Investigating Misconceptions in Mechanics Using MCQs

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Inquiry based learning places a strong emphasis on students questioning what they observe and analysing different possibilities. These skills are at the core of multiple choice questions (MCQs). The study reported here used a modified form of MCQ where students were encouraged to display the work they did in choosing their answers. The MCQ-tests examined the topic of Mechanics in Physics for Leaving Certificate. The concepts that caused greatest difficulty were identified. Misconceptions were also recognised and the "alternative thinking" that contributed to these misconceptions was explored. Many students had difficulty with aspects of motion and force in particular. Sixty questions were answered by 100 students in this study. The study took place in the academic year 2013-14. Teachers may find these results helpful in deciding what aspects to emphasize in teaching mechanics concepts.

INTRODUCTION

Multiple Choice Questions (MCQs) offer a valuable tool for learning. While their primary function is assessment of learning, they can be used to enhance learning. One of the advantages of multiple choice questions is that they are objective, so variations in marking due to subjective factors are eliminated (Jolliffe et al, 2001). MCQs are efficient because questions take less time to complete and less time to correct, compared to other forms of test (Simes et al 1997). Obviously, the more carefully crafted the question, the greater is the potential for learning. Questions which simply test memory of facts are quick to produce, and quick to answer but only serve a limited purpose. They only test the base level of Bloom's taxonomy of educational objectives…..Recall of facts. However, well designed MCQs have the capacity to test higher order learning like, comprehension, application, analysis, synthesis and evaluation. Through doing so, students are forced to think more deeply and hopefully reach a fuller understanding.

One of the most crucial things to do to probe student understanding is to choose really good *distracter*s that present the student with plausible answers that are not correct. This may deflect their attention from the correct answer and force higher order thinking to select the answer they believe to be correct. In the event that one of the distracter answers is chosen, it can reveal misconceptions that the student has, or uncertainties. Thus for effective learning to take place, the incorrect answers need to be teased out between student and teacher so that true understanding occurs.

In the early 1980s Hestenes and Halloun developed an instrument called the Mechanics Diagnostic Test (MDT) that measured the discrepancy between the students' common sense beliefs and their belief in the Newtonian force concept as taught in lectures. In 1992, an improved version of the MDT was published as the Force Concept Inventory (Hestenes et al, 1992). The Force Concept Inventory (FCI) is a test measuring mastery of concepts commonly taught in a first term of physics at University. The FCI could be used by any physics instructor to evaluate their own students. Another mechanics tests is the FMCE or Force Motion Concept Evaluation (Thornton & Sokoloff, 1998) which is an instrument similar to the FCI that looks at fewer concepts and makes heavy use of graphical and pictorial representations. The FCI and the FMCE are the two most commonly used physics concept tests in use today. Unlike most multiple choice tests, the FCI distracters come from common-sense student responses to open-ended versions of the questions used on previous occasions.

The research reported here was based on an attempt to apply the broad principles of the FCI and the FMCE to school physics classes in Ireland. Completely new questions were constructed tailored to the Irish Physics curriculum at Leaving Certificate level. The research was conducted in senior cycle classrooms in Ireland in the academic year 2013-2014. Nine teachers facilitated one or more tests with their students during normal teaching periods as part of assessment for learning consistent with the programme of study the students were undertaking. Some classes had as few as seven students and others had as many as twenty students. In some cases the students were in 5th Year and in other cases they were in 6th Year. The gender of the students was not identified as this was not under investigation. The nine teachers who participated were the ones who volunteered to do so out of a random sample of twenty who were invited to participate.

RESEARCH DESIGN

The topic of mechanics on the Leaving Certificate Physics higher level course was chosen for this investigation. The topic was subdivided into six units based on the subdivisions commonly recognised by most teachers. The six units were:

- Velocity and Acceleration
- Force, Mass, Momentum
- Pressure, Gravity, Moments
- Work, Energy, Power
- Circular Motion
- Simple Harmonic Motion

Questions were constructed using the Multiple Choice Question MCQ format where four or five possible answers were offered. Only one answer was correct, and the other answers were designed to be as plausible as possible and are referred to as distracters. The art of providing good distracters is an important skill in writing good MCQs (McKenna & Bull, 1999).The option to use two-tier MCQ was considered but since the Irish curriculum makes very infrequent use of MCQs it was felt that many students might be over-awed by the complexity of two-tier questions. The MCQ tests were designed to help both student and teacher to identify student problem areas so they could be re-taught to correct any misconceptions or areas of difficulty and develop a deeper understanding of a topic (Mann & Treagust 1998; Odom, & Barrow 1995).

The questions themselves were designed so as to appeal to different learning styles and to test different skills. A bank of questions was assembled involving a variety of styles including; some visual, some mathematical, some verbal, as well as those which required students to interpret graphs, or to solve problems. In order to achieve a degree of consistency and uniformity for the students and the teachers who would use these MCQ tests, each test had the following characteristics:

- Each test was contained on the two sides of a single A4 page
- There were ten questions on each test (five on each side)
- Each batch of ten questions had a variety of styles (verbal, visual, mathematical)
- Questions were graded so that questions one and two were easy and questions four and five were challenging (Similarly, questions six and seven were easy and questions nine and ten were challenging)
- Teachers could choose to set five questions or ten questions for their students to do at a time.
- Teachers could choose whether to allow five, ten or fifteen minutes depending on circumstance.
- As much space as possible was allowed on the page for students to write.
- Teachers were asked to encourage their students to display all relevant work (with the incentive that if the answer were incorrect, that the work might merit some attempt mark)
- In the event of an incorrect answer, the students' written work could be analysed to see the type of thinking that led the student to offer the answer they chose.

The content validity of the MCQ tests was established in three ways. First, early versions of the tests were critiqued by physics teachers and by graduate students. Second, the MCQ tests were taken by graduate students to verify agreement on correct answers. Third, the tests were read by a Science Teacher without a specialist Physics background to ascertain if the language of the questions and the multiple choice responses was understandable.

It is difficult to give the same MCQ tests to the same students twice after a meaningful time interval. Accordingly the reliability of the tests was established in the following two ways. First, the results of two class groups who completed the MCQ tests were compared to the results that the same students obtained on a conventional written exam on the same material. The same students did well both times and for the most part the same students who scored poorly in the MCQ also scored poorly in the conventional written exam. Second, the results of the various MCQ tests across several different class groups (taught by different teachers) showed similar patterns of answer profiles.

Upon completion of the tests, the teacher was asked to photocopy the student work, correct and return the originals and forward the copies to the researcher for analysis. Codes were assigned to each test received to facilitate *cross-analysis*. The copies of the tests were then corrected and the chosen answers; A, B, C, D and E entered in a spreadsheet. Numerical data was gathered on the sixty questions that were answered by one hundred students. This collated data on how many students chose the correct answer to each question and how many chose each other “incorrect answer” was analysed. Questions where significant numbers of students chose a particular incorrect answer were examined. In some of these cases possible interpretations are offered for the choice of answer or for the popularity of a particular answer.

FINDINGS

The responses from 100 students were analysed and the response levels for the various questions are therefore presented as percentages. In many cases, a high percentage of students chose the correct answer. However quite a large number of questions, approximately one third of the sixty questions revealed some interesting insights into where students had difficulty. In some cases an incorrect answer may indicate a simple lack of knowledge. In some cases there is a certain evidence of *misconception* and certainly examples of *alternative thinking* arise in many of the student responses. Some of the most noteworthy findings are outlined below. In some of the more difficult questions, students didn’t choose any answer and so the percentages in these cases may seem not to tally. Percentages were calculated based on the number of students who sat the tests not on the number who answered any particular question.

Motion

When a ball is thrown vertically and returns to its starting point, which of the following is true?

A. Its velocity throughout is constant
B. Its acceleration was zero at the highest point
C. The time going up exceeded the time falling down
D. Its displacement is zero

The correct answer D was chosen by 52% of students. It is interesting to note however that 44% chose option B.

A car, starting from rest with constant acceleration, travels 64 m in 4 seconds.
What is the magnitude of the acceleration?

A. 2 ms^{-2}
B. 4 ms^{-2}
C. 8 ms^{-2}
D. 16 ms^{-2}

The correct answer C was chosen by 51% of students but 45% chose D. They would appear to have concluded that division of the two given numbers was the best option.

A body starts from rest with a uniform acceleration, a.
The time t taken for it to undergo a displacement s is given by

A. $t^2 = 2s/a$
B. $t^2 = 2a/s$
C. $t^2 = a/2s$
D. $t^2 = s/2a$

The correct answer A was chosen by 47% of students but 37% chose B. Perhaps some of those who chose B were familiar with $v^2 = u^2 + 2as$ and thought the 2a/s sounded right.

Momentum
When a cannon ball is fired and the cannon recoils which of the following is true?

A. the cannon's momentum is greater than the canon ball's momentum
B. the cannon's momentum is equal to the canon ball's momentum
C. the cannon's momentum is less than the canon ball's momentum
D. the sum of the two momentum values is zero

The correct answer D was chosen by 34% but 46% chose B. Some of the high number who chose B may have overlooked the vector nature of momentum.

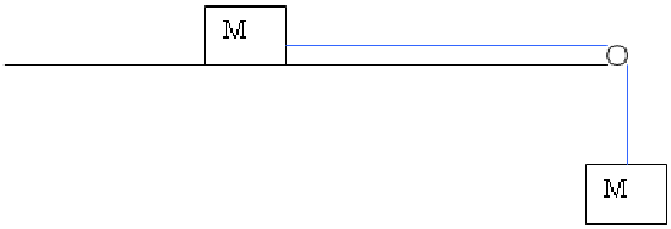
Two bodies, each of mass ,m, are travelling in opposite directions with speeds of $4\ ms^{-1}$ *and* $6\ ms^{-1}$*, respectively, when they collide. After the collision they move together as one body with speed* v*. The value of* v *in* ms^{-1} *is*

A. 10
B. 5
C. 2
D. 1

The correct answer D was chosen by 12% of students. The fact that 50% chose C may indicate difficulties with the use of mathematics in problem solving in Physics

Force

If the contact between the table and the box is smooth and if the pulley is smooth, and the inelastic string taut, and the masses equal, the acceleration of the hanging mass will be



A 2g
B g
C g/2
D 0

where g denotes the acceleration due to gravity

The correct answer C was chosen by 19% of students but 49% chose B

Gravity
The gravitational force between two objects in outer space is 5400 N.
How large would the force be if the two objects were three times as far apart?

A. 16200 N
B. 1800 N
C. 600 N
D. 200 N

The correct Answer C was chosen by 28% of students but 59% chose B.

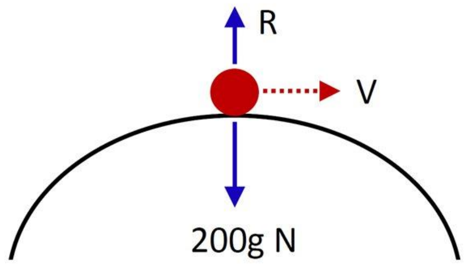
Work
When a person holding a box applies a force of 40 N vertically upwards so as to keep the box stationary at a height of 2 m above the ground, the work done by the person is

A. 80 J
B. 40 J
C. 20 J
D. 10 J
E. 0 J

The correct answer E was chosen by 26% of students but 35% of students chose A. This might indicate that some students missed the point that while the object is stationary, the displacement is zero and the resultant work is zero.

Circular Motion

A bridge is in the shape of an arc of a circle of radius 80 m. The greatest speed that a ball of mass 200 kg can travel over the highest point of the bridge without losing contact with the road is



A. 32 ms^{-1}

B. 28 ms^{-1}

C. 24 ms^{-1}

D. 20 ms^{-1}

E. 16 ms^{-1}

The correct Answer B was chosen by 43% of students but 23% chose C

Simple Harmonic Motion

SHM1: A horizontal platform is oscillating in a vertical plane with simple harmonic motion of amplitude 0.05 m. The greatest number of oscillations per second so that an object at rest on the platform remains in contact with the platform at all times is

A. 7π

2π

B. $\frac{7}{\pi}$

C. $\frac{\pi}{2}$

D. $\frac{\pi}{7}$

The correct Answer C was chosen by only 15% of students but 18% chose B , 23% D and 24% E

SHM2: It is assumed that the depth of water in a harbour rises and falls with simple harmonic motion. On a certain day the low tide has a depth of 9 m at 1220 and the following high tide had a depth of 13 m at a time of 1820. Which of the following is true:

A. amplitude is 4 m and period is 12 hours
B. amplitude is 2 m and period is 6 hours
C. amplitude is 4 m and period is 6 hours
D. amplitude is 2 m and period is 12 hours

The correct Answer D was chosen by 23% of students but
21% opted for A, 18% for B and 19% for C

DISCUSSION

In the case of motion, many students struggle to accept that a body could have a non-zero value for acceleration when the body has a zero value for velocity. Teachers might need to emphasize that a ball thrown vertically is continually subject to the acceleration due to gravity until it returns to the hand that threw it. In the case of momentum, where a collision occurs between two bodies that approached each other, one of the initial velocities needs a negative sign, and many students didn't seem to consider this necessary.

In the problem where forces move a pair of bodies joined by a string, the two bodies form *a system* which then has properties different from the individual bodies. So the acceleration of the system needs to be considered, not just the absence of friction between one body and the table. In the case of gravitational attraction between two bodies it would seem that many students failed to appreciate the significance of an *inverse square* relationship between the quantities of force and distance.

In the question on Circular Motion where a body might lose contact with the road as if it travelled too quickly over a bridge, the concept of *reaction forces* seemed to present a difficulty for students and in particular the idea that the reaction equals zero at the instant that contact is broken.

The question on Simple Harmonic Motion (SHM1) where a platform went up and down with increasing frequency until a block placed on it first lost contact with the platform, required a lot of problem solving. The fact that a very small percentage got it right is testament to the challenge it offered. The fact that three of the distracters (incorrect answers) each accumulated responses of approx 20% may suggest that many students resorted to a guess and that there was no particular misconception in this case.

The second question on Simple Harmonic Motion (SHM2) the tidal problem, highlights that many students think that the amplitude is twice the true value and think the period is half its true value.

CONCLUSION

The findings in this investigation suggest that multiple choice questions can be effective in identifying where students encounter difficulty in understanding certain concepts in Mechanics. The findings give some interesting insights into the type of alternative thinking that was brought to bear by some students in answering the questions. The numerical analysis of the data gives an indication of whether the particular misconception is rare or common. Teachers might feel that certain issues are worth an increased emphasis in their teaching. Researchers might be motivated to explore the reasons behind these misconceptions.

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APPENDIX

MCQ-test: Simple Harmonic Motion

Instructions: Outline on this page all relevant work leading to your answer. In the event of a wrong answer, your work may merit partial credit.

1 When a particle is travelling with simple harmonic motion its
A. displacement is proportional to its velocity
B. velocity is proportional to its acceleration
C. acceleration is proportional to its displacement
D. displacement is proportional to its speed
E. speed is proportional to its acceleration

2. With regard to the period of a simple harmonic motion which of the following statements is correct?
A. The period is the time for one complete oscillation.
B. The period is the interval between the times when the velocity is zero.
C. The period is the interval between the times when the acceleration is zero,
D. The period is the time taken to travel a distance equal to twice the amplitude.
E. The period is equal to the time taken to travel from one extreme position to another.

3. A mass oscillates up and down at the end of a vertical spring.
If the period of the motion is two seconds, the frequency is

A four cycles per second

B two cycles per second.

C one cycle per second.

D half of a cycle per second

4. The period of a simple pendulum is

A. proportional to its length

B. proportional to its length squared

C. proportional to the square root of its length

D. inversely proportional to the square root of its length

E. inversely proportional to its length squared.

5. A horizontal platform is oscillating in a vertical plane with simple harmonic motion of amplitude 0.05 m. The greatest number of oscillations per second so that an object at rest on the platform remains in contact with the platform at all times is

A 7π B 2π C $\frac{7}{\pi}$ D $\frac{\pi}{2}$ E $\frac{\pi}{7}$

Assessment: Simple Harmonic Motion

Instructions: Outline on this page all relevant work leading to your answer. In the event of a wrong answer, your work may merit partial credit.

6. For a particle travelling with simple harmonic motion about a fixed point ***0,*** which of the following statements is correct?

A. The acceleration is away from 0 when the velocity is away 0.
B. The acceleration increases as the velocity increases,
C. The velocity increases as the displacement increases.
D. The acceleration is a maximum when the velocity is zero.

7. A simple pendulum has a period of 1 s. The length of the string is approximately

A. 1 m B. 2 m C. 4 m D. $\frac{1}{2}$ m E. $\frac{1}{4}$ m

8. A particle is travelling with simple harmonic motion such that its acceleration, in metres per second squared, is equal to four times its displacement, in metres. The period of the motion, in seconds, is

A 4 B $\frac{\pi}{2}$ C π D 2π E 4π

9. It is assumed that the depth of water in a harbour rises and falls with simple harmonic motion.

On a certain day the low tide has a depth of 9 m at 1220 and the following high tide had a depth of 13 m at a time of 1820. Which of the following is true:

A amplitude is 4 m and period is 12 hours

B amplitude is 2 m and period is 6 hours

C amplitude is 4 m and period is 6 hours

D amplitude is 2 m and period is 12 hours

10. A simple pendulum is used in an experiment to determine the value of the acceleration due to gravity g . A graph is plotted of period squared (T^2) against Length (L) as shown.
If m is the slope of the graph then g is given by

A $\frac{2\pi}{m}$ B $\frac{m}{2\pi}$ C $\frac{m}{4\pi^2}$ D $\frac{4\pi^2}{m}$ E $4m\pi^2$