Educational Research (ISSN: 2141-5161) Vol. 4(5) pp. 430-436, May, 2013
Available online@ http://www.interesjournals.org/ER

Full Length Research Paper

Investigating the State of Knowledge of the Physics Concepts by UAE University Students

***Ehab Malkawi, I. M. Obaidat and N. Qamhieh**

Department of Physics, U.A.E. University, Al-Ain, P.O. Box: 15551, U.A.E.

Abstract

We investigate the level of understanding of the basic physics concepts by students taking the introductory physics course in Mechanics at United Arab Emirates University (UAEU). Based on a short research-based multiple-choice test, we extract information about the level of knowledge of the students. In general, the students were found to have a poor understanding of Kinematics and Force-Motion relation. The results of the test have been analyzed by using the mathematical functions, *concentration factor C* and *concentration deviation* Γ as function of the score S (percentage of students responded to the correct answer). The results show that our students may hold particular incorrect models in both topics. Nevertheless, student responses to some of these questions which deal with Newton's II law show relatively good performance.

Keywords: Physics concepts in mechanics, concentration factor, concentration deviation, mental models, evaluation methods, multiple-choice test.

INTRODUCTION

Overview of the performance of students

Physics instructors all around the world are constantly reporting on students level of understanding basic concepts in physics at all levels of study; especially in the introductory physics courses (Obaidat et al., 2009a,b; Redish, 1998; Hammer, 1994; May et al., 2002; Obaidat et al., 2008; Halloun, 1985). Several factors are considered to affect students' attitudes towards understanding physics concepts in introductory physics courses: Ineffective instruction methods, students' misconceptions inherited from pre-college about physics, negative attitudes toward learning physics, weakness in critical thinking, insufficient mathematical skills, poor problem-solving techniques, poor testing methods, and inconvenient evaluation methods could be some of the possible factors.

In the last decade, weak performance in understanding physics has been observed at United Arab Emirates University (UAEU). However, the factors that influence the weak performance are difficult to be completely specified, isolated, and quantified. Some work has been conducted to expose the importance of the issue in the physics department (Obaidat et al., 2008, Obaidat et al., 2009). Nevertheless, much work still needs to be dedicated to initiate serious studies to revise and enhance the instruction methods, the physics curriculum, and eventually the students' performance.

Multiple-choice questions are a very useful instrument to evaluate student understanding of the physical concepts (Killoran, 1992), especially in large classes. However, usual multiple choice analysis normally relies on scores. It doesn't extract information from the student's incorrect answers, which contain a large body of information on students' understanding physics concepts. If multiple choice questions are prepared based on various reasoning that students might have about the physics problems, valuable information can be obtained by focusing on mental models that lead students to select the wrong answers.

In this work we extend our pervious study (Obaidat et al., 2009) on the investigation of students' grasp of the basic physics concepts. There is one major improvement in this work, namely, a more comprehensive and detailed test is used. In this work the test is composed of 10

*Corresponding Author E-mail: emalkawi@uaeu.ac.ae; Tel: +971-37136318

multiple-choice questions which cover the basic concepts included in the study. In the previous study the test was composed of only 5 multiple-choice questions. The larger number of questions enabled us to discriminate better between the choices of the students and provided a better tool for quantifying the grasp of the basic concepts. The study involved 210 first year science students who were taking their first course in classical mechanics at UAEU. The students were mainly females and were distributed on 12 sections taught by several instructors. The test covers material that was taught and explained during the first two months of the semester. Students wrote the test one week after the mid-term examination. To measure the distribution of students' responses to multiple-choice questions in all sections, a very convenient method, concentration analysis, is used (Obaidat et al., 2009a, b; Redish, 1998; Hammer, 1994; May et al., 2002; Obaidat et al., 2008; Halloun, 1985; Killoran, 1992; Bao, 2001). Concentration analysis may indicate if students have common incorrect models. A key element of this method is the *concentration factor.*

The concentration factor

The distribution of students' responses to multiple-choice exams can provide valuable information on their state of understanding (Obaidat et al., 2008; Obaidat et al., 2009; Bao, 2001; Bao, 1999a, b). When the responses are highly concentrated in a particular question, it implies that many students are applying a common mental model associated with the particular question. On the other hand, responses can be close to a random distribution among all the choices if the students have no consistent models of the topic. Therefore, the distribution of the students' responses can yield information on students' thinking models.

Concentration factor is a function that maps the response of a class on a multiple-choice question to the interval [0, 1] with 0 corresponding to the random distribution of answers selected by students and 1 corresponding to all students selecting the same answer (Bao, 1999a). To define the concentration factor, suppose that a multiple-choice question with m choices is given to N students. The concentration factor, C, can be written as:

$$C = \frac{\sqrt{m}}{\sqrt{m}-1} \times \left(\frac{\sqrt{\sum_{i=1}^{m} n_i^2}}{N} - \frac{1}{\sqrt{m}} \right), \qquad (1)$$

where n_i is the number of students selected the *i-th* choice.

The concentration factor was used successfully in analyzing the students answers of Force Concept Inventory (FCI) exams (Bao, 2001; Bao, 1999a, b; Hestenes et al., 1992). Herein the value of C can provide information about the concentration/diversity of students' responses on a particular multiple-choice question.

Student response patterns are formed by combining the question's concentration factor (C) with the question's score (S), which is the percentage of students who answered a particular question correctly. Like the concentration factor, the score has values in the range of [0, 1]. A three-level coding system is used to classify the scores: For a score between 0 and 0.4, a low level (L) is given. A medium level (M) is specified for score above 0.4 and below 0.7, and a high level (H) is given for a score between 0.7 and 1. By combining C and S in a CS-plot we can analyze whether the question triggers a common "misconception". A situation of low score (S < 0.4) but high concentration value (C > 0.5) is represented with an LH type of response. It is often indicates that students are likely to have a very popular incorrect model. In a situation of medium score (0.4 to 0.7) and medium concentration (0.2 to 0.5), referred as an MM type of response, students are often in a mixed state between the correct and incorrect models (Bao, 2001). Students' responses to each question represent a point on the C-S plot. Due to the entanglement between the score and the concentration factor, data points can only exist in certain regions on a C-S plot. With m choices multiple choice questions, the allowed values of C are bounded between the two boundaries defined by:

$$C_{\min}(S) = \frac{\sqrt{m}}{\sqrt{m}-1} \times \left(\frac{\sqrt{(m-1)\left(\frac{N-S}{m-1}\right)^2 + S^2}}{N} - \frac{1}{\sqrt{m}} \right), \qquad (2)$$

and

$$C_{\max}(S) = \frac{\sqrt{m}}{\sqrt{m}-1} \times \left(\frac{\sqrt{(N-S)^2 + S^2}}{N} - \frac{1}{\sqrt{m}} \right). \qquad (3)$$

The concentration Deviation

The concentration factor gives the overall structure of student responses and is dependent on the score (correct choice). In order to untangle the concentration and the score and to see a more detail distribution of the incorrect responses, another concentration variable called the *concentration deviation*, Γ, can be defined (Bao, 2001):

$$\Gamma(S) = \frac{\sqrt{m-1}}{\sqrt{m-1}-1} \times \left(\frac{\sqrt{\sum_{i=1}^{m} n_i^2 - S^2}}{N-S} - \frac{1}{\sqrt{m-1}} \right). \qquad (4)$$

Equation (4) is basically similar to equation (1), the difference is that the score (correct response) is removed from the sum, which makes Γ and S independent. Hence, whatever the score, Γ is unlike C, it can have any value within the full range of [0, 1]. Consequently, on the ΓS plot there is no restriction on the allowed area.

In evaluating the overall model condition of student responses to multiple choice questions, both Γ and C are important to be considered to properly model the student responses for different aspect of the data.

The Test

Our test aims to investigate and quantify the students' understanding of basic physics concepts of motion. The test consisted of 10 multiple-choice questions which tackled basic concepts of kinematics and dynamics, which are part of the topics students covered in an introductory physics course. The questions were written in very simple English and tackle directly physics concepts. Hence, students might hold a misconception and a naïve mental model if a considerable fraction of students miss the correct answer. The study includes several questions on each concept.

The study involved 210 first year science students who were taking their first course in classical mechanics at UAEU. The students were mainly females and were distributed on 12 sections taught by several instructors. The students were given 20 minutes to finish the test. The test covered material that was covered and explained during the first two months of the semester and students sat for test one week after the mid tem examination. The test is attached in the appendix.

RESULTS

Table 1 shows the number of students with their choices in all questions, where n_1, n_2, and n_3 correspond to the number of students responded to choices a, b, and c respectively. Table 1 also shows the correct answers for each multiple choice question. By using equations (1) and (4), the values for the concentration factor C and the concentration deviation Γ are calculated for each question. To visually study the results, the C-S and the Γ-S plots are constructed in figure 1 and figure 2, respectively. In these plots, S is the percentage of students responded to the correct answers. The values of C_{min} and C_{max} for each score (correct answer) are calculated using equation 2 and 3 and then are plotted on the C-S plot.

Each point on figure 1 represents a response to a question. It is clear from figure 1 that responses to all choices are located in the region bounded by the two boarders defined by C_{min} and C_{max}, in view of the fact that C depends on the score. Also figure 1 shows an overlap between some responses and the score whenever that choice the correct answer. Following the three-level coding scheme, L, M, and H discussed in section 1, it is easy to see that all questions have either LM or ML type, and there are no questions have the other types like, LH, LL, MM, and HH exist. The questions and their types are listed in table 2. It is interesting to see how the concentration of student responses to incorrect answers is distributed in the CS plot. In general the data show that they are concentrated at the boundaries of the allowed region at a specific concentration, except at high performance cases where S is large. For instance, the answer of Q10 is choice "c", and has C = 0.38. At this concentration factor, the score of student responses to choices "a" and "b" are 0.014 and 0.67, respectively. For Q6, figure 1 show that all choices have the same student response, they are uniformly distributed. The same procedure can be applied for all questions.

To get more information on students' giving incorrect answers, we plot the entangled parameters Γ versus S as shown in figure 2. From the data, we can see the interesting result that the Γ's for low performance questions, like Q10 which has LM type, are consistently higher than that of mid and high performance questions, like Q2. Since the high values of Γ indicate strong distracters, it can be inferred that the low performance questions are dominated by situations where student responses have strong alternative models.

DISCUSSION

The CS plot shown in figure 1 could be divided into regions according to the coding scheme discussed in section 1. Each region specifies a type of answers. There are important different types based on the score and the concentration factor values. If a question has high score and high concentration, it is classified as HH type; this implies that there exists only one correct model system, and the students doing well in this question. If the question is classified as LH, it means that there is a one dominant incorrect model system. The LM tells that there are two incorrect model systems. When the question has MM type, it implies that there are two model systems, one is correct and the other is incorrect. With low scores and also low concentration (LL type) the majority of model systems are represented evenly, and students did not predominantly favor one or two particular choices (they choose their answers randomly).

The poor performance of the students in understanding the physics concepts in the test is evident as shown in the CS and ΓS plots in figures 1 and 2, respectively. The data displayed in figure 1 indicate that student responses are grouped into two major categories, LM and ML. The LM type is a strong indication for the existence of two incorrect models. While the scores of the students are low, most of the responses are concentrated on one of the two incorrect choices. The questions with LM type are listed in table 3, and they are classified according to their contents which deal with two physics concepts, the Kinematics, and Force-Motion relation. By analyzing the distracters of the questions listed in table 3 it becomes clear that these questions are associated with

Table 1. The number of student responses, the concentration factor C, and the concentration deviation Γ for all questions.

Question	Correct Choice	n1	n2	n3	C	Γ
Q1	c	131	25	54	0.26	0.50
Q2	c	33	64	113	0.14	0.12
Q3	c	22	134	54	0.28	0.56
Q4	c	120	10	80	0.26	0.75
Q5	b	135	45	30	0.27	0.45
Q6	b	85	87	38	0.07	0.19
Q7	a	50	133	27	0.26	0.48
Q8	c	26	122	62	0.20	0.46
Q9	c	101	18	91	0.18	0.53
Q10	c	3	139	68	0.38	0.93

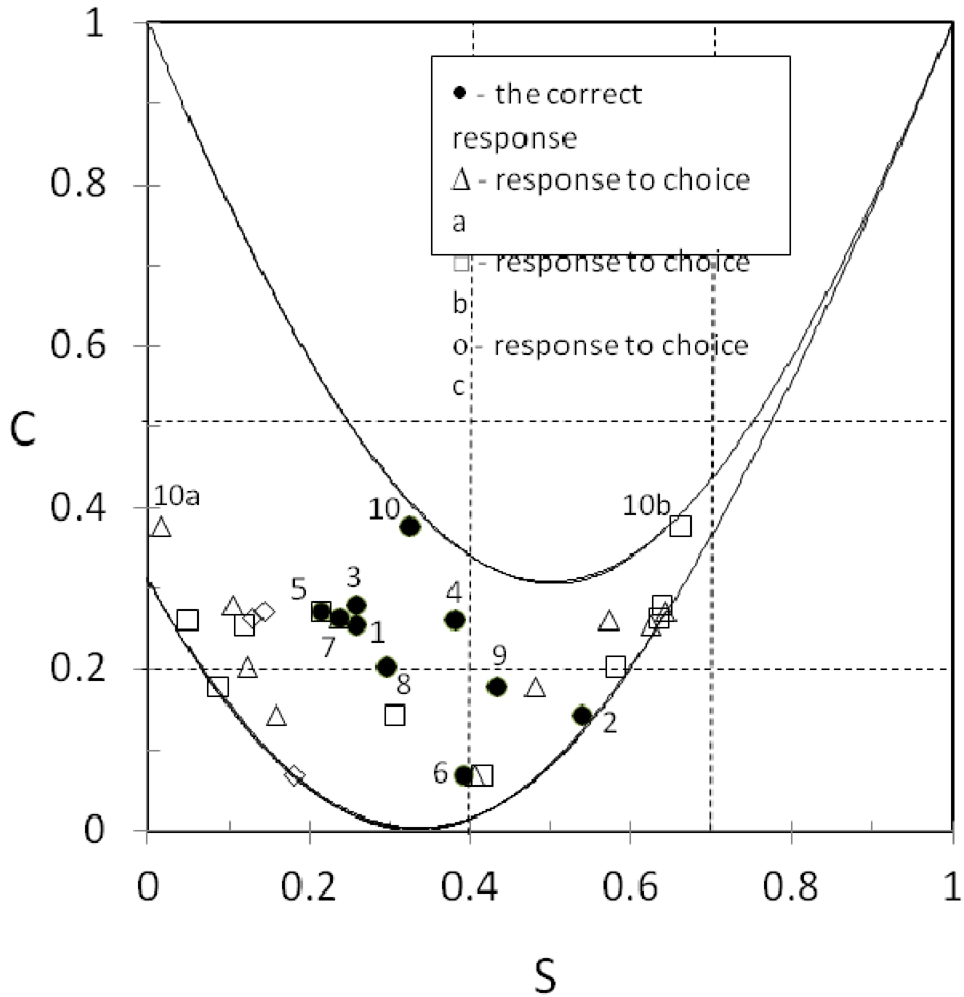


Figure 1. The concentration factor is plotted versus the response to each choice in all questions. The full circle is the score (correct response). The regions bounded by the dashed lines define the type of the student response, and the numbers next to the symbols correspond to the question numbers.

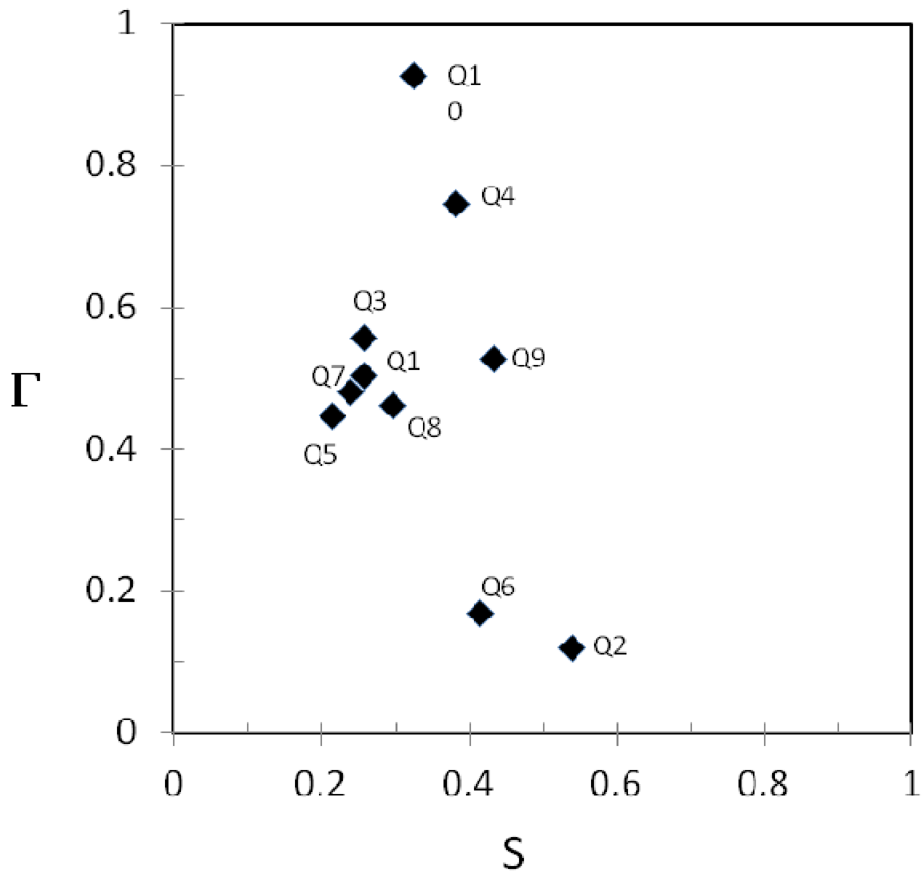


Figure 2. The concentration deviation versus students score (ΓS plot) for the 10 multiple choice questions in the test. The higher is the Γ value the lower is the performance.

Table 2. Using the three-level coding scheme, the table shows the response types for all questions.

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
S	0.26	0.54	0.26	0.38	0.21	0.40	0.24	0.30	0.43	0.32
C	0.26	0.14	0.28	0.26	0.27	0.07	0.26	0.20	0.18	0.38
Type	LM	ML	LM	LM	LM	ML	LM	LM	ML	LM

two naïve models. In Kinematics, the selected distracters of the questions make it clear that many students might hold a misconception about acceleration. Their naïve mental model is based on the statement which says "*the object with a larger speed will have a larger acceleration"*. This single incorrect model is evident from the high students percentage appears in table 3 who choose the associated distracters as well as from the CS plot in figure 1. In Force and Motion, many students believe that *the direction of motion of an object must be the same as the direction of the force acting on it*. Therefore, students might hold a misconception about Force and Motion, and a single mental model can be associated to their thinking and understanding to this topic. The relatively high values of Γ associated to the MM questions is an evident to misconceptions students might hold. The worst result was for question 10, about Force-Motion relation; herein students thought that *force is a must to act on a moving object*.

The MM type questions, questions 2, 6, and 9, implies that more than 40% of the students are doing well but a significant number of students (more than 40%) have a tendency to use a common incorrect model. In question 2, while 53% of the students respond to the correct choice "c", 30% of them chose choice "b". Thus, many students are found to understand the kinetic equilibrium of objects; an object moving with a constant velocity has no acceleration. In question 6, students are more or less divided between the concept refers to the Newton's II law where 41% of the students have the correct model and 40% of them have the wrong one. Moreover, students responded to question 9 are divided similarly divided where 43% and 48% corresponded to the correct and incorrect model, respectively. It is interesting here to note that all questions with MM type are related to Newton's II law. The relatively good performance is clearly displayed in figure 2, where values of low Γ are presented for these questions.

We believe that our multiple choice test is well designed to target the naïve mental models which our students may hold. It is obvious from the CS plot which does not show any score with an LL type. This is an indication that the chosen distracters are attractive to the students. As we can see in all questions, the distracters reflect common student models, and the context of the question also does include a common student model.

CONCLUSION

We have investigated the level of comprehension of very basic physics concepts among first year students at UAEU. The study was conducted using a well-designed multiple-choice test that focused on the concepts of kinematics and Force-Motion relation. The concentration factor, C, versus the score S plot show that most of the students share a single incorrect mental model in both Kinematics and Force and Motion topics. In general, the low performance of students is evident from the high concentration deviation, Γ values on the Γ-S plot, except for questions on Newton's II law which demonstrate low Γ values. The poor performance of our students reveals that our students may hold common alternative naïve mental models.

ACKNOWLEDGMENT

The authors would like to thank all instructors helped in conducting this study. This work is supported by the Academic Affairs department at the UAE University.

REFERENCES

Bao L (1999a). Model Analysis; A Quantitative Approach to Study Student Understanding of Physics, Ph.D. thesis, University of Maryland.

Bao L (1999b). Dynamics of Student Modeling: A Theory, Algorithms, and Application to Quantum Mechanics, Ph.D. dissertation, University of Maryland.

Bao L, Redish EF (2001). Concentration Analysis: A Quantitative Assessment of Student States, Phys Edu Res Supp to the A. J. Phys, 69, S45-S53.

Halloun I, Hestenes D (1985) The initial knowledge state of college physics students, Am. J. Phys. 53, 1043.

Hammer (1994). Epistemological beliefs in introductory physics, *Cognit. Instruct.* 12, 151-183.

Hestenes D, Wells M, Swackhamer G (1992). Force Concept Inventory. Physics Teacher 30, 141-158.

Killoran J (1992). In Defense of the Multiple-Choice Question, Social Education.

May DB, Etkina E (2002). College students' Epistemological self-reflection and its relationship to conceptual learning, *Am. J. Phys*. 70, 1249-1258.

Obaidat IM, Malkawi E (2009a). The Grasp of Physics Concepts of Motion: Identifying Particular Patterns in the Students' Thinking at UAEU, IJ-SoTL 3, 1, 16pp.

Obaidat IM, Malkawi E (2008). Enhancing Learning Physics through Challenging the Methods of Evaluation. Int. J. Sci. Res. 17, 147-152.

Obaidat IM, Malkawi E (2009b). Naïve Mental Models of UAEU First Year Students: Poor Performance in Basic Concepts of Motion. Int. J. Sci. Res. 18, 17-23.

Redish EF, Saul JM, Steinberg RN (1998). Students expectations in introductory physics, *Am. J. Phys*. 66, 212-224.

Appendix

The test

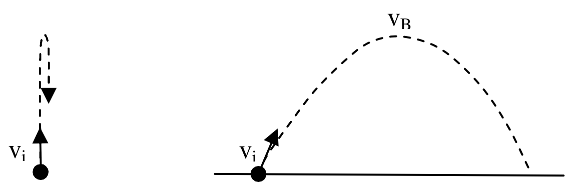
1- If the velocity of an object at some instant of time is zero, then at that instant of time
a. its acceleration must be zero
b. its acceleration cannot be zero
c. its acceleration may not be zero

2- If the acceleration of an object is zero at some instant of time, then at that instant of time:
a. its velocity must be zero
b. its velocity cannot be zero
c. its velocity may not be zero

3- Two objects of masses m_1 and m_2 are moving to the east as shown in the figure below. At some instant of time their speeds are v_1 = 10m/s and v_2 = 20m/s. Which statement is correct?
a. $a_1 > a_2$
b. $a_1 < a_2$
c. we cannot determine which object has larger acceleration

4- In one-dimensional motion, if the acceleration of an object is negative, then
a. the object is slowing down
b. the object is speeding up
c. the object might be speeding up or slowing down. This depends on its direction of the motion

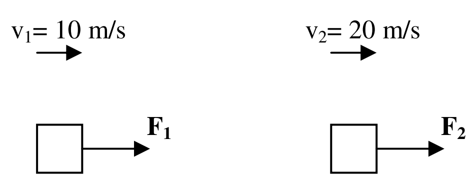
5- In the figure shown below, which statement is correct?
a. $v_A = v_B = 0$
b. $v_A = 0$, but $v_B \neq 0$
c. $v_A \neq 0$, but $v_B = 0$



6- If the net force acting on an object is constant, then
a. its velocity must be constant.
b. its velocity must be changing.
c. the object must be at rest.

7- Which statement is correct?
a. An object can move in the opposite direction of the net force acting on it.
b. An object must move in the same direction of the net force acting on it.
c. An object must move in a perpendicular direction to the net force acting on it.

8- Two objects of masses m_1 and m_2 are moving to the east under the effect of the forces $\mathbf{F}_1$ and $\mathbf{F}_2$ as shown in the figure below. At some instant of time their speeds are v_1 = 10m/s and v_2 = 20m/s. Which statement is correct?
a. $F_1 > F_2$
b. $F_1 < F_2$
c. We cannot determine which force is larger



9- If the net force acting on an object is zero, then
a. the object must be at rest.
b. the object must be in motion.
c. the object may be in motion.

10- If an object is moving, then
a. there must be no forces acting on it.
b. there must be forces acting on it.
c. there might be forces acting on it.