figure described as well.
- Type B: Questions related to visualizing and spatial resonance skills but with no language [14-16]. These questions were solely visual and had drawings of several steps of folding a piece of paper. The paper folding question consisted of 11 steps; each step showed a drawing of a square piece of paper which had been folded 11 successive times. The final drawing in the sequence showed the folded paper with multiple holes punched through it at different positions. The students were asked to choose (multiple choice) from drawings of several unfolded papers to identify the one showing what the punched sheet from the 11 steps would look when fully opened.

The accuracy and the amount of details the students provided in their diagram was compared to the ideal diagram and was significantly important to this study.

3 Student Response

All students' answers were compared to the answer key in order to determine the degree to which the students were able to understand the text and produce the diagram described in the text. The accuracy of their answer was measured based on how many major details, such as direction, the correct angle, position of some objects to the reference, they included in their sketch. The accuracy of their drawing should demonstrate their ability to understand the question and then visualize it in order to draw the image.

Also, students were asked about their opinion of the type of questions, and how much it affected their ability to answer if those questions types were in a physics exam.

Results

Following the marking scheme of each question; each question was evaluated out of 4 marks, students sketches were compared to the ideal sketch. From group one with the passive voice, there was an average accuracy rate of 55.93% for undergraduate students and 47.78% average for preparatory students. Group two type A "active voice": there was an average accuracy of 63.20% for undergraduate students (increase 7.27%) and 51.65% average for preparatory students (increase 3.47%). There were two questions which posed a significant

challenge to students in both group one and group two in the "type A" category that students were unable to draw it accurately or at all. Any question not receiving a passing mark was considered failed. Group two type B "visualizing and spatial resonance": there was an average of accuracy 80.0% for undergraduate students and 70.0% average for preparatory students.

Discussion

Results of this study highlight some major issues that students face in solving physics problems. The two main issues that should be analyzed are the difficulties that language deficiencies present and the issues that students have with their basic knowledge of physics and their ability to use critical thinking and spatial reasoning skills.

Language

English is the second language for all the students involved in this study and the students have varying degrees of language ability and familiarity. This poses a particular issue for questions which are given to them which are written in an indirect way. When a person begins to learn English they will most likely be exposed mainly to sentences constructed in active voice instead of passive voice. This is because active voice is seen as much easier to understand because it is more direct and straightforward. A sentence in active voice is one that follows the pattern of subject-verb-object and in which the subject of the sentence is the one doing the verb. In contrast, a sentence in passive voice would be one in which the verb is being done to the subject. Passive voice can be challenging for students of English to master as they find it difficult to figure out who is doing the action and who is receiving the action when the sentence is structured this way. This poses a problem for students at the university level who are studying physics and who will encounter problems that describe certain situations, because physics textbooks will often use passive voice. For example, a physics textbook might say something like "the box is pushed down the plane by a spring," but the students will have a difficult time understanding that the spring is thing doing the pushing. Instead, they may assume that the box is pushing the plane because they are used to the active voice structure.

In this study the physics questions used were mostly framed in passive voice (group one) and an attempt was made to rewrite the question in active voice to see if that small change could make them more easily accessible to the students. For example, the original form of one of the questions stated "a 1 kg box is launched from spring." Assuming the students understand the word launched, they may still struggle to understand that the spring is the thing that is causing the action because in this structure the box is the subject and it may cause students to believe that the box is doing something to the spring. This question was reworded to say "a spring launches a 1kg box" That change is quite simple, but the fact that the spring is now the subject will help students to connect the action of launching to the spring.

Students enrolled in these courses certainly should understand passive voice, but they may need to be explicitly taught the difference before they are expected to understand a passage written in passive voice.

Another issue that had to be addressed in order to make the questions more accessible to second language learners was the issue of uncommon vocabulary. A marker of a language learner is that when confronted with a word that has more than one meaning, they often will only know the most common meaning of the word. This becomes an issue in physics because the questions contained words like plane and beam in this study. Students will often read the word “plane” and instead of envisioning a flat surface, will assume it is referring to an airplane. This misunderstanding can throw off the whole visual. Students either need to be pre-taught that in physics the word plane means a flat surface or there needs to be clarification in the question itself. The same is true of the word “beam”. One of the questions in this study contained the word “beam” referring to a long and thick piece of wood or metal. However, students will have heard the word beam referring to a beam of light more often than referring to metal or wood. This could be due to the use of the phrase “high beams” in their cars or from the phrase “laser beam” in video games. This misunderstanding would cause confusion because a beam of light would not be able to support any amount of weight “the question mentioning a worker standing on a beam”. In the updated version of the questions this issue was clarified by using the term “wooden beam”

Another strategy that was used in rewriting the questions was to put the actions in the order in which they occurred. One the questions stated “The glass strikes the floor after falling vertically a distance (h) and moving horizontally a distance (d) from the edge of the table” This could present a challenge to students who have difficulty understanding that “after” when used in this way signifies that the falling vertically actually happened before the striking the floor. The question was modified to read “The glass fell off the table vertically a distance (h) and horizontally a distance (d) and then struck the floor”

By reducing the areas of possible confusion in the way the question is explained, the language deficiencies that many students face become less of an issue and teachers are better able to assess students’ understanding of the actual physics concepts instead of those results being distorted by a simple misunderstanding of the wording and word order of the questions.

It is interesting to note that in the first set of questions, students had to rely on their language skills to understand the question and that in the second set of questions where students were asked to visualize the folded piece of paper, there was no language requirement and students did significantly better at the tasks that did not require reading or language, keeping in mind students had this part supported with multiple choices answer, which could consider as extra support to imagine the situation. Therefore, while many professors worry that the students’ struggle with questions lies, in large part in their deficiencies in critical thinking, it cannot be said that language plays no part in their struggle with physics. This indicates that in

order to improve students' success rate in physics, the language deficiencies must be addressed because we cannot take language completely out of physics.

Physics concepts

Many school subjects, like biology for example, involve lots of memorization. A typical biology question might ask students to 'draw the parts of the digestive system, label them, and explain what they do. This type of question is fairly straightforward and easy to accomplish if the students have studied, because humans are actually very good at memorization. Physics, on the other hand, requires, not only a certain amount of memorization, such as remembering Newton's third law, but also requires students to apply what they've learnt in order to solve problems. This study illustrated that difference quite well. The students know the meaning of a system in equilibrium from their physics classes, but they were not able to apply that knowledge in order to draw the forces acting on an object when that image was described to them in a few lines of English text.

Another issue that students face in physics is that they attempt to use the same thought process in physics that they use in other subjects. Rather than understand why the equations or ideas work, they attempt to learn a 'method' or a process of solving the problems and then use that one method on all questions. Therefore, if a student gets a problem about motion in one dimension they know this is a problem of type 'x' so they try to apply a solution they've learnt for problems of type 'x'. Unfortunately, if the problem is slightly different to one they've seen such as making the motion in the y- axis, they make mistakes in the linear acceleration (a) and the gravity acceleration (g). This is frustrating because the student doesn't understand what they've done wrong and they therefore, believe that the problem, and physics in general, is more difficult' simply because they have to rely on the specific approaches that they have memorized and are unable to come up with other paths to the solution.

In addition, physics is extremely hierarchical. In biology, for example, a student might learn about the respiratory system and about the human senses, but a student who doesn't understand the respiratory system might still understand the human senses. Understanding one of these is not dependent upon an understanding of the other. Physics usually involves starting with basic ideas and building on them. If you don't understand motion in one dimension, you won't understand motion in two dimensions. Hierarchical, in this sense, means 'building upon previous concepts' and physics is much more hierarchical than other subjects. In other words, students must know when to apply the knowledge they learnt previously without being prompted.

Many students look at physics and think it is not relevant to their daily life', but what they don't understand is that the physics principles are used everywhere in our everyday lives. For example, when playing billiards, you are applying physics rules of collisions or when car companies create designs to minimize the damage that could happen in a car accident, follows

the impulse rules. This is a problem which students and possibly some teachers face, which is the inability to link information.

In addition to all the reasons mentioned above, spatial reasoning was a major factor in student's ability to transfer these text questions into a figure or image. Spatial reasoning is a category of reasoning skills that refers to the capacity to think about objects in space and, in the case of this study, draw a picture about the objects from the limited information provided from a set of physics questions. The availability of spatial working memory could directly affect the ability of drawing some of our questions such as; "There are two smooth benches of different heights connected by a ramp. The taller bench is X1 m and the lower is X2 m. On the taller bench a spring is compressed by a (M) g ball. The spring is released and sets the ball into motion… etc.". In order to successfully draw the image described, students would have to integrate multiple components such as; the horizontal motion, incline surface and later the 2D projectile motion. A certain amount of visual spatial working memory is required to be able to visualize the scenario and draw it from beginning to end. Consequently, students who lack spatial reasoning skills will find it extremely difficult to draw an image for physics problems because so many of them include multiple spatial parameters.

Conclusion

The ability to visualize a scientific text is an important part of solving problems. Students might face different types of difficulties in solving physics problems in homework or exam. One of these major challenges is the ability to convert the text into a mental image and apply the physics concepts at the same time. This challenge is not necessarily due entirely to deficiencies in the English language nor to an insufficient knowledge of math; it is more related to a student's spatial reasoning ability and how they can think through multi-step scenarios. In order to combat these issues, students need to be introduced to the scientific language used in the physics textbooks including the use of passive voice and the vocabulary used in physics that may have another meaning. More importantly, they need to be taught to understand and visualize the scenario from the question and not rely only on the figure provided with the question. Students need to demonstrate their understanding of physics vocabulary and concepts as well as show scientific critical thinking in order to be successful in their work.

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