

Conversion Immersion: Converting Old and Writing New Clicker Questions for Your Biology Courses

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Clickers (aka Personal, Audience, or Classroom Response Systems) have received attention for several advantages they offer. One major challenge with instructors adopting clickers is their inability to compose effective questions, since this requires different pedagogy than composing effective test or homework questions. One of the authors successfully uses clickers in her introductory biology laboratory by following some basic principles of good practice and by using well-written questions. During our workshop, we presented a brief background on clicker usage related to science education, worked on converting existing clicker questions to ones that promote interaction and learning, and composed new clicker questions.

Keywords: clickers, classroom response systems, critical thinking, Bloom's Taxonomy

Introduction

Clickers are useful for a variety of reasons, both in lecture and laboratory courses. A non-exhaustive list of these advantages, which may vary by brand and software, includes: taking attendance, breaking up lecture and lab monotony, promoting understanding of content and concepts with active learning activities, giving pop quizzes, checking understanding of material, replacing Scantron® forms on multiple choice exams, collecting homework, and collecting anonymous opinions about controversial or embarrassing issues. Effective use of clickers necessitates well-written questions and prompts for many of the above reasons, including the usage on which we focused: promoting understanding of content and concepts with active learning activities. Characteristics of discussion or critical thinking prompts are different than characteristics of good exam and assessment questions (Beatty et al., 2006), so most instructors need training and practice in identifying and composing good clicker prompts.

Preszler et al. (2007) used clicker questions in the lecture portion of lower- and upper-division biology courses at New Mexico State University. The number of questions presented in lecture varied within each section in order to test the hypothesis that use of clicker questions (multiple choice, often with discussion between classmates before submission) was positively correlated with performance on exam questions related to those clicker topics from class. Although the paper does not specify the wording or exact content of these clicker questions, it is interesting to note that there was a positive impact of clicker usage on student performance on related biology lecture exam questions. We hope to maximize

the positive learning effects seen by Preszler et al. (2007) by using the most pedagogically sound clicker questions or prompts possible.

Note that the purpose of our workshop was not to discuss tips for effective use of clickers (see, for example, Caldwell, 2007 and Premkumar, 2008), technical details on best brands or software, or research on clicker usage in general (e.g. Kay and LeSage, 2009), but rather to focus on the identification and composition of clicker prompts to promote critical thinking and understanding in lecture and laboratory.

Notes for the Instructor

Tools for Writing Multiple Choice Questions

Writing multiple-choice questions that test for factual knowledge is easy, but many instructors would like to test for higher order learning. The problem is that there isn't a simple formula for creating good questions that actually test what we want our students to learn. Many publications provide tips, guidelines, and best practices, but there is no substitute for practice and experience when it comes to writing questions that promote and assess higher order learning.

The first step in converting questions is to learn to identify the level at which an existing question is written. Table 1 shows the Blooming Biology Tool from Crowe et al. (2008). The authors developed this tool to help educators (and students) assess the "Bloom's level" of exam questions.

Table 1. Blooming Biology Tool (used by permission from Crowe et al., 2008)

	Knowledge ¹	Comprehension ¹	Application ¹	Analysis	Synthesis	Evaluation
Key skills assessed	LOCS ² IDENTIFY, RECALL , list, recognize, or label	LOCS ² DESCRIBE or explain in your own words, re-tell, or summarize	LOCS ² HOCS ³ PREDICT an outcome using several pieces of information or concepts; use information in a new context	HOCS ³ INFER ; understand how components relate to each other and to the process as a whole	HOCS ³ CREATE something new using/ combining disparate sources of information	HOCS ³ DETERMINE/CRITIQUE relative value; determine merit
General examples of biology exam questions	Identify the parts of a eukaryotic cell; identify the correct definition of osmosis	Describe nuclear transport to a lay person; provide an example of a cell signaling pathway	Predict what happens to X if Y increases	Interpret data, graphs, or figures; make a diagnosis or analyze a case study; compare/contrast information	Develop a hypothesis, design an experiment, create a model	Critique an experimental design or a research proposal; appraise data in support of a hypothesis
Type of question						
Labeling	X	X	X			
Fill-in-the-blank	X	X	X	X		
True-false	X	X	X	X		
Multiple-choice	X	X	X	X		
Short answer	X	X	X	X	X	X
Essay	X	X	X	X	X	X
Characteristics of multiple-choice questions	Question only requires information recall. Possible answers do not include significant distracters ⁴	Question requires understanding of concept or terms. Possible answers include significant distracters ⁴	Question requires prediction of the most likely outcome given a new situation or perturbation to the system	Question requires interpretation of data and selection of best conclusion	N/A: If provided with choices, students only differentiate between possible answers rather than synthesize a novel response	Question requires assessment of information relative to its support of an argument

¹ The first three levels of Bloom's are usually hierarchical; thus, to complete an analysis-level question, students must also demonstrate knowledge-, comprehension- and application-level skills.

² LOCS indicates lower-order cognitive skills.

³ HOCS indicates higher-order cognitive skills.

⁴ Significant distracters are those answers that represent common student misconceptions on that topic.

Keep in mind that it is impossible to classify a question with certainty outside the context of what students have already done in class or what is available in their course readings. An *Application* question for one class may be a *Knowledge* question in another class if the specific example was already described in the student's lecture or lab section. However, we believe this is a useful tool for both converting existing questions and composing new ones.

How Are Clicker Questions Different from Exam Questions?

Good discussion clicker questions at any level have some different characteristics than good exam or homework questions. Exam and quiz questions are generally designed to test an individual student's mastery of specific pieces of content. This same goal may apply to clicker questions as well. But because they are completed in class, often in collaboration with other students, clicker questions may have an expanded list of objectives. Clicker questions should achieve specific content and cognitive or process goals, increase or assess content knowledge, and/or increase or assess skills (Beatty et al., 2006; Caldwell, 2007).

For example, possible goals for clicker questions may include:

- fact/concept check ("does everyone get it?")

- apply course material in a novel situation
- peer instruction ("convince your neighbor that your answer is right")
- promote discussion among students
- collect student opinions ("is it better to be overweight or underweight?")

Identifying the goal is therefore an important step in the construction of a new clicker question. The literature suggests that authors of effective clicker questions should first identify content goals, cognitive goals, and metacognitive goals before choosing a tactic and drafting a question (Beatty et al., 2006; Skinner, 2009).

Skinner (2009) says that clicker questions should satisfy three goals:

- Content goal: What subject are you trying to teach?
- Process goal: What cognitive skills do you want students to use? Do you want them to know, explain, describe, compare, contrast, discuss, and summarize...?
- Metacognitive goal: What beliefs about learning [the subject] do you wish to reinforce? Skinner (2009) offers the following example: "Students should ... [strive] to understand basic processes and concepts and [apply] them to various systems, anatomical constructs, and physiological occurrences."

Example of Activity 1: classifying a question.

Question:	Sample #1: Tropical grasslands are also known as A. taiga B. tundra C. savanna D. chaparral E. temperate plains	Sample #2: If a fossil contains 1/8 th the amount of ¹⁴ C as a live organism, the animal probably died ___ years ago. A. 17,190 B. 11,460 C. 5,730 D. 0	Practice Question: DNA strand synthesis is initiated with which primer? • RNA • DNA • protein • ligase • primase
Blooming Biology level:	Knowledge	Application	
Content Goal:	Names of biomes	Radiometric dating	

Often, but not always, the best clicker questions are qualitative, meaning that the answer is not “cut and dried.” That is, the correct answer should not be obvious but rather should require some discussion and higher-order thinking. Beatty and Gerace (2009) advocate “question-driven instruction” and suggest the following qualities of good questions:

- Questions must be “deeply challenging to students’ understandings.”
- “Questions must often draw together multiple ideas.”
- “Questions should be disputable (as opposed to ‘you know it or you don’t’ styles), and should generally be qualitative...to facilitate linguistically rich discussion.”

Instructors should keep these many possible goals in mind as they work on converting existing and composing new questions for use with clickers.

Activities to Assist with Prompt Classification and Composition

1. Classify sample clicker questions

A good first step for those wishing to hone their clicker question conversion skills is to classify existing questions as to the Bloom’s level (Table 1 is a good place to start). It is also useful to determine the content goal of questions, as listed by Skinner (2009) above. At the top of the page are two worked examples followed by an additional question to practice your classification.

2. Revise sample clicker questions

Next, practice converting three lower Bloom’s level questions using tactics described by Beatty et al. (2006). The “Makeover Practice Worksheet” (Appendix A) is designed to assist with these conversions. For each question, do the following:

- While maintaining all or some of the content goal for each question, identify deeper process/metacognitive goals.

- Next, select three tactics or question types per question. See Table 2 for some examples of tactics that could help reach those goals.
- Finally, rewrite or modify each question in three different ways, using EACH of the three tactics.

Often, the best way to revise a question is to ask it in two ways. Table 3, which appears just below the multi-page Table 2, may also help trainees to think about different ways to phrase the same question. Below we provide an example of a question that we classified and modified using three tactics from Table 2. Some of the conversions from workshop participants appear in Appendix B. For further reading see Demetrulias and McCubbin (1982).

Question:	The body form of most fungi is a: A. mycelium B. porous, vase-shaped vessel C. leafy green stem D. single, motile eukaryotic cell E. single prokaryotic cell
Content Goal:	identify the body form of fungi as distinguished from that of other life forms
Process Goal/ Blooming Biology Level:	visualize body forms / recall a fact (knowledge)
Metacognitive Goal:	to recognize that our brains can categorize organisms by common characteristics

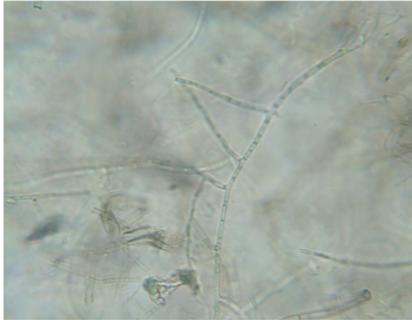
Tactic:	Interpret the representation	Identify a set or subset	Compare/Contrast
Converted Question:	<p>What type of organism is this?</p> <p>A. bacterium B. protozoan C. fungus D. moss E. sponge</p> <p>* </p>	<p>How many of the following organisms have a body form that consists of a mycelium?</p> <p><i>fungus, protozoan, algae, moss, sponge</i></p> <p>A. 1 B. 2 C. 3 D. 4 E. 5</p>	<p>The leafy green stem is to a moss as a ___ is to a fungus.</p> <p>A. mycelium B. porous, vase-shaped vessel C. single, motile eukaryotic cell D. single prokaryotic cell E. spore</p>
<p>*image from http://commons.wikimedia.org/wiki/File:Rhizoctonia_hyphae_160X.png</p>			

Table 2. Question design tactics for four common cognitive goals in physics education (adapted from Beatty et al., 2006).

Tactics	Notes/Description	Example
<i>Tactics for directing attention and raising awareness:</i>		
Remove nonessentials	Doesn't include anything that doesn't lend to your objective	[Self-explanatory]
Compare and contrast	[Self-explanatory]	What features unite (or differentiate) the items in the following list?
Extend the context	Asks a familiar question about a new situation	After students learn the parts of a generic flower, show various photos of real flowers (complete, incomplete, etc.) and have students identify the parts from the photos
Reuse familiar question situations	Change variables within the same question structure	Present the same genetics questions with alterations in the parental genotypes, parental phenotypes, and number of offspring
Oops-go-back	Sequence of two questions, the first of which seeks to draw the incorrect answer from students for the second question	Any question that reliably elicits misconceptions from a large proportion of the class would work here. E.g. first question elicits the misconception that most of a plant's biomass comes from soil; the second question shows an old plant in a pot and somehow forces confrontation with the fact that the biomass comes from the atmosphere.

Tactics	Notes/Description	Example
<i>Tactics for stimulating cognitive processes:</i>	<i>Ask questions that demand the student exercise a certain cognitive pathway</i>	
Interpret representations	Process = seek alternate representations; Provide answer options in a different representation than in the question (graph, textual, figure.)	“Describe an object’s motion with a graph and then ask a question about its behavior that requires students to recognize and interpret the information latent in aspects of the graph, such as a slope or the area under a curve.” (Beatty et al., 2006, p35.)
Compare and contrast	Process = compare and contrast	[See above]
Extend the context	Process = extend context	Give mapping units and ask students to determine the order of genes on a chromosome; then, in a follow-up question, add another gene or two to the scenario and ask students to determine where the new genes fit in.
Identify a set or subset	Process = categorize and classify; Present students with sets of objects or processes and ask them to identify a subset.	Present a list of 15 or so organisms, and ask students <i>how many</i> or <i>which ones</i> are eukaryotes, autotrophs, protists, etc.
Rank variants	Process = categorize and classify; Present students with sets of objects or processes and ask them to rank the types/options.	Arrange the following items from smallest to largest, or from most to least closely related to some reference organism, or from most inclusive to least inclusive, etc.
Constrain the solution	Process = generate alternate solutions; direct student to use or not use a certain approach to solve a problem.	Determine the number of possible gametes by drawing all possible chromosome configurations or by using the 2^n formula.
Reveal a better way	Process = generate alternate solutions; give students a problem they will probably work a tedious/hard way, then reveal an easier way.	What is the probability of parent AaBBcc and AAbbCc having a child of genotype AABbCC? (Punnett square versus product rule.)
Strategize only	Process = strategize, justify, and plan; ask students for principles or approach to solve a problem (but don’t solve it.)	After presenting the results of one experiment, ask students to identify the most logical next question to ask; or show the results of an experiment and ask students to identify a logical follow-up hypothesis.
Include extraneous information	Process = strategize, justify, and plan; different than removing nonessentials because it serves the instructor’s pedagogical purpose of making student explicitly aware of what is necessary to answer question/solve problem.	If the first three children in a family are boys, what is the probability that the next child will be a girl? Alternatively, in interpreting pedigrees, include information that is not necessary to interpret the inheritance pattern.

Omit necessary information	[Same as above]	Ask students to calculate the probability of two healthy parents having a child with cystic fibrosis, without saying whether the parents are homozygous dominant or heterozygous.
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Tactics	Notes/Description	Example
Tactics for formative use of response data:	Allow histograms (question responses) to be useful in revealing student difficulties	
Answer choices reveal likely difficulties	Include common errors as answer choices	[Self explanatory; the difficulty is in identifying the common errors. Published concept inventories can help, as can paying careful attention to student discussions and questions]
Use “none of the above”	This can help avoid guessing; make it the correct answer on occasion.	[Self-explanatory]

Tactics	Notes/Description	Example
Tactics for promoting articulation discussion:		
Multiple defensible answers	Allows arguments for “their answer” with evidence and assumptions	Follow up the previous osmosis question with a true-false question about whether it matters whether the solute is a sugar or a salt; could also include “H” gene in ABO blood type question and have students try to deduce parental genotypes.
Qualitative questions	Helps students think conceptually and about inter-relationships	Have students choose which of several concept maps best depicts the relationship among topics. Alternatively, list some terms (A = adrenal gland; B = thyroid gland; C = parathyroid gland; D = pancreas; E = release; F = absorb; G = blood; H = urine; I = lymph; J = uterus; K = bone; L = increases; M = decreases; N = calcium, etc.) and ask which is the correct sentence, e.g.: <i>C produces PTH which travels in the G and interacts with receptors in K and L the concentration of N in the blood.</i> Or, instead of giving the nouns, students can be asked to choose among possible connecting sentences.
Analysis and reasoning questions	Promotes analytical skills and deeper thinking by students	Give mapping units and ask students to determine the order of genes on a chromosome; alternatively, show the locations of genes on a chromosome and have students calculate that mapping units. OR ... Give the concentrations of salt on either side of a semi-permeable membrane and ask students to predict the direction of water movement.
Require unstated assumptions	Promotes disagreement between students during discussion	100 kg of nuts, 100 kg of grass. True/False: each would support the same biomass of secondary consumers [If true, requires assumption that the “10% rule” is accurate.]

Trap unjustified assumptions	[Same as above]	100 kg of nuts, 100 kg of grass ► t/f each would support the same biomass of secondary consumers [If false, elicits the unjustified assumption that all food sources are assimilated equally.]
Deliberate ambiguity	[Same as above]	T/F Bottled water is healthier than tap water. Or, which is the safer choice: bottled water, mountain stream water, tap water, rain water collected in a bucket, Diet Coke.
Trolling for misconceptions	Promotes disagreement and helps them identify misconceptions in the future	The only chromosomes in the gametes are the sex chromosomes. [This could become an “oops go back” if you follow up with a question about how many chromosomes in the zygote.]

Table 3. Sample pairs of questions that “test the link between the general and the particular.” (from Wit, 2003)

What is the definition of this concept?	What concept is defined by this definition?
Which of these statements are correct about this plot?	Which of these plots can you associate with the following statement?
Which of these analysis methods is useful for this data?	Which of these datasets could be analyzed by this method?
Which of the following interpretations corresponds to this output?	Which of the following outputs warrants the following interpretation?

3. Write new clicker questions

During the last part of our workshop, participants identified topics to write clicker questions about. They used the instructions summarized in this paper: state the goals for each question, use the tactics or question types from Table 2, and draft some clicker questions at a variety of Bloom’s levels. We advised the participants to be creative; we encouraged them to think beyond testing content and promoting discussion and to also consider including some opinion/survey questions that could get students thinking about a lab topic and/or lead to student discussion.

Discussion and Conclusion

The authors have found that brainstorming and working together with colleagues often yields richer question prompts, both with clicker conversions and with new question compositions. In addition, take heart that with practice, this process does become faster. The yield should be a rewarding experience for students, both in terms of rich discussion and their deeper understanding of course content.

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Online Resources (modified from Crowe et al., 2008)

Websites with information to guide development of multiple-choice questions at each level of Bloom’s cognitive domains.

- Provides the philosophical framework and the references for creating good multiple choice questions: <http://www.utexas.edu/academic/ctl/assessment/iar/students/plan/method/exams-mchoice-bloom.php>
- Annotated bibliography of website resources for creating good multiple choice questions created by the University of Medicine and Dentistry of New Jersey: http://cte.umdny.edu/student_evaluation/evaluation_constructing.cfm
- Designing and managing multiple choice questions. A manual developed by the University of Cape Town Home page:
<http://web.uct.ac.za/projects/cbe/mcqman/mcqman01.html>
<http://web.uct.ac.za/projects/cbe/mcqman/mcq-qappc.html>

- Using Bloom’s Taxonomy to create a knowledge survey to be used for assessment of student learning (E. Nuhfer and D. Knipp): <http://ed.isu.edu/depts/deld/ISUAssessmentHand.pdf>
- We also direct the reader to the practice GRE subject tests available on-line, as many of the multiple choice questions which refer to graphs or figures are good examples of questions at analysis and evaluation levels of Bloom’s Taxonomy: <http://www.ets.org/portal/site/ets/menuitem.1488512ecfd5b8849a77b13bc3921509/?vgnextoid=5689a552d81b5010VgnVCM1000022f95190RCRD&vgnnextchannel=095b46f1674f4010VgnVCM10000022f95190RCRD>

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Appendix A: Clicker Conversion Practice Worksheet

Original Question/Prompt:

Makeover #1

- Content goal: Process/metacognitive goal:
- Tactic (from Beatty 2006):
- Revised question stem and distractors:

- New Bloom's level:

Makeover #2

- Content goal: Process/metacognitive goal:
- Tactic (from Beatty 2006):
- Revised question stem and distractors:

- New Bloom's level:

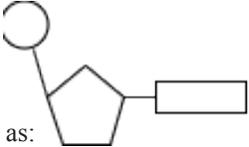
Makeover #3

- Content goal: Process/metacognitive goal:
- Tactic (from Beatty 2006):
- Revised question stem and distractors:

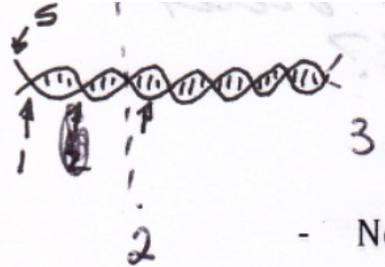
- New Bloom's level:

Appendix B: Examples of Workshop Participants' Conversions, 23 June 2010

Group 1, AM

Original question	Converted question
<p>The question shows a picture of a nucleotide and asks the following question:</p> <p>The diagram to the right represents the building block of a large molecule known as:</p> <p>a) nucleic acid b) carbohydrate c) amino acid d) protein</p> 	<p>Content goal: Monomers/polymers; nucleic acid structure Tactic: "Identify a set or subset" Revision: Include a set of 6 images, three polymers and three monomers (1 = simple sugar, 2 = nucleotide, 3 = DNA, 4 = polysaccharide, 5 = amino acid, 6 = protein). The question then asks: Image 1 is to image 4 as a) image 2 is to image 3 b) image 5 is to image 6 c) image 6 is to image 5 d) image 4 is to image 2</p>

Group 2: AM

Original question	Converted question
<p>If each cell in one organism has 10 chromosomes, how many molecules of DNA?</p> <p>a) 10 b) 20 c) too many to count d) I have no idea</p>	<p>Content goal: DNA is an important macromolecule Tactic: "Oops go back." The students would not be showed the answer immediately after answering. Revision: Show a picture of the DNA double helix, labeled with arrows and numbers.</p>  <p>Which of the following is true?</p> <p>a) Strands 1 and 5 are two separate molecules b) The areas between 1 and 2 and between 2 and 3 are separate molecules c) The area between 1 and 3 is one molecule</p> <p>Once this question uncovers misconceptions about the DNA molecule, go back to the original question about the number of chromosomes/DNA molecules.</p> <p><i>[Following discussion, participants suggested adding irrelevant info like whether the cell is haploid or diploid, or adding additional layers of information like "n=5."]</i></p>
<p>What are the hazardous wastes for this lab?</p>	<p>Content goal: Safety awareness Revision: List chemicals to be used in a lab and ask questions such as, "Which of the above chemicals can go down the sink?" Alternatively, could show several receptacles (e.g. sink, broken glass container, liquid waste, biohazard bag) and ask "Which of the above chemicals can go in [container]?"</p>
<p>How to use a spectrophotometer</p>	<p>Content goal: Equipment knowledge Revision: Place the steps in the correct order. Could also ask, "What should you do if the reading is off the scale?"</p>
<p>How to use pipettes</p>	<p>Revision: Could show pictures of different pipettes and ask which should be used to transfer volume [X]. Could also have a picture of a meniscus and ask where to read the volume.</p>

Group 3: AM

Original question	Converted question
The question is a polling question that asks: What do farmed fish eat? a) whatever is in the water b) algae c) corn d) other fish	After the lesson about the global food supply, ask additional questions such as “What trophic levels do farmed fish occupy?” or “Calculate the energy efficiency of farmed fish occupying different trophic levels” or “Place the farmed fish at the correct trophic level in this diagram.”

Group 4: AM

Original question	Converted question
The original questions were from a series of open-ended lab questions about osmosis occurring across chicken egg membranes. Among others, questions include: What is the solute concentration of a chicken egg’s cytoplasm? Is a 40% sucrose solution hypotonic or hypertonic to egg cell cytoplasm?	<p>Content goals: differentiate between hypotonic and hypertonic; understand the movement of water</p> <p>Revision: A 10% NaCl solution is __. a) hypertonic b) hypotonic c) hypertonic to a 40% NaCl solution d) hypotonic to a 40% NaCl solution e) isotonic to a 40% NaCl solution</p> <p>If an egg is 1% glucose, what would happen if it were placed in distilled water? a) Egg would increase in size because water enters the egg b) Egg would decrease in size because water enters the egg c) Egg would increase in size because water leaves the egg d) Egg would decrease in size because water leaves the egg e) Egg would stay the same size; no net movement of water would occur. <i>[Following discussion, participants suggested leaving out info like external concentration.]</i></p>

Group 1: PM

Original question	Converted question
Endocytosis moves materials _____ a cell via _____. a) into; facilitated diffusion b) into; membranous vesicles c) into; a transport protein d) out of; diffusion e) out of; membranous vesicles	<p>Content goal: Differentiate between endocytosis and other forms of cell transport</p> <p>Revision: <i>How many</i> of the following processes involve endocytosis? release of neurotransmitters</p> <ul style="list-style-type: none"> • water moving into and out of cells • an amoeba engulfing a yeast cell • glucose absorption in the intestine • movement of cholesterol from plasma into a liver cell • transfer of plasma proteins across the capillary endothelium

Group 2: PM

Original question	Converted question
<p>The smallest biological unit that can evolve over time is</p> <p>a. a cell b. an individual organism c. a population d. a species e. an ecosystem</p>	<p>Content goal: Recognize difference between scientific and popular definition of “evolve” Tactic: Trolling for misconceptions Revision: <i>In scientific terms</i>, the smallest biological unit that can evolve over time is</p> <p>a. a cell b. an individual organism c. a population d. a species e. an ecosystem</p> <p><i>[The group suggested this type of question (answered individually, without allowing discussion) could be used as a measure of student learning, pre- and post- covering material about evolution]</i></p>

Mission, Review Process & Disclaimer

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