

Supplemental Material

CBE—Life Sciences Education

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File S1: Tutorial information for student authors and TA training instructions

Tutorial information

Best practices for writing good multiple-choice questions

There are some simple guidelines for constructing robust multiple-choice questions. What follows is a brief synopsis of the 'do's and don'ts' that will assist you in authoring unambiguous questions that will serve as good learning and review tools by you and your peers. You should be aware that there is a large body of educational literature aimed at pedagogy, the study of effective teaching and learning methods. In 1956, Benjamin Bloom and colleagues published a framework to categorize educational objectives, and this became known as Bloom's Taxonomy. The levels range from the simple recall of facts, to the ability to use information to create new knowledge. Each level of this hierarchy builds upon the lower levels. A summary of Bloom's Taxonomy is included below the basic rules, and some suggested verbs to use for your questions will help you to categorize the questions and the level of knowledge being tested. There are some hyperlinks and references at the end which you may wish to consult for more information and examples.

First, a note about Quizzical and its optional elements. Your instructor may require you to provide either an image (generally from the images from your textbook that your instructor has uploaded to Quizzical) to associate with your question, a reference that might be useful to the test taker in exploring the question in more detail (e.g. a figure number or page from your textbook) and/or the instructor may require that you justify your answers and distractors. All of these options ARE ONLY VISIBLE after the quiz taker has attempted the question. They are displayed such that the quiz taker can see the image and associate it with the question to help them envision the subject/process being tested, and the justifications provide them with the logic of why an answer is correct and the distractors are incorrect. Providing strong justifications is an important aspect of your authorship grade, and they enable your question to become a learning tool. You've solidified your knowledge of the subject of your question, and now your hard work will help your peers to understand the subject.

Lastly, you have undoubtedly attempted multiple choice questions that you felt were 'tricky' or 'picky'. This may have been because they were indeed poorly written. If you adhere to the best practices outlined below, that will ensure that your question is a good one. UNLESS.....there can be an enormous number of discipline specific terms that you will need to master in most courses. Knowing the terminology is key to understanding the language and complexity of the subject. Thus, your question could be ambiguous if you don't learn the 'vocabulary words' and employ them correctly. Your goal should be to construct a rigorous question, and the resources you provide (the image, reference and justifications) should allow a student that does not know the answer to learn something.

The Question:

1. It is suggested that you begin with the idea of 'what do I want to test?'. Maybe it is one of the learning objectives of the class? With this in mind, write the question and then the answer, followed by the distractors.
2. The stem (question) should be unambiguous and should take the form of a question.
3. Try to avoid negative phrasing (e.g. "Which of the following are not components of the ribosome?"). If you must use negative phrasing, it is recommended that you underline, bold, and/or capitalize the 'NOT'. If you must use NOT, do NOT have negatives in the answer/distractors (e.g. 'none of the above' constitutes a double negative that is confusing).
4. Do not refer to lectures, figures, tables or other materials that are not available to the test taker (e.g. "In figure 8.23a, which mechanism of enzyme action..."). Note that the figure you specify for your question is only revealed after the quiz has been attempted. This will help the quiz taker to understand your question, the answers, and justifications (see below).
5. Avoid the use of terms such as 'typically, often, usually'. These words imply that the question relates to a specific situation or exception and may be 'tricky'.
6. You will be required to categorize your question as either a 'recall' question (explores information that you can memorize) or an 'application' question (focusses on the use of knowledge to interpret data, make predictions, differentiate between choices, etc.). On the Quizzical question form filler, there are some suggestions for an appropriate verb to use when constructing each type of question.

Answers and Distractors

1. Avoid the use of 'Type K' questions. These are questions for which there is more than one correct answer. For example, some questions have three potential answers, followed by choices such as 'both a and b' and perhaps 'both b and c'. These are effective for testing some topics and can be very discriminating, but keep their use to a minimum.
2. Following from tip 1 above, be sure that there is only one correct answer. Contemplate whether there are circumstances that would make one of the distractors a correct answer. If this is the case, you may wish to reconstruct the stem, or construct a different question.
3. Distractors are potential answers that do not satisfy the question. These must be legitimate. Good distractors are often true statements but they do not address the question.
4. Avoid weak distractors. An example: you might be asked to associate the name of a scientist with a discovery. Having Drake or Shakespeare as one of the choices immediately eliminates that option for most people and makes 'guessing' the correct answer easier.
5. Make the distractors of approximately equal length and avoid wordy (long) answers.
6. Use distractors that are similar to the correct answer in language, grammar, and form.
7. Avoid the use of 'all of the above' and 'none of the above'. Certainly do not employ both in the same question!

Justifications:

If you are required to provide justifications for your answer/distractors, keep in mind that your goal is to help someone understand why the correct answer is correct and EVERY distractor is incorrect. Thus, doing something simple like 'Answer D is incorrect because answer A is correct.' is useless and will result in your grade being penalized. Provide a rich (but not too wordy) description of why the answer is correct and each of the distractors is incorrect.

A few other do's and don'ts: I'm interested in you learning about the mechanisms of biological systems and not in memorizing mundane facts that do not contribute to this goal. In that regard, I will never test you on names (e.g. Which of the following researchers elucidated the structure of DNA?), dates (In which year did Watson and Crick publish their findings about DNA structure?), or minutiae (How many proteins are in the large subunit of the ribosome?). So, since that's off limits for me, it is for you as well. Focus your questions on things that are important for understanding how molecules, cells, tissues and organs work.

Finally, and importantly, I suggest that you compose your question, answers and justifications in a word processing program and then cut and paste the relevant information into the form filler boxes on Quizzical. BEFORE you do that, run a spelling/grammar check to be sure that your text is flawless.

Bloom's Taxonomy of Educational Objectives

Bloom categorized different abilities/outcomes of our cognitive processes to inform our thinking about course/learning objectives. These categories are summarized below, along with some information about learning objectives that are associated with them. To facilitate question writing, some appropriate question verbs are given. Note that for multiple choice questions, some of the more advanced categories are difficult/impossible to test, but it is possible to construct 'recall' (knowledge/comprehension) questions and more difficult 'analytical' (application/analysis) questions.

Knowledge – Recognizes students' ability to use rote memorization and recall certain facts.

- Test questions focus on identification and recall of information.
- Learning objectives at this level: know common terms, know specific facts, know methods and procedures, know basic concepts, know principles.
- Question verbs: Define, select, list, state, identify, label, name, who? when? where? what?

Comprehension – Involves students' ability to read course content, extrapolate and interpret important information and put other's ideas into their own words.

- Test questions focus on use of facts, rules and principles.
- Learning objectives at this level: understand facts and principles, interpret verbal material, interpret charts and graphs, translate verbal material to mathematical formulae, estimate the future consequences implied in data, justify methods and procedures.
- Question verbs: Explain, distinguish between, classify, predict, interpret, infer, summarize, convert, translate, give example, account for, paraphrase x?

Application – Students take new concepts and apply them to another situation.

- Test questions focus on applying facts or principles.
- Learning objectives at this level: apply concepts and principles to new situations, apply laws and theories to practical situations, solve mathematical problems, construct graphs and charts, demonstrate the correct usage of a method or procedure.
- Question verbs: Arrange the order, How could x be used to y? How would you show, make use of, modify, demonstrate, solve, or apply x to conditions y?

Analysis – Students have the ability to take new information and break it down into parts to differentiate between them.

- Test questions focus on separation of a whole into component parts.
- Learning objectives at this level: recognize unstated assumptions, recognizes logical fallacies in reasoning, distinguish between facts and inferences, evaluate the relevancy of data, analyze the organizational structure of a work (art, music, writing).
- Question verbs: Diagram, determine, order, estimate, differentiate, compare / contrast, distinguish x from y, how does x affect or relate to y? why? how? What piece of x is missing / needed?

Synthesis – Students are able to take various pieces of information and form a whole creating a pattern where one did not previously exist.

- Test questions focus on combining ideas to form a new whole.
- Learning objectives at this level: write a well organized paper, give a well organized speech, write a creative short story (or poem or music), propose a plan for an experiment, integrate learning from different areas into a plan for solving a problem, formulate a new scheme for classifying objects (or events, or ideas)
- Question verbs: Design, construct, develop, formulate, imagine, create, change, write a short story and label the following elements:

Evaluation – Involves students' ability to look at someone else's ideas or principles and see the worth of the work and the value of the conclusions.

- Test questions focus on developing opinions, judgments or decisions.
- Learning objectives at this level: judge the logical consistency of written material, judge the adequacy with which conclusions are supported by data, judge the value of a work (art, music, writing) by the use of internal criteria, judge the value of a work (art, music, writing) by use of external standards of excellence.
- Question verbs: Justify, appraise, evaluate, judge x according to given criteria. Contrast, criticize, compare.

Some web resources and references

<http://cft.vanderbilt.edu/teaching-guides/assessment/writing-good-multiple-choice-test-questions/#stem>

<https://facultyinnovate.utexas.edu/sites/default/files/writing-good-multiple-choice-exams-fic-120116.pdf>

- Burton, Steven J., Sudweeks, Richard R., Merrill, Paul F., and Wood, Bud. How to Prepare Better Multiple Choice Test Items: Guidelines for University Faculty, 1991.
- Cheung, Derek and Bucat, Robert. How can we construct good multiple-choice items? Presented at the Science and Technology Education Conference, Hong Kong, June 20-21, 2002.
- Haladyna, Thomas M. Developing and validating multiple-choice test items, 2nd edition. Lawrence Erlbaum Associates, 1999.
- Haladyna, Thomas M. and Downing, S. M.. Validity of a taxonomy of multiple-choice item-writing rules. Applied Measurement in Education, 2(1), 51-78, 1989.

- Morrison, Susan and Free, Kathleen. Writing multiple-choice test items that promote and measure critical thinking. *Journal of Nursing Education* 40: 17-24, 2001.
- Zimaro, D.M. Writing Good Multiple-Choice Question Exams. Faculty Innovation Center, University of Texas. 2016.

TA guidelines for evaluating Quizzical questions

Note to CBE-LSE readers: this advice for TAs is based upon implementing the optional features of Quizzical: requiring student authors to provide a reference for their question, selecting an appropriate textbook image to associate with the question, and providing justifications for both the correct answer and the distractors. We also designated some participation marks in the grading scheme to encourage students to participate in quizzes on each lecture. These features can be activated at course set-up. We also used a maximum score of 4 for each question, but this also can be altered during set-up. We suggest that you view the two supplementary videos that describe relevant aspects of Quizzical for instructors (<https://play.library.utoronto.ca/kIYIj0Ni3HVI>) and students (<https://play.library.utoronto.ca/6XzobNLPS8jx>).

You now have access to the Quizzical application within the learning management system. I want to thank you for agreeing to TA for the course, but there are some strict guidelines that I want share.

1. Because students are required to take quizzes on each lecture and there is a time limit for them, it is important that you keep up with the work flow. Based on our class size, you will have about 12-14 questions per lecture. Since there are two lectures per week, this means 24-28 questions will come your way every week. These must be evaluated within a few days of their submission, so set aside enough time to meet this goal.
2. You have a good background in the subject area, but be aware that students can author a question on any aspect of the lecture. Some of you have taken the course before, but if you have not, or your command of a subject is questionable, have a look at the one-page summary that outlines the figures from the textbook that will be the focus of the lecture, and of course the lecture slides are available on the course webpage. Naturally, you are welcome to attend the class. You have a copy of the textbook, and I have designated six hours of your contract for 'review'. Thus, if you are rusty and/or a student writes a question that you don't understand, there is time to sort out the answer. If you cannot do so, do not hesitate to consult with me. In general, I anticipate that it will take between 5-10 minutes to evaluate a question, provide feedback if necessary (see below), and record a mark for the student. Note also that you'll likely see multiple versions of the same question (e.g. What are the components of DNA?), as multiple students may pick one of the main lecture topics/figures for their question.
3. Now for the rubric. Half of the marks scheme is rote and simple, and half of it is more subjective (but the idea is to make it objective). There are four marks total. A student receives 1 mark for submitting on time. You don't have to keep track of this as Quizzical will expire overdue questions and you won't see them, so any question that comes your way gets at least one mark.
 - a. There are 0.5 marks designated for correctly categorizing the question as either a recall question or an application question and using an appropriate verb in the question. The levels of Bloom's Taxonomy are covered in the material for the first tutorial and includes a lengthy list of verbs. On your Quizzical page there are hyperlinks to this.

- b. There also are 0.5 marks designated for associating an appropriate image/reference with the question. I've uploaded the images from the textbook, and it makes the most sense for the student to use and cite the most appropriate image. I would expect that a student would choose one of the primary figures I've covered in the lecture, but images from other chapters or things we've covered previously may well be good choices.
 - c. Now for the hard part. The other two marks are based upon the student author adhering to the best practices for writing good questions, and for the strength of the justifications. Let's talk about best practices first. The accompanying document summarizes these do's and don'ts, so I will not repeat them here other than to say that the question needs to be unambiguous, there is only one correct answer, and the distractors (the incorrect answers) must be both reasonable answers (generally they are true statements or related words but do not address/answer the question) and they must be incorrect. Be aware that some MCQs can be 'tricky' because students don't have command of the technical terminology that is requisite for clarity. If you look at the One-Page summary for each lecture there is a list of vocabulary words which you should know (these are also listed on the first slide of each lecture). Consult the best practices as we'll go through them at our TA meeting.
 - d. Now let's talk about the justifications. The student author is required to justify both the correct answer and each of the distractors. They should provide an adequate explanation for each, that would enable a student understand why the answer or distractor was correct/incorrect. In general, each should be justified independent of the others (that is, an author can't state that 'Answer A is incorrect because answer D is correct' or 'Answer A is incorrect for the same reason that answer B is incorrect').
4. Providing guidance for question editing. In many cases, it may be easy for you to clean up minor imperfections (e.g. grammar) rather than sending the question back to the student author for editing. Depending on the extent of these issues, you may wish to deduct marks (e.g. 0.5 marks) if there are multiple spelling/grammatical errors. However, if there are more serious issues with the question, use the box at the bottom of the page to provide specific guidance to the student to fix the question. Some simple statements like those that follow will give you some examples:
- a. 'You've misused the word_____. Please review and edit'
 - b. 'You don't seem to understand the mechanism in answer B. Please review and edit'
 - c. 'The question is too long...has too much irrelevant information....is ambiguous based on
 - d. 'The distractors are too different in complexity from the correct answer. Try to simplify them....
 - e. 'Figure 10-7 is not very relevant for your question; consider choosing another image...
 - f. 'The justifications of answers A and C do not convey any useful information to help students understand why these answers are correct/incorrect....

Once you've provided the guidance, click on the box to send your comments to the student.

- 5. Re-evaluating the question. I've given students 48 hours to revise and resubmit their flawed questions. They have only one opportunity. When an edited question comes

back to you, be sure to carefully review it. The author may have fixed the problem you identified, but they may also have changed other things that are now incorrect. Our goal is to populate the quiz bank with high quality questions, so be vigilant about this.

6. Scoring. This is a very important issue. Each question is worth 4 marks, and I've set 3 marks as a threshold to push the question into the quiz pool. Many of the submitted questions will be good from the start and will require minimal action by you and no editing by the author. Others will have minor flaws that are easily fixable and will achieve the 3 marks that are required to get them into the quiz pool. A minor percentage will be significantly flawed and will merit a score that exclude it from the quiz pool. This is logical as we don't want poor quality questions in the quiz pool.

Supplemental Figure 1



Riggs, Charles (Instructor) [Log out](#)

Overview - ITIF Projects Sandbox: Quizzical Upgrade

[Overview](#) [Scheduling](#) [Teaching Assistants](#) [Figures](#) [Students](#) [Questions](#) [Question Pool](#) [Report](#) [Grades Export](#) [Settings](#)

Scheduling Details

Total Students: 50 Total Assignments: 100 Total Lectures: 22 Total Assignments/Lec: 5

Alerts

This Lecture section is active and live

[Edit Schedule](#)

Class Statistics

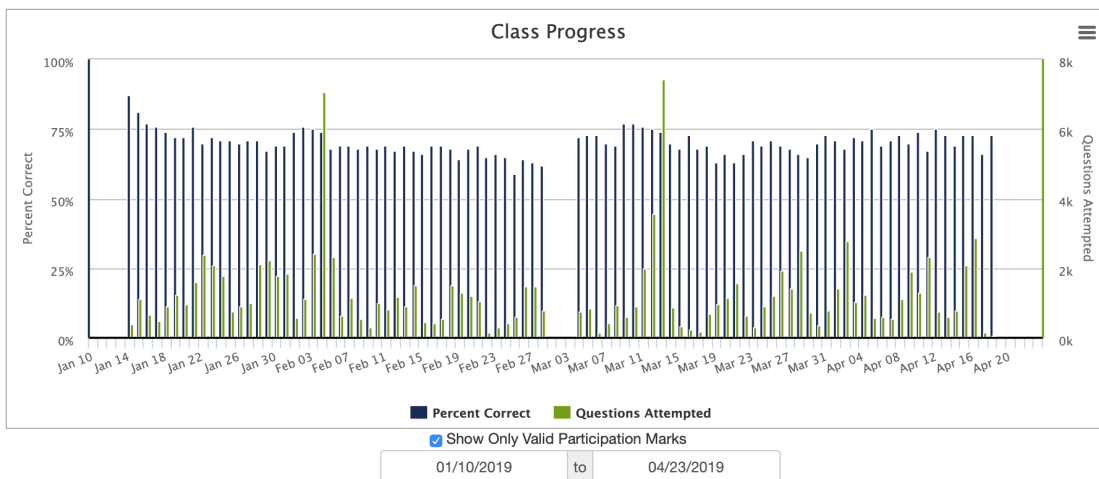
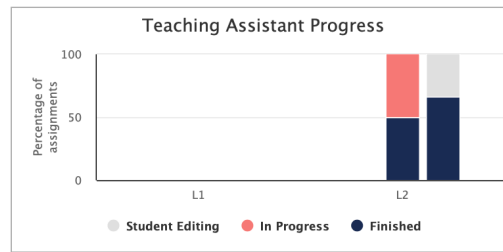
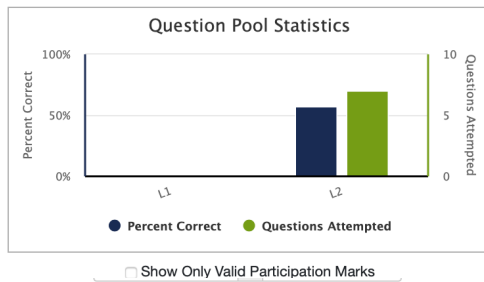


Figure S1. Instructor Dashboard Screenshot. Ten navigation tabs are displayed at the top of the page that allow the instructor to set up the course, assign or modify TA grading responsibilities, upload figures from a textbook, view questions, examine statistical analysis of questions, and export grades. There are graphs of question pool statistics (by lecture #), TA grading progress, and overall class progress (partially hidden by the screenshot limitations). Student authors can be reassigned (e.g. in the case of illness) and individual student activity can be viewed (Scheduling and Student tabs, respectively) for the purpose of advising. The Report tab allows the instructor to see the point biserial score (a measure of question quality) and student rating of each question, such that questions might be chosen for export (in Word format) for inclusion in formal exams. Grades are exported for both authoring and participation marks (if you selected both options) in excel format and are easily incorporated into your gradebook. The graph on TA progress allows you to monitor TA activity. Hovering over the bars will identify the individual TAs such that the instructor can be sure grading is proceeding in a timely fashion. The graph at the bottom of the page is from a completed term, showing class engagement for each of the lectures. For a comprehensive tour of Quizzical and its features, please consult the Supplemental Video 1.

Supplemental Figure 2

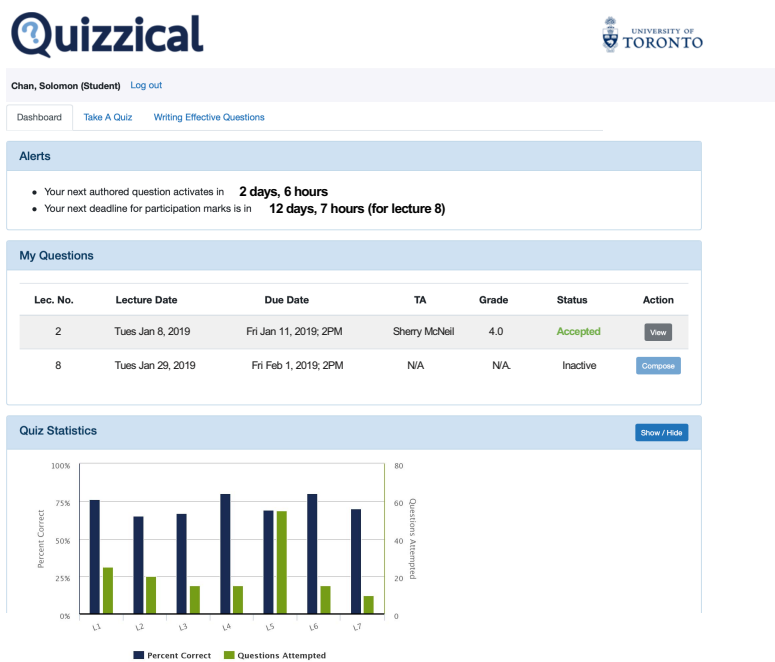


Fig S2: Student Dashboard Screenshot: There are three tabs on the student view. The dashboard shows alerts for upcoming assignments. In this case, the instructor has elected to have the students author questions as well as earn participation marks by taking timely quizzes. The Questions box suggests this student has been assigned two questions during the term and their dates and the status of each question is shown. The Quiz statistics box shows the student's engagement in lectures 1-7, and a lower graph charts student progress chronologically (not shown in this screenshot). The former allows the student to evaluate their comprehension of the material for each lecture, while the latter is a proxy for how continuously they've engaged. By clicking on 'compose' in the Questions box, the student is taken to a form filler for authoring their question (see Fig S3). The second tab at the top is 'Take a Quiz', which takes the student to a page where they can select lectures on which to be quizzed. This also gives them a tabular view of their progress on each lecture, such that they might evaluate where they need to focus future efforts. The 'Writing effective questions' tab takes the student to a page of best practices for writing MCQs and it also has some hyperlinked references. For a more fulsome description of the student dashboard and the authoring/quiz features, please consult Supplemental Video 2.

Supplemental Figure 3

The image shows a web-based form for creating quiz questions. It is split into two main panels: 'Question' and 'Answers'.
The 'Question' panel has a 'Category' dropdown menu with a question mark icon. Below it is a rich text editor with a toolbar containing icons for undo, redo, bold, italic, text color, and link. The 'Question' text area is empty. Below that is a 'Reference' text field with the placeholder 'Page number or figure number.' and a 'Select Figure' button with a 'Choose Figure' sub-button.
The 'Answers' panel has a header 'Indicate correct answer' on the right. It contains a rich text editor for the answer text with the placeholder 'type answer here'. To the left of this editor is a radio button next to the letter 'A'. Below the answer editor is another rich text editor for justifications with the placeholder 'type justification here'.

Fig S3: Student authoring page form filler. From the dashboard a student clicks on 'Compose' and is taken to this page, a modified form filler. There are several mandatory elements and three optional elements, depending on the options that the instructor chooses. The mandatory elements include categorizing the question as either a recall or an application question, typing text into the Question and Answer boxes (only the answer box for choice A is shown), and identifying the correct answer by selecting the appropriate radio button. Note that help is available for the category choice: a drop down menu briefly explains aspects of these levels of Bloom's taxonomy and provides some appropriate verb choices. The optional elements are for the student to provide a reference for their question (e.g. Figure 10-7;page 454), to choose an appropriate image to associate with their question (Select figure), and/or to provide justifications for both the correct answer and the distractors. These optional elements are not shown to the student attempting the question on a quiz, but rather are displayed after the student attempts the question. If all options are employed, the testee can utilize the reference (typically this would be a textbook figure or page number) to consult the textbook for more information. Likewise, the associated figure should provide information that supports the correct answer and/or disproves the distractor(s). The written justifications ideally provide solid reasoning for why the answer is correct and each distractor is incorrect. Employing these options will provide students with the resources to more effectively learn from both successful and unsuccessful attempts.

Supplemental Figure 4



Goodman, Gerard (Student) [Log out](#)

ITIF Projects Sandbox: Quizzical Upgrade

[Dashboard](#) [Take A Quiz](#) [Writing Effective Questions](#)

[Exit Proxy Login](#)

Question 3 of 3

01:44

Question ID	1
Category	Application
Question	An inhibitor known as Anti-Cdk is injected in the organism. The role of Anti-Cdk is to inhibit the activation of the cyclin-dependent kinase. Using this information choose the CORRECT statement below.
A	<input type="radio"/> The deactivation of the cyclin-dependent kinase (Cdk) leads to the phosphorylation of pRB, which can no longer bind the E2F protein
B	<input type="radio"/> The cell will be able to progress from G1 into S phase of the cell cycle
C	<input type="radio"/> If cyclin-dependent kinase (Cdk) is not activated the pRB will stay bound to the E2F protein
D	<input type="radio"/> The pRB will stay bound to the E2F protein, which will convert it into a transcriptional activator (E2F), leading to expression of the genes being regulated

[Submit Answer](#)

Fig S4: The quiz question page. In the upper right corner a countdown timer is shown and the time limit can be set by the instructor. There is no penalty for time expiration, but a warning message about time management appears if it expires. The question and the potential answers are shown, and students click on the appropriate radio button to choose their answer. Figure S5 shows the output of this particular question.

Supplemental Figure 5

ITIF Projects Sandbox: Quizzical Upgrade

Question 3 of 3

Question ID	1	Category	Application
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Question

An inhibitor known as Anti-Cdk is injected in the organism. The role of Anti-Cdk is to inhibit the activation of the cyclin-dependent kinase. Using this information choose the CORRECT statement below.

Reference

Page 642 Fig. 16-12

A

The deactivation of the cyclin-dependent kinase (Cdk) leads to the phosphorylation of pRB, which can no longer bind the E2F protein

Incorrect! If Cdk is not activated, it will not be able to phosphorylate the pRB and therefore the pRB will stay bound to the E2F protein

B

The cell will be able to progress from G1 into S phase of the cell cycle

Incorrect! Since the pRB will stay attached to the E2F protein, the cell will not be able to undergo transcription and translation. The progression from G1 to S phase is dependent on the protein translated, but this is not possible as there is no mRNA for the protein transcribed.

If cyclin-dependent kinase (Cdk) is not activated the pRB will stay bound to the E2F

The diagram illustrates the regulation of E2F. In step 1, E2F (green) and pRB (blue) are bound to DNA, leading to gene repression. In step 2, Cdk activation leads to pRB phosphorylation (pRB-P), causing it to dissociate from E2F. In step 3, E2F is free to bind DNA and initiate transcription.

Fig S5: The quiz question output page. Because of space limitations only answers A and B are shown. Note that if the instructor requires the student authors to provide references, an appropriate figure, and justifications for their answer/distractors, only now, on the output page, do these appear. These optional requirements afford learning opportunities for quiz takers, as they can go to the textbook reference for more information, and they can leverage the image and the justifications to enhance their comprehension of the topic.

Table S1: ANOVA, Tukey's Multiple Comparisons, and ANCOVA tables

Table S1-1: ANOVA table

a. Dependent variable: Final Grades (average of three term test scores)

Source	Df	SS	MS	F	P-value	Effect Size (Cohen's F)
Quizzical Group	2	27572	13786.0	84.9921	<2e-16 ***	0.46
Years	1	0.05	0.05	0.0003	0.0946 .	0.00065
Residuals	795	128952	162.2		0.9853	

Table S1-2: summary of Tukey's multiple comparisons

Category	Mean Difference	Lower Limit	Upper Limit	Adjusted p-value
Low-High	-16.357638	-19.359456	-13.355821	≈0
Mid-High	-5.944411	-8.540851	-3.347972	3e-07
Mid-Low	10.413227	7.821162	13.005292	≈0

Table S1-3: ANCOVA Tables

a. Test of the effect of quiz participation on course performance

Dependent variable: Final Grade (average of three term test scores)

Independent Variables	Df	SS	MSE	F	P-value	Effect Size (Cohen's F)
Q.group	2	26148	13074	194.2007	3.037e-14 ***	0.71
Year	1	0.74	0.74	0.0109	0.9168	0.004
cGPA	1	69104	69104	1026.4705	< 2.2e-16 ***	1.16
Error	769	51770	67			

* Q.group has three levels: "High", "Mid" and "Low" based on Quizzical Participation Scores

b. Test of the effect of authorship on course performance

Dependent variable: Final Grade (average of three term test scores)

Independent Variables	Df	SS	MSE	F	P-value	Effect Size (Cohen's F)
Q.Author.group	2	13261	6631	98.5787	<2e-16 ***	0.51
Year	1	43	43	0.6374	0.4249	0.03
cGPA	1	81993	81993	1218.9922	< 2.2e-16 ***	1.26
Error	769	51725	67			

* Q.Author. group has three levels: "High", "Mid" and "Low" based on Quizzical Authorship Scores

c. Test of the effect of combined authorship and quiz participation on performance

Dependent variable: Final Grade (average of three term test scores)

Independent Variables	Df	SS	MSE	F	P-value	Effect Size (Cohen's F)
Q. Engagement.group	2	25254	12627	187.6352	<2e-16 ***	0.70
Year	1	0.15	0.15	0.0022	0.9627	0.002
cGPA	1	70018	70018	1040.4407	< 2.2e-16 ***	1.16
Error	769	51751	67			

* Q.Engagement.group has three levels: "High", "Mid", and "Low" based on the Quizzical Engagement Scores that are defined as: Quizzical Participation Scores + Quizzical Authorship Scores

Table S2: Summary of pair-wise T-tests and ANCOVA tables

Table S2-1: all pair-wise T-test summary for both years

Response Variable	Group Means	T-statistic value	Df	P-value	Effect Size (Cohen's F)
2017 Term Test 2	65.85508 (0) 68.70752 (1)	-2.0676	416.03	0.03929 *	0.2
2017 Term Test 3	61.49755 (0) 64.98134 (1)	-2.3179	269.29	0.0212 *	0.245
2018 Term Test 2	60.55337 (0) 65.17464 (1)	-2.913	342.55	0.003814 **	0.31
2018 Term Test 3	63.59664 (0) 68.45833 (1)	-3.1236	257.76	0.00199 **	0.34

* Quizzical Group 0 – Quizzical participation scores are not improved for the time-period; Quizzical Group 1 – Quizzical participation scores are improved for the time-period.

Table S2-2: ANCOVA table: control by cGPA

a. Dependent variable: Term Test 2 Scores

Independent Variables	Df	SS	MSE	F	P-value	Effect Size (Cohen's F)
Q.Diff.Group	1	2397	2397	28.639	1.155e-07 ***	0.19
cGPA	1	91422	91422	1092.371	< 2.2e-16 ***	1.20
Year	1	3596	3596	42.966	1.026e-10 ***	0.24
Error	762	63773	84			

b. Dependent variable: Term Test 3 Scores

Independent Variables	Df	SS	MSE	F	P-value	Effect Size (Cohen's F)
Q.Diff.Group	1	2914	2914	32.459	1.759e-08 ***	0.21
cGPA	1	85212	85212	949.249	< 2.2e-16 ***	1.13
Year	1	1603	1603	17.859	2.677e-05 ***	0.16
Error	738	66248	90			

Table S3 ANCOVA Tables

a. Dependent variable: Final Exam Questions related to Term Test 1 materials

Independent Variables	Df	SS	MSE	F	P-value	Effect Size (Cohen's F)
Q.Group	1	8443	8443	59.932	3.037e-14 ***	0.28
Term.Test	1	100613	100613	714.196	< 2.2e-16 ***	0.96
Year	1	23019	23019	163.400	< 2.2e-16 ***	0.46
Error	782	110165	141			

Regression Summary

b. Dependent variable: Final Exam Questions related to Term Test 1 materials

Independent Variables	Estimate	St.Error	t -value	P-value
intercept	-19.3155	2.3812	-8.112	1.93e-15 ***
Q.Group (1)	2.7839	1.1271	2.470	0.0137 *
Term.Test	0.9845	0.0348	28.289	< 2.2e-16 ***
Year (2018)	10.9921	0.8599	12.783	< 2.2e-16 ***

c. Dependent variable: Final Exam Questions related to Term Test 2 materials

Independent Variables	Df	SS	MSE	F	P-value	Effect Size (Cohen's F)
Q.Group	1	13232	13232	95.185	< 2.2e-16 ***	0.36
Term.Test	1	59042	59042	424.708	< 2.2e-16 ***	0.75
Year	1	44372	44372	319.187	< 2.2e-16 ***	0.65
Error	754	104819	139			

Regression Summary

d. Dependent variable: Final Exam Questions related to Term Test 2 materials

Independent Variables	Estimate	St.Error	t -value	P-value
intercept	-18.2473	2.3976	-7.611	7.86e-14 ***
Q.Group (1)	3.1819	1.2505	2.544	0.0111 *
Term.Test	0.8611	0.0351	24.530	< 2.2e-16 ***
Year (2018)	15.5269	0.8659	17.932	< 2.2e-16 ***