The Art of Designing a Quality Multiple Choice Question in Chemistry *

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In recent times, multiple-choice test items have evolved into a useful tool to analyse the learning outcome of students. They have both advantages and disadvantages in assessing the students’ academic growth. While multiple-choice test items often seem more informal, they become a powerful tool when designed and implemented in a well-planned manner. Teachers often frame questions demanding either basic recall or lower-order thinking skills, thereby obstructing the promotion of higher-order and critical thinking, a prerequisite for success in academics. Strategic planning of questions utilising the various cognitive taxonomies will aid the teachers in developing a range of questions anticipating students to analyse, apply and create. This article attempts to discuss the pros and cons of multiple-choice questions (MCQs), a brief discussion on Bloom’s taxonomy, the anatomy of quality MCQs, and a few guidelines for constructing them, especially in chemistry education.

1. Introduction

A question is a sentence generally used to assess a student’s understanding. Questioning, a vital constituent of the teaching/learning process, is embedded in quality instruction and strategic thinking [1]. Questioning is an indispensable component of efficacious teaching, and therefore, plays a critical role in the general success of a classroom. It is a major form of human thought and interpersonal communication. In other words, it is a way to explore a subject matter, an impression, or something fascinating or in-

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Questioning as a teaching/learning tool dates back more than 2000 years to Socrates, a Greek philosopher. He used to inspire his students to explore prior-held beliefs, which could thereby build stronger and more scholarly views. In this context, it is worth mentioning that questioning as a teaching/learning tool dates back more than 2000 years to Socrates, a Greek philosopher. He used to inspire his students to explore prior-held beliefs, which could thereby build stronger and more scholarly views. He firmly believed that only through questioning one can develop and enhance logical and rational thinking based on the knowledge and understanding they had gained through their experiences in life [4]. His approach involved posing a succession of organized and well-planned questions to students, reflecting and improving their thinking skills. The primary focus was to get a better insight into their personal beliefs and philosophies. Nowadays, this approach is extremely famous and generally known as the Socratic approach. The key objective of the Socratic approach is not looking at a specifically correct answer but inspiring and motivating students to reflect on their thinking abilities [5, 6].

In the past few years, multiple-choice questions (MCQs) have become undoubtedly an important tool for assessing students’ understanding of the subject. Students often find MCQs less intimidating than a typical and conventional question that demands a long written answer format. While multiple-choice test items often seem more informal, they become a powerful tool when designed and implemented in a well-planned manner. Designing a proper and quality MCQ is an art. This is not less than conventional research. The thinking skills of a teacher are reflected when creating a quality MCQ [7, 8]. In this article, the focus will be on framing quality MCQs in the domain of chemistry.
2. A Brief Overview of Bloom’s Taxonomy

Bloom’s taxonomy classifies educational learning objectives into levels of complexity and specificity using a set of three hierarchical models. These models were named after Benjamin Bloom, who worked with a committee of educational psychologists like Englehart, Furst, Hill, Krathwohl, and others in 1956 to establish that these levels of cognition are fairly important in learning. He also chaired the committee of educators that devised the taxonomy, delivering an important framework for teachers to use when developing questions of all standards. Benjamin Bloom edited the first volume of *Taxonomy of Educational Objectives: The Classification of Educational Goals*.

Educational objectives have been classified into three domains: cognitive, affective and psychomotor by Bloom et al. [9–11].

The cognitive domain encompasses the growth and development of knowledge and intellectual skills, whereas the affective domain includes how individuals deal with things emotionally. The psychomotor domain comprises physical movement and motor skills. The cognitive domain can be broken into the following six levels: remember, understand, apply, analyze, evaluate, and create. The affective domain involves the way people react emotionally, and here the levels are: receiving, responding, valuing, organizing, and characterizing. The psychomotor domain, on the other hand, defines the ability to physically manipulate a tool. Though Bloom never formed subdivisions for skills in the psychomotor domain, Simpson, in 1972, proposed the following subdivisions: perception, set, guided response, mechanism, complex overt response, adaptation, and origination. The taxonomy is represented as a pyramid (Figure 1) with higher-order thinking (cognition) at the top [10].

Bloom’s taxonomy provides a scaffold for asking questions that gradually become increasingly challenging. Thereby it provides a structure for educators to model complex thinking that, in turn, can help students to become independent thinkers capable of developing their own viewpoints.
3. MCQs: Indispensable in Chemistry Education

Multiple-choice (MC) test items can be constructed to assess various learning outcomes in several branches of chemistry, starting from simple recall of facts to Bloom’s highest taxonomic level of cognitive skills—evaluation [10]. Like any other test item, they have certain advantages and disadvantages, and to use MC items effectively, teachers need to be aware of these positive and negative characteristics. It is true indeed that in many different subjects, MC test items can be appropriately used to measure a wide variety of educational objectives. They can cover various levels of learning outcomes ranging from simple recall of knowledge to more complex levels, like analyzing a particular phenomenon, applying the basic principles to new situations, comprehending the concepts and principles in a better way, interpreting the cause-and-effect relationships, making inferences from the given data, ability to interpret charts and graphs, judging the relevance of information, discriminating between fact and opinion and above all ability to solve problems [11–13]. The level of difficulty of MC items can be adjusted by varying the alternatives. As the alter-
natives become more and more homogeneous, the students must make finer distinctions to identify the precise answer. Compared to the MC test items, responding to an essay test item takes much longer. From a student’s perspective, they can answer more MC items in the stipulated time than a single essay question. From the viewpoint of reliability, well prepared MC test items are more favoured than other test items like true-false test items, where blind guessing often leads to scoring. Even scoring MC test items is often easier than in short answer test items, as there is no requirement to recall information. As MC items are scored accurately, these are not at all affected by the inconsistencies of the scorer, as observed in essay questions. Other factors that lower the reliability of essay test scores are bluffing and writing ability factors. MC items are amenable to rapid scoring as the scoring process is often done by scoring machines, thereby expediting the reporting of test results [9, 11].

4. MCQs Are Not a Panacea

There are certain limitations of MC items. In an MC item, a student needs to select a response from a list of alternatives instead of supplying or constructing a response. Hence, MC test items are not adaptable to measure certain learning outcomes like displaying thought processes, furnishing information, organising personal thoughts, performing a specific task, producing original ideas and judgements, providing examples and articulating explanations. They are better measured by short answer type questions, essay type questions, and other performance tests. Although MC items are less vulnerable to guesswork than simple true-false test items, they are still affected to a certain extent. However, if the number of test items increases, the reliability reduction can be counterbalanced to a certain extent [14].

Apart from that, one must consider that designing quality MC items are more complex and time-consuming than creating other types of test items. Selection of plausible distractors demands skill from the teacher’s counterpart, which can only be achieved
through continuous practice, study and experience [9, 11, 15].

5. Anatomy of a Good MCQ

A standard multiple-choice test item consists of two basic parts—a problem known as stem and a list of suggested solutions known as alternatives. The stem may be represented in the form of either a question or an incomplete statement. The list of alternatives contains one correct choice (the answer) along with some incorrect alternatives known as distractors. The quality distractor should be such that it appears as a plausible solution to the problem for those who have not understood the objective being measured by the test item. The distractors appear as implausible solutions to the students who have realised the objectives of the test item [11, 16].

The very purpose of the distractors is to appear as plausible solutions to the problem for those students who have not achieved the objective being measured by the test item. Conversely, the distractors must appear as implausible solutions to those students who have achieved the objective. Only the answer should appear plausible to these students [17, 18].

6. Constructing Quality MCQs in Chemistry: Guidelines and Examples

Several guidelines with the best possible examples in organic chemistry have been mentioned here for a better understanding
of the readers. The correct answer is marked with a check mark throughout this section.

A. The stem of an MC item should be sufficiently meaningful by itself, and the stem of its own should present a definite problem.

While framing an MC item, we often encounter a serious issue where the problem definition is revealed in the options, and the stem appears to be a meaningless one. The central idea of the problem should be well reflected in the stem rather than in the options [8, 18].

Item 1: 1, 3-dimethylallene is
(a) an example of an asymmetric molecule
(b) an example of a disymmetric molecule ✓
(c) an example of an optically inactive molecule

Analysis: Here in Item 1, students face three true-false options. Moreover, the three options cover such a set of widely dissimilar stereo-chemical ideas of an organic molecule that evaluation, by comparison, is not possible.

Item 2: How many different stereoisomers do you expect for the compound \((\text{EtCH=CH})_4\text{C}\)?
(a) 2
(b) 3
(c) 4
(d) 5 ✓

Analysis: Here in Item 2, students can think about the correct answer rather than figuring out what the actual problem is. Item 2 demonstrates one way to make the stem become a more definite and clearly stated problem. It is also worthwhile to note that the stem has forced the four options to be parallel in content.
The stem should be devoid of internal or beginning blanks.

Often we represent a stem as an incomplete statement, which is to be completed by inserting the correct option. According to measurement specialists, this completion format is not the best approach to follow. In this approach, a student has to retain the stem in their short-term memory while completing the stem with each option. If we consider the perspective of test anxiety, it becomes much higher if the student is not a speaker of the English language. Suppose the situation appears such that the completion format is inevitable; we should place the omission obviously towards the end rather than at the beginning or the middle of the stem.

Item 3: ............... no. of $C_2$ axes are present in naphthalene molecule.

(a) 1
(b) 2
(c) 3 ✓
(d) 4

Item 4: How many $C_2$ axes are present in Naphthalene molecule?

(a) 1
(b) 2
(c) 3 ✓
(d) 4

Analysis: Both Item 3 and 4 want to check the same understanding level of students. However, Item 4 is a much-improved version as Item 3 is a complete format and omission is given at the beginning.
C. Negatively stated stem can only be used when substantial learning outcomes require it.

Understanding the meaning of negatively phrased items imposes difficulty for most students. Most often, the students read through the negative terms, for example, ‘not’, ‘no’, and ‘least’, and surprisingly they often forget to reverse the logic of the relation being tested.

Item 5: Which one of the following molecules is not likely to show enantiomerism?

(a) Phenyl ethane ✓
(b) α-hydroxy propionic acid
(c) 2-amino pentane
(d) 1-bromo-1-phenyl ethane

Item 6: Which one of the following techniques mostly helps us to study the free radicals?

(a) UV spectra
(b) Microwave spectra
(c) IR spectra
(d) CIDNP ✓

Analysis: It is better to avoid the use of negatively stated stem as in Item 5.

Item 7: Among the following solutions, which one is the least concentrated?

(a) In 200 cc of water, 120 g of potassium sulphate is dissolved ✓
(b) In 200 cc of water, 60 g of sodium chloride is dissolved
(c) In 100 cc of water, 50 g of calcium carbonate is dissolved
(d) In 100 cc of water, 65 g of potassium nitrate is dissolved

Item 8: Among the following solutions, which one is the most concentrated?

(a) In 100 cc of water, 65 g of potassium nitrate is dissolved ✓
(b) In 100 cc of water, 50 g of calcium carbonate is dissolved

(c) In 200 cc of water, 120 g of potassium sulphate is dissolved

(d) In 200 cc of water, 60 g of sodium chloride is dissolved

Analysis: Both Items 7 and 8 assess the same chemistry concept, but some students may answer Item 7 incorrectly due to the word least. Because the terms least and concentrated are diametrically opposed, the phrase ‘least concentrated’ is more difficult to grasp than the phrase ‘most concentrated’.

**D. While framing a quality MC item, irrelevant difficulty should be avoided.**

It is better to avoid irrelevant difficulty while framing a quality MC item. We should always focus on assessing the concepts and try to make the stem as simple as possible without puzzling the students with irrelevant information [9, 11, 14, 18].

Item 9: In order to dilute 57.35 cm$^3$ of 1.96 M NaCl to 1.50 M, what volume of water should be added?

(a) 42.65 cm$^3$

(b) 112.41 cm$^3$

(c) 17.59 cm$^3$ ✓

(d) 74.94 cm$^3$

Item 10: In order to dilute 60 cm$^3$ of 2.0 M NaCl to 1.5 M what volume of water should be added?

(a) 40 cm$^3$

(b) 120 cm$^3$

(c) 80 cm$^3$

(d) 20 cm$^3$ ✓

Analysis: We must avoid any difficulties when incorporating more and more complicated information into the stem. If the only goal is to assess the student’s understanding of the concept of dilution, we should agree that Item 9 is more confusing than 10, because the values in Item 10 will evaluate the same learning outcome.
without the difficulties and errors.

**E. We should not attempt to increase the difficulty of an item by using unnecessarily complex or unfamiliar vocabulary.**

It is preferable to avoid using unnecessary, complicated vocabulary to improve the quality and objective of a stem [9].

**Item 11:** Among the following ions mentioned below, which one is responsible for the colour of the gemstone called Topaz?

(a) $\text{Cr}^{3+}$
(b) $\text{Cu}^{2+}$
(c) $\text{Mn}^{3+}$
(d) $\text{Fe}^{3+}$ √

**Item 12:** Which of the following ions is most likely responsible for the yellow colour of gemstones?

(a) $\text{Cr}^{3+}$
(b) $\text{Cu}^{2+}$
(c) $\text{Mn}^{3+}$
(d) $\text{Fe}^{3+}$ √

**Analysis:** We should avoid unnecessary difficulty in the stem. In Item 11, the word Topaz increases the difficulty. The goal here is to assess the student’s understanding of which ions produce a yellow colour. However, anyone who does not know or remember that Topaz is yellow will be lost. Item 12 appears to have a significantly higher learning objective than Item 11. Here, we should keep in mind that we aim to assess students’ understanding of the subject and their ability to solve a problem.

**F. The distractors should be as convincing as possible.**

Without a doubt, the most important factor to consider when framing a quality MC item is the distractors. A good distractor should be selected by low achievers rather than high achievers. Distractors can be set using common misconceptions of chemistry stu-
dents [9, 11, 18].

Item 13: Pepsi Cola shows pH around

(a) 1
(b) 2
(c) 3 ✓
(d) 4

Item 14: Pepsi Cola shows pH around

(a) 3 ✓
(b) 5
(c) 6
(d) 8

Analysis: If the distractors of both Items 13 and 14 are closely scrutinised, it will be observed that the correct answer in both the items is pH = 3. A common misconception among the students is that a solution is only drinkable if the pH of the solution is around 7. Hence the distractors present in Item 14 are convincing. Teachers are encouraged to frame distractors keeping an eye on the common misconceptions of students.

G. We should avoid designing a complex MC item in order to make them harder.

A complex MC item consists of a list of primary responses, which are potentially correct answers. Secondary responses are a list of primary response combinations. To answer the item, we expect students to choose one of the secondary options [9, 18].

Item 15: Which of the following chemicals is/are present in town gas?

(1) hydrogen, (2) sulphur dioxide, (3) carbon monoxide, (4) gaseous naphtha

(a) (3) only
(b) (1) and (2) only
(c) (2) and (4) only
(d) (1), (3) and (4) ✓

Item 16: What is the main component of Hong Kong’s town gas?
(a) gaseous naphtha
(b) carbon monoxide
(c) methane
(d) hydrogen ✓

Analysis: If we examine Item 15, we can see that if a student knows the primary response, ‘sulphur dioxide’, is false, they will prefer option (d) because sulphur dioxide does not appear in options (a) or (d). An MC item becomes more complex when it contains more than one primary response. A complex MC format is clearly less discriminating and reliable than a single-answer format. Item 16 is an improved version of Item 15.

II. We should avoid using “none of the above” or “all of the above” as an option.

Often a teacher finds it easy to incorporate ‘none of the above’ and ‘all of the above’ as options in MC items. However, according to several specialists, these options are not recommended. A teacher will not understand whether the students recognize the correct answer or not.

The option of all of the above also possesses difficulty. If a student knows that two of the three distractors are correct, then this information can guide the student towards selecting the option all of the above. Hence this option allows the student to choose the correct answer based on partial knowledge rather than complete knowledge [11, 18].

Item 17: Which of the following rearrangements gives a γ,δ-unsaturated carbonyl compound?
(a) Claisen rearrangement ✓
(b) Hofmann rearrangement
(c) Fries rearrangement
(d) None of the above
Item 18: Which of the following reactions leads to the formation of a C-C bond?

(a) Aldol condensation √
(b) Wittig reaction
(c) Claisen ester condensation
(d) All of the above

Analysis: When it is analysed from the student’s viewpoint, after realising that one of the distractors is incorrect, students will understand that all the options given are wrong without even analysing the remaining options.

7. Summary

Guiding and motivating students to ‘think about their thinking’ or ‘metacognition’ can lead them to a deeper and finer understanding of the subject. Undoubtedly, designing quality questions is among the most powerful teaching tools in this context. When teachers increase their repertoire of questioning techniques, the quality of instruction significantly improves. This article showcases the importance of MCQs, their anatomy, and the guidelines to create quality MCQs with several examples involving various branches of chemistry.

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Suggested Reading


