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*Original Paper*

# Exam Questions from Essay to MCQ with Different Levels of Difficulty in Engineering Mechanics

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***Abstract***

*In this paper some techniques to avoid students' guessing of the correct answer in MCQ exams are proposed. An example from engineering mechanics course is introduced with different levels of difficulty. Random and adaptive selections of choices are introduced according to the physics and difficulty of the problem. The proposed techniques proved to be efficient in reducing guessing of correct answers based on partial or no knowledge of the subject matter. Also, a proposal of establishing online exam using pools of MCQ's with different levels of difficulty is introduced. Five basic types of exams with different number of questions based on instructors' desire are tabulated.*

## 1. Introduction

Multiple-choice questions or MCQs are used to quantitatively measure the students' understanding in certain disciplines. They usually take shorter time to be graded, especially when using specific computer grading software. The idea of using computers in grading can reduce the effect of differences in instructors' personal attitudes or styles in grading as in traditional essay questions. MCQs can also be used in case of differences in language skills among students (Karl, Graef, & Eitner, 2007). In addition, in case of large number of enrollments, such as in aptitude tests that qualify high school students to some universities and early undergraduate serving courses, MCQs are necessary (Karl, Graef, & Eitner, 2007; Bauer, Kopp, & Fischer, 2007; Ghazy & Ata, 2019, 2020). Comparison, between MCQs and essay questions in evaluating students is extended to non-engineering fields (Shima, Mina, & Azadeh, 2016).

In MCQs, students focus on final answers instead of going through the detailed derivation steps of the solution and reflect their critical thinking skills. Some students can even guess the correct answers. Thus, in some situations MCQs do not represent the best choice and other modified versions were

created. For example, Computer-interactive exams (Karl, Graef, & Eitner, 2007) and permutational MCQs (Farthing, Jones, & McPhee, 1998) were introduced in addition to the traditional MCQs. Graesser investigated mathematically the problem of students' guessing of correct choice in MCQs very early in the fifties (Graesser, 1958).

Engineering mechanics course, like other early undergraduate engineering courses, usually has large number of enrollments (Ghazy & Ata, 2019, 2020). In this course, most of the essay questions are not so short and a single problem cannot be included in one MCQ question. Although a problem can be defragmented into small parts so that each part can be included into a single question, answers of these questions are not independent because of the nature of the problem. It is not always possible for the instructor to find a variable which is independent of any other variable in the problem. This nature of engineering mechanics course makes preparing a MCQ exam a tedious and time-consuming process. But instructors prefer this type of questions to avoid long time grading of the essay questions especially for large number of students. Moreover, the efforts to design the exam is always during the semester time while grading essay questions is normally done after the examination period which is more tedious for the same instructor.

In the second section an example of essay question describing a particle's motion in a plane is introduced and necessary steps for the solution are listed. In the third section, different MCQ versions of the same example with different levels of difficulty are represented. Different ideas are proposed so that a student can't easily guess the correct answers of two related unknowns in two consecutive questions. In the fourth section, the obtained results are discussed and possible future extension of the current work is explored. Finally, in the fifth section, conclusions are drawn.

## 2. Example 1: Essay

A particle of negligible size is moving down a smooth curved surface, whose cartesian equation is given by $y = \sqrt{3}x^2 / 2$, starting from rest at point A as shown in figure 1. Calculate the velocity and surface normal reaction on the particle at point B, if the particle's mass is 10 kg and $x_A = 1\text{m}$, $x_B = 0.5\text{m}$.

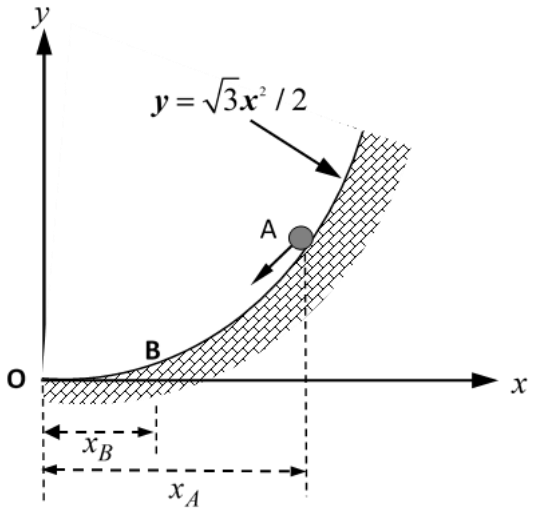


**Figure 1. A particle Moves down a Smooth Surface**

The student will apply the principle of work and energy between the two points A and B to find the velocity of the particle at B. Before that, he needs to calculate the slope and the radius of curvature. Then applies Newton's second law at point B to find the reaction from the surface.

$$\theta = \tan^{-1}\left(y'\right) = \tan^{-1}\left(\sqrt{3}x\right) \tag{1}$$

$$\rho = \frac{\left(1+y'^2\right)^{3/2}}{\left|y''\right|} \tag{2}$$

$$V_B^2 = V_A^2 + 2g \times \left(y_A - y_B\right) \tag{3}$$

$$N_B = mg\cos\left(\theta_B\right) + m\frac{V_B^2}{\rho_B} \tag{4}$$

The results of the above steps give $V_B = 3.57\,\mathrm{m/sec}$, $N_B = 169.5\,\mathrm{N}$

*2.1 Example 1: Elementary MCQ*

Given the same information in example 1, choose the correct answer to the following questions:

1. The radius of curvature of the path at point B is

| | | | |
|---|---|---|---|
| **(a)** 1.34 m | (a) **(b)** $\sqrt{3}$ m | (b) **(c)** 0.5774 m | (c) **(d)** 1 m |

2. The velocity of the particle at point B is

| | | | |
|---|---|---|---|
| **(a)** 12.74 m/sec | (d) **(b)** zero m/sec | (e) **(c)** 3.57 | (f) **(d)** 10 m/sec |

3. The surface normal reaction on the particle at B is

| | | | |
|---|---|---|---|
| **(a)** 138.6 N | (a) **(b)** 169.3 N | (b) **(c)** 389.2 N | (c) **(d)** 392.4 N |

This type of MCQ example is for an instructor who is familiar with essay exams and starts using MCQ exams. In each question, random choices are given in addition to the correct answer. When the instructor selects choices in each question independent of choices in other questions there is a chance that a student can quickly guess the correct answer in some questions by knowing the relation between the variables in this question and the previous one. For example, if the student selects the correct answer for the radius of curvature in question 1, he can substitute choices from question 2 into Newton's second law to find the value of the normal reaction at B. The student knows that, the correct answer is definitely given in the choices of question 3. The student will take a maximum of four trials to reach the correct answer. Doing this, the student could find the correct answers in question 2 and question 3 together at once. In this case, even though the answer is correct and the student applied Newton's second law, he didn't apply the principle of work and energy at all. This actually represents a partial knowledge in this part of the course.

*2.2 Example 1: Intermediate MCQ*

The same problem in example 1 is revisited but with little modification. One simple technique to avoid guessing the correct answer for reaction is using two values for the velocity that give the same value for the reaction at B. For a simple question as the one mentioned above this simple approach is enough to test student's understanding. In a more general approach, choices in question 3 can be built on choices of question 2, in this case all values in question 2 will give values in question 3.

1. The radius of curvature of the path at point B is

| | | | |
|---|---|---|---|
| **(a)** 1.34 m | (g) **(b)** $\sqrt{3}$ m | (h) **(c)** 0.5774 m | (i) **(d)** 1 m |

2. The velocity of the particle at point B is

| | | | |
|---|---|---|---|
| **(a)** 12.74 m/sec | (j) **(b)** zero m/sec | (k) **(c)** 3.57 m/sec | (l) **(d)** 10 m/sec |

3. The surface normal reaction on the particle at B is

| | | | |
|---|---|---|---|
| **(a)** 1285.4 N | (d) **(b)** 74.16 N | (e) **(c)** 169.3 N | (f) **(d)** 820.4 N |

The instructor is free to propose choices in question 3 regardless of choices in both question 1 and question 2. Firstly, because the value of radius of curvature is independent of the velocity and the student can't use choices of velocity to guess the value of the radius of curvature. Secondly, because, if the student needs to guess the answers in the three questions, he needs to substitute choices from both question 1 and 2 to find correct value of the reaction at B in question 3. Obviously, this will take much time and makes the guessing process not practical.

*2.3 Example 1: Difficult MCQ*

In this example the content of question 1 is modified so that the student will integrate his knowledge in the subject matter. Properties along the whole trajectory are needed to solve for the reaction at one point. The surface Cartesian equation can generally be given as $y = f(x)$ shown in Figure 2. The

student needs to use the Cartesian form of the equation of radius of curvature and the slope angle at any point. This step requires more knowledge and analysis from the student.

One single question can be dedicated to the calculation of the radius of curvature and the other question to calculate the slope angle at selected point on the trajectory. As the slope at point A is independent of both velocity and reaction at B, the question about slope at A can be inserted in between the questions about velocity and reaction at B. The questions in case $y = \sqrt{3}x^2 / 2$ are:

1. The velocity of the particle at point B is

| | | | |
|---|---|---|---|
| **(a)** 3.57 m/sec | (m) **(b)** zero m/sec | (n) **(c)** 12.74 m/sec | (o) **(d)** 10 m/sec |

2. The slope of the surface at point A is

| | | | |
|---|---|---|---|
| **(a)** 30 degrees | (p) **(b)** 90 dgrees | (q) **(c)** 60 degrees | (r) **(d)** 10 degrees |

3. The surface normal reaction on the particle at B is

| | | | |
|---|---|---|---|
| **(a)** 169.3 N | (g) **(b)** 74.16 N | (h) **(c)** 1289.4 N | (i) **(d)** 822.3 N |

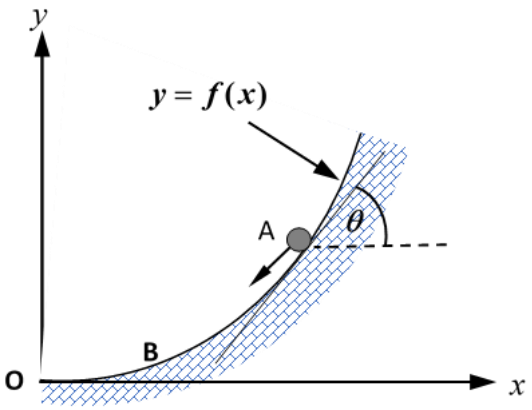


**Figure 2. A particle Moves down a Smooth Surface and the Slopes at Different Points are Needed**

*2.4 Example 1: Advanced MCQ*

In this version of the question, a small extension of the problem is added so that it doesn't affect its previous structure. The addition allows more freedom in selecting unknowns that could be subject to MCQ's. A straight horizontal path is added after point B, and another question can be added about the reaction just after B or about the difference between the reaction before and after B. This segment of the trajectory can have considerable friction characteristics as shown in figure 3. The reaction after B is independent of previous trajectory parameters. Such an isolated unknown can be included in a question that can be put anywhere between two related unknowns and interrupts the process of detection of correct values.

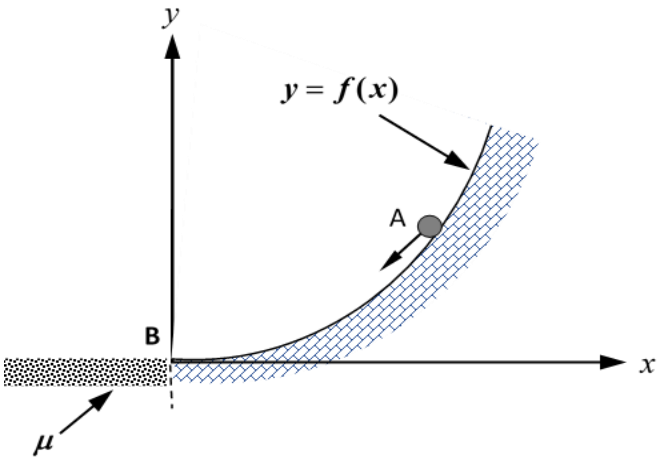


**Figure 3. A particle Moves down a Smooth Surface then on a Rough Surface**

The questions in this case can be written as follows:

1. The surface normal reaction on the particle at point A is

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **(a)** | 301.5 N | (j) | **(b)** | 265.56 N | (k) | **(c)** | 49.05 N | (l) | **(d)** | -167.5 N |

2. The surface normal reaction on the particle just after B is

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **(a)** | zero N | (m) | **(b)** | 10 N | (n) | **(c)** | 98.1 N | (o) | **(d)** | 822.3 N |

3. The surface normal reaction on the particle just before B is

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **(a)** | 169.3 N | (p) | **(b)** | 74.16 N | (q) | **(c)** | -674.02 N | (r) | **(d)** | 1289.4 N |

In this example, generally, a student needs to go through more steps to reach the answer of a question. As a result, the probability that a student solves all questions correctly is very small. In addition, guessing the correct answer of one of the questions is very difficult.

### 3. Discussion and Future Work

These four types of questions can be put into categories or pools so that when instructors put an exam, he may select a question from each pool to construct an exam that covers different levels of difficulty. This technique will be helpful in online examinations through any online learning platform. In general, an instructor can choose different number of questions from each pool. Generally, the total number $N$ of questions in exam can be calculated from the following formula

$$N = a_1 p_1 + a_2 p_2 + ... + a_i p_i + ... + a_n p_n, \ n = 4 \quad (5)$$

Where, $p_i$ is the $i^{th}$ pool and $a_i$ is an integer number of questions from this pool. An instructor can decide the difficulty of exam by deciding the value of each $a_i$. When $a_1$ and $a_2$ are much bigger than $a_3$ and $a_4$ the exam is more straight forward in terms of choices in questions and possibility of guessing correct answers is high. On contrary, when $a_3$ and $a_4$ are much bigger than $a_1$ and $a_2$, choices in questions are indirect and possibility of guessing correct answers is low.

So, based on the application of equation (5), It is easier now for the instructor to design the MCQ exam according to the level of the students and the type of materials taught in classroom. For example, five possible formulations of an exam of four questions are listed. If $a_3 = a_4 = 0$, the exam is considered elementary. If $a_3 = 0, a_4 = 1$ or $a_3 = 1, a_4 = 0$ the exam is considered intermediate. If $a_1 = a_2 = a_3 = a_4 = 1$ the exam is considered balanced. If $a_1 = 0, a_2 = 1$ or $a_1 = 1, a_2 = 0$ the exam is considered difficult. Finally, if $a_1 = a_2 = 0$ the exam is considered advanced. The arrangements for possible types of exams are shown in Table 1.

**Table 1. Basic Possible Exam Levels in Terms of Difficulties**

| | elementary MCQ | intermediate MCQ | difficult MCQ | advanced MCQ |
|---|---|---|---|---|
| exam 01 (elementary) | 2 questions | 2 questions | | |
| exam 02 (intermediate) | 2 questions | 1 question | 1 question | |
| exam 03 (balanced) | 1 question | 1 question | 1 question | 1 question |
| exam 04 (difficult) | | 1 question | 1 question | 2 questions |
| exam 05 (advanced) | | | 2 questions | 2 questions |

## 4. Conclusion

Based on the introduced examples, an instructor can select the level of difficulty of his exam when changing from essay questions to MCQ ones. He can select the type and level of MCQ's in his exam based on the proposed ones in this paper. Also, he can construct an exam similar to one of the five basic types introduced in section 4.

Sometimes, if there is a penalty for guessing the answer, students are reluctant to select the answers randomly. In some universities, the rules prevent this penalty on the basis that it may punish the students twice if he selects the wrong answer. One possible solution is to increase the number of choices from four choices to five choices. This makes it more difficult for students to guess the correct answer or select one column and accidently pass the exam. To add more difficulty, a "non-of the mentioned" answer can be introduced as one of the five options. This will force students to think many times before guessing the answer for any question. However, the instructor should be wise and select as minimum options as possible, since it affects the students' confidence in selecting the proper answer especially if the answer depends on previous steps. In this case, If the student makes any mistake, he can select this choice wrongly.

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