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1 Title: Seven practical strategies to add active learning to a science lecture

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14 15 Abstract

16 Multiple research studies have shown active learning can increase student performance, reduce fail rates,
17 and increase the success of marginalized students in STEM. In this mini-review we discuss a simple
18 framework for planning and implementing active learning in the classroom. We provide seven strategies
19 to support faculty members who want to implement this framework, with five suggested teaching
20 activities and two mechanisms of creating space in the lecture to use the activities. Each strategy is given
21 with a foundational research paper describing the evidence that it improves learning, engagement and
22 inclusion in the classroom. We include our own experiences using these strategies in large biology
23 lectures that had segments devoted to neuroscience topics, but they are effective in smaller classes as well.

24 25 Key Words:

26 Active learning

27 Teaching

28 Education research

29 Discipline based education research

2	
30	Biology education research
31	Flipped class
32	Underrepresented minority
33	Diversity
34	Inclusive teaching

35 Introduction

36 A number of reports have called for a change to teaching practices in large lectures in STEM (science,
 37 technology, engineering, mathematics) [1,2]. STEM degrees are associated with better economic
 38 outcomes [3], but this benefit is not equally distributed across all students. Almost 60% of all bachelor's
 39 degrees are awarded to women, but in STEM this figure is only 34% [4]. This underrepresentation in
 40 STEM, including biology, is also seen in students of color. In 2016, the US population was 17.9%
 41 Hispanic, but the percentage of STEM bachelor's degrees awarded to Hispanic students was 12.1% [5,6].
 42 The US population is 13.4% African American, but in 2016 the percentage of STEM bachelor's degrees
 43 awarded to Black students was 8.6% [7,8]. Of all Bachelor's degrees in biological sciences awarded in
 44 2015, only 10.5% went to Hispanic students and 7.6% went to Black students [8]. It is these disparities
 45 that lead many to suggest that improved university instruction may provide a mechanism to increase
 46 engagement and retention of women and underrepresented students in STEM.

47

48 When a change in biology teaching is recommended, the teaching practices proposed are, broadly,
 49 increased structure [9], and increased active learning [10]. High structure and active learning in a biology
 50 course require that the instructor:

- 51 a) determine what they want students to be able to demonstrate by the end of the course,
- 52 b) determine which of those learning objectives and skills are difficult for students to master on their
- 53 own,

- 3
54 c) develop activities to carry out during class that will give students practice in these difficult skills
55 while in the presence of instructional staff who can motivate them and provide feedback (active
56 learning),
57 d) provide a framework of content and accountability before, during and after class to maximize
58 student engagement with the work (increased structure).

59
60 Faculty members in neuroscience have the desire to improve the success of students from disadvantaged
61 backgrounds, but also have progressively larger classes and very high demands on their time. Being asked
62 to “make your class more active and structured” is not a trivial request given the required steps listed
63 above. But the good news is that even small changes in teaching can have positive effects on student
64 learning, as we have found in our own classes [11]. For those faculty members who want to move up the
65 spectrum of increased structure and active learning, we present a series of evidence-based techniques that
66 range from minimal time to maximal reward (Fig. 1).

Seven Practical Strategies *to add active learning to the large lecture*

Use Class Time to Increase Engagement

1. Increase community with name tents
2. Increase equity with random calling
3. Generate peer discussion with clickers
4. Use “exam” questions outside of exams
5. Use collaborative exams to increase interaction and community

Create Time in Class for Activities

6. Create reading guides and pre-class quizzes
7. Encourage students with pre-class videos

67
68 For this review, we are focusing on steps “c” and “d” in the framework above: developing the
69 work/activities to carry out in class (active learning) and providing a mechanism of content delivery and

4
70 accountability outside of class (structure). For every example, we provide a foundational research study, a
71 short take-home message, and a description or plan of implementation.

72
73 The tools we present are intended to be adoptable by any instructor, but all of them do require a different
74 effort or intentionality than a traditional lecture requires. We have found this effort to be worthwhile. The
75 increased work of preparation of new materials and strategies can be minimized by making small changes
76 on a regular basis. We have also found that a classroom that is more engaging and active for the students
77 is far more stimulating and interesting for us. We would never start a new experiment in the lab without
78 first reading the literature and consulting experts, regularly monitoring progress and modifying and/or
79 developing strategies to achieve our research goals. We have found that investing effort in expanding and
80 improving our teaching by building on evidence-based practices of others, continuously evaluating
81 progress, and regularly modifying our approach provides similar intellectual rewards. It also generates
82 progress toward our goal of increased achievement and success for our diverse student body.

83 Step 1: Use class time to increase engagement with the material and people

84 After you have determined the skills that you want your students to be able to demonstrate, and you have
85 carefully considered which of those skills are most difficult and require expert guidance, it is time to
86 create a lecture environment that supports that guidance. It is particularly important to recognize that
87 students vary in experience with the material, and also enter the class with different expectations of what
88 an environment of learning looks like. Recognizing the diversity of student voices will improve the ability
89 of each student to engage with the material. And recognizing that each of us as instructors enter the
90 classroom with our own cultural expectations and unconscious biases can help us avoid behaviors that can
91 prevent all voices from being evenly heard. The strength of these resources is that not only can active
92 learning give students additional practice with course content, but it can also increase a student's sense
93 that their presence is valued in the classroom and, more broadly, in science.

95 Example: Increase community with name tents

96 Foundation paper: Cooper, K. M., Haney, B., Krieg, A., & Brownell, S. E. (2017). What's in a name? The
97 importance of students perceiving that an instructor knows their names in a high-enrollment biology
98 classroom. *CBE—Life Sciences Education*, 16(1). [12]

99 Message: Small steps to learn student names makes a big impact on students.

100 Implementation and discussion:

101 Students who feel tentative about their skills in science often feel faceless and unimportant in a lecture
102 hall of hundreds. Even students who find learning the material to be straightforward can find it distasteful
103 to have all of their biology and chemistry occur in classes with no connection to other students or the
104 instructor. The small step of telling students that their names matter will instantly demonstrate to students
105 that you want to know who they are. One of us (Author 1) is currently using name tents in our courses
106 (150 to 400 students) and provides students with 5x7 index cards and permanent markers to borrow. If
107 you are in a room with very small desks, you may find it more practical to provide inexpensive
108 conference-style nametag lanyards for students. We have students fill out the name tents on the first day
109 of class, and have them incorporate their names when introducing themselves to their neighbor. We have
110 to provide more name tent supplies a few weeks in when many students have managed to lose the first
111 one. We do have to remind students to get them out, and occasionally encourage them when doing a
112 group discussion to be sure everyone knows the names in the group.

113 Why we like it: We find the benefits of nametags to be similar to the benefits of active learning activities
114 in microcosm. Some students embrace the idea, while others sigh heavily and do not seem motivated to
115 use theirs. But we find that the ability to talk to students and refer to them by name reduces a significant
116 barrier to interaction. Perhaps even more importantly it provides a mechanism for students to introduce
117 themselves to each other and to continue conversations from lecture to lecture. Without this prompt, some
118 students would chose not to engage rather than admit they do not remember the name of the person they
119 met previously. We tell students they are welcome to add their pronouns to their name tents, which can
120 make the classroom environment more comfortable for LGBTQA+ students who wish to identify this

6
121 information. We have also asked students to provide phonetic spelling so we can pronounce their name
122 correctly. Because these name tents or tags are portable, we or the teaching assistants can require them in
123 discussions or labs as well. All these actions reinforce the message that even though there are many
124 students in this class, each of them is unique and important.

125 Additional reading: Cash et al., 2017 [13]

126

127

128 **Example: Increase equity with random calling**

129 Foundation paper: Eddy, S. L., Brownell, S. E., & Wenderoth, M. P. (2014). Gender gaps in achievement
130 and participation in multiple introductory biology classrooms. *CBE—Life Sciences Education*, 13(3). [14]

131 Message: Instructors can overcome unconscious implicit biases with simple changes.

132 Implementation and discussion:

133 Many instructors value asking questions to the class during their lecture as a method of engaging students.

134 However, it is important to be aware that there are students in the class who will never volunteer to

135 answer because they are nervous about speaking in a large class or afraid of being wrong. Importantly,

136 studies show that people who do not volunteer are more likely to be women and people of color [9, 15].

137 Even more interesting is the unconscious bias that may occur when instructors *choose* students to answer
138 a question [16, 17].

139 Unconscious bias is difficult to accept because we all want to be fair and supportive of all students. But

140 because research indicates that we all have unconscious thinking and behaviors, we cannot assume that

141 intention and effort is sufficient to make us equitable teachers. If you do want to call on students, it is

142 therefore helpful to have practices in place that generate increased equity, and random calling is a good

143 example of a simple strategy that increases the variety of voices in the classroom. Random calling can be

144 easily implemented in any size classroom or lecture hall. Instead of asking the class a question and

145 waiting for someone to raise their hand (which often produces male and ethnic majority volunteers), make

146 it clear that you will randomly call on students in this class. Create a list of student names (and survey

7
147 students to get pronunciation early in the term), and randomly sort the list each day. You can sample
148 without replacement each day, so students who have answered once know they won't be called on again.
149 Because random calling can be very stressful for students, particularly in large classes, we recommend
150 these strategies to faculty members who normally ask students to volunteer answers in lecture.

- 151 • Think carefully about your philosophy of asking questions of the class. What is your goal in
152 doing so? Are there other ways you can engage students that are less anxiety-producing and
153 increase the participation of everyone?
- 154 • Reduce the number of questions you are going to ask students to answer. For easy questions, we
155 ask everyone to shout out the answer, engaging the entire room. For questions with a binary
156 choice (afferent or efferent, higher or lower) we take a quick vote by raised hand - engaging
157 everyone.
- 158 • For difficult questions, we first ask it as a clicker question and encourage students to discuss the
159 question with their neighbors or small group, and then click in. Afterward, when we randomly
160 call on a student, we ask them, "what did your group think was the correct answer?" which
161 lessens the student's fear of being wrong because the group shares the blame.
- 162 • Tell students they are allowed to "pass," or to ask a clarifying question instead of providing an
163 answer.

164 Why we like it: Neither of us tends to ask for student volunteers to answers during lecture, so we
165 implement random call less than other techniques. The first author often asks students for shout-out
166 answers (above) or uses group clicker responses, moving among groups to ask about answers. The second
167 author has used small group work followed by random call using a jar of cardboard tags with seat
168 numbers. When we visit classes where the instructor regularly requests student volunteers to answer
169 questions, we encourage them to consider group work and random call instead. By maximizing
170 involvement by all students in every question asked, it encourages everyone in the classroom to work
171 through the problems, use the vocabulary of neuroscience, and get feedback from their neighbors.

172 Additional reading: Grunspan et al., 2016 [15]

174 The remaining examples presented in this section require time in class to implement. We will cover how
175 to carve out that time in the next section, but for now imagine that the instructor has at least five to ten
176 minutes available to carry out small group work, and has a mechanism available to collect student work.

177

178 **Example: Generate peer discussion with clickers**

179 Foundation paper: Smith, M. K., Wood, W. B., Adams, W. K., Wieman, C., Knight, J. K., Guild, N., &
180 Su, T. T. (2009). Why peer discussion improves student performance on in-class concept questions.
181 *Science*, 323(5910). [18]

182 Message: Peer discussion enhances learning, even when none of the group originally understood the
183 topic.

184 Implementation and discussion:

185 Most faculty members are familiar with clickers, and many use them in their large lectures. But using
186 clickers to their maximal effectiveness is not intuitive. Some faculty members use clickers as an
187 attendance tool, while others ask very simple questions after each concept, which rarely generates interest
188 or energy from students. Often faculty members say they do not know how to organize a more complex
189 activity using clickers and questions to generate discussion. Below we present a short overview of a
190 simple but high-quality clicker activity that incorporates student discussion.

- 191 • First, use difficult questions relevant to the current lecture topic, and if these can be identified as
192 questions from previous exams this helps get the students' attention. The best questions have
193 common misconceptions as the wrong answers, so students are really unsure what the correct
194 answer is and are motivated to find out. Have students first answer the question on their own with
195 clickers, but do not show them the histogram of responses or tell them the right answer.
- 196 • Second, generate peer discussion. With good clicker questions, students sitting near each other
197 likely chose different answers. You can see (before revealing to students) that a question had
198 many incorrect answers chosen, and can encourage students to discuss the best answer with a

9
 199 neighbor. It can be helpful at this point to walk around the room and ask students privately why
 200 they chose different answers. After the discussion, have the students re-vote to see if
 201 understanding improves. Refrain again from showing the clicker-generated histogram.

- 202 • Third, give an explanation of the answers. A good question has created interest and student
 203 engagement. Multiple answers seemed reasonable, and students want an explanation of why the
 204 right answer is right and why the wrong answers are wrong. Your explanation should combine
 205 this student interest with content clarification. If you are particularly dramatic you can explain all
 206 the wrong answers until only the right answer and the most popular wrong answer are left, and
 207 then produce a big reveal, generating a big response of joy or disappointment from the students.

208 Why we like it: We have found the most powerful time of using a difficult clicker question is that moment
 209 after students have voted but before we reveal the answer. Students are poised to find out if they were
 210 correct - they argued for their answer with their neighbor and discussed why the wrong answers seemed
 211 wrong. At that moment they are *interested* in the topic and are ready to hear more.

212 Additional reading: Smith and Wood, 2011 [19]
 213

214 **Example: Use “exam” multiple-choice questions outside of exams**

215 Foundation paper: Nicol, D. (2007). E-assessment by design: using multiple-choice tests to good effect.
 216 *Journal of Further and Higher Education*, 31(1), 53-64. [20]

217 Message: Good classroom activities use something students care deeply about (and you already have
 218 available).

219 Implementation and discussion:

220 Perhaps a faculty member is perfectly willing to try active learning, but has no idea how to create an
 221 activity other than clicker questions. One activity that is easy to implement is to create a small-group
 222 discussion around old multiple-choice exam questions. This is useful to students because they often do
 223 not spend much time carefully thinking through these questions during an exam. A solid implementation

10
224 for creating an activity around an old exam question follows a template we use for all our active learning
225 activities: craft, sell, collect a product, debrief.

226 • Crafting an activity requires the instructor to plan something difficult enough that students will
227 need to give it attention and focus, but not so difficult that they see no way to make progress on
228 the problem. An old exam question fits this requirement, but it is important to pick an old exam
229 question that will stand up to student attention. It should match the learning goal of the lecture,
230 have reasonable difficulty (30-75% correct), and show good discrimination (students who
231 answered correctly did well on that exam overall). Ideally, the question should have incorrect
232 responses that are common student misconceptions.

233 A good activity to use with an old exam question is simply to present the question on a slide, and
234 tell students, “This is an exam question I gave students in a past term. For the next ten minutes, I
235 want your group to write a response to each option on this multiple choice exam question.

236 Explain why each incorrect option is wrong, and why the correct option is correct. You will turn
237 in your response in ten minutes, and then I will explain my reasoning when I wrote the question.”

238 As students work on this project, the instructor (and TAs or LAs if present) can circulate and
239 listen, and be available to answer student questions. This time is often illuminating for instructors,
240 as it may be the first time they hear a student describe why they have chosen or discounted a
241 question option on one of their exam questions.

242 • Selling an activity means explaining to the students why it will be beneficial to them to complete
243 the activity. If a student believes that working hard on something will provide a clear benefit, they
244 are more likely to participate and discuss the activity with neighboring students. Studying an old
245 exam question written by the instructor is an easy sell, because students are motivated to answer
246 future exam questions correctly.

247 • Collecting a product is a critical step that we often see instructors skip because of the perceived
248 effort involved. Collecting the student’s work has two main benefits. First, it forces the instructor
249 to think about what the collected product should look like, which causes them to give clearer

11
250 instructions and improves both the sell and the engagement of the students. Second, students who
251 know they will have to turn in their responses before hearing the answer will recognize that they
252 need to put in the work and cannot just sit quietly or chat and wait for the instructor to provide the
253 answers.

254 For this activity, the instructor can collect the responses using an analog tool or a digital tool. A
255 simple analog tool is index cards, which students can bring to class or can be handed out by the
256 instructor. Students can write the answer on one side and student names or IDs on the reverse.
257 Index cards are easy to sort and quick to check them off for participation by the instructor or TA.
258 The benefits to index cards are that their size limits the student response, and in rooms with a
259 document camera the instructor can display several cards anonymously and discuss best
260 responses.

261 Digital collection, such as having students type their responses into an assignment in their
262 learning management system (LMS) in class, can also work well. It automatically associates the
263 response with a student for grading, and collects and stores the responses without the need for
264 paper. In many LMSs, the instructor can hide student names and show several responses to the
265 class using their own login to the LMS as soon as they are received.

266 ● Debriefing is an important step for both the instructor and the students. Working on an exam
267 question may expose misconceptions about the topic being studied. Students are also motivated to
268 hear if their logic was correct for why answer choices were right or wrong. They will often ask
269 questions to get clarification on why their logic wasn't supported. The instructor may realize at
270 this point that students have valid reasons for discounting an option intended to be the correct
271 answer, or for choosing an option that was incorrect.

272 Why we like it: We have found this activity benefits both the students and us as instructors. Focusing on
273 an exam question is often a great summary of a topic we have just discussed, and students tend to be
274 engaged and interested. Exposure to sample exam questions provides students feedback on their level of

12
275 preparation [21]. This activity has also improved our ability to write effective exam questions because we
276 get regular feedback about how students interpret our questions.

277 Additional reading: Tanner, 2013. [22]

278

279 **Example: Collaborative exams increase interaction and community**

280 Foundation paper: Jang, H., Lasry, N., Miller, K., & Mazur, E. (2017). Collaborative exams: cheating? Or
281 learning? *American Journal of Physics*, 85(3), 223-227. [23]

282 Message: Change exams from isolating endeavors to community-building experiences.

283 Implementation and discussion:

284 Collaborative or “two stage” exams are a technique that can be used for either small quizzes or large,
285 summative exams. The main idea is that students take an exam twice - once on their own, and then again,
286 immediately, as small groups. Their final exam score is some combination of the two exam scores. This
287 activity works best on exams that have fewer but difficult questions. The basic format of a collaborative
288 exam is as follows:

- 289 • The instructor passes out the exam to each student, and each student works on their own to
290 complete the problems. The exam is submitted to the instructor. The majority of exam time is
291 given to the individual stage (up to 3/4 of exam time), but the exam itself will need to not take the
292 full time period. The majority of the exam score (often 85 - 90%) comes from the individual
293 score, so students are not tempted to reduce their study time.
- 294 • While individual exams are handed in, students move themselves into predetermined groups of 3
295 or 4. A second exam of the same (or very similar) questions is handed out to students. Students in
296 each group turn in a single answer sheet, so they must come to consensus in the time available.
297 The group exam time is packed with conversations about the question and students are motivated
298 and focused to understand the concepts involved.

299 Why we like it: We have not yet used this strategy for high-stakes exams, but have used it regularly in
300 discussion sections and have seen very strong engagement by students. Energy in the room is high and the

13
301 conversations about biology are on topic. Our regular course times are 50 minutes, which is tight for a
302 two-stage exam, but we hope to implement it in the near future in introductory biology.
303 Additional reading (including benefit to marginalized students): Roberts et al., 2018 [24]
304

305 Step 2: Create Time in Class

306 Now that we have outlined the kinds of activities that are possible when we take a break from lecture, we
307 can discuss evidence-based methods to move lecture content out of classroom. In our own teaching, we
308 have used different techniques to do this, and for different amounts of class material. One of us (Author 2)
309 has used both reading guides and short “screencast” videos that move 5-10 minutes of lecture content to
310 work that is done pre-class. The reading is followed by online quizzes. This shift provides time for a
311 single in-depth activity during class. Alternatively, one of us (Author 1) fully “flipped” the same
312 introductory biology class, preparing screencast videos and online quizzes for the all the course content,
313 allowing all class time to be used for problem solving and discussion of scientific research. In each of our
314 iterations, class size was over 400 students. Whether small amounts or large amounts of content are
315 moved outside of the classroom, time is now available during class that can be used for an organized
316 activity like the ones described in the previous section. Below we provide options for how to move this
317 content outside of class.

318

319 **Example: Create reading guides and pre-class quizzes**

320 Foundation paper: Heiner, C. E., Banet, A. I., & Wieman, C. (2014). Preparing students for class: How to
321 get 80% of students reading the textbook before class. *American Journal of Physics*, 82(10), 989-996.
322 [25]

323 Message: A focused reading guide and pre-class quiz will greatly increase the number of students who
324 read the textbook.

325 Implementation and discussion:

14
326 Most instructors would likely be willing to remove the introductory concepts or vocabulary that they
327 cover in a lecture if this material is covered clearly in the textbook. But instructors are stymied by the
328 unwillingness of students to do the assigned reading before class, so they feel they need to spend the class
329 time teaching material that students could easily teach themselves. This creates a negative cycle where
330 students do not need to do the reading because the instructor covers all the necessary material in class.
331 We have found it is relatively straightforward to motivate students to do pre-class work and come to class
332 familiar with the basics of the lecture. Here is advice we offer:

- 333 • Provide very clear guidance to students about what you want them to learn before class. It is not
334 sufficient to give students a chapter, or even a chapter section, particularly if you normally write
335 tests based on your lecture notes. Instead, provide a reading guide with questions students should
336 answer from the reading. You can also focus a reading guide around figures in the text, and list
337 questions about the experiment or principle for students to answer. Make sure this is content that
338 is clearly related to exam questions. Help students feel confident that they have captured exactly
339 what they need to know for class and exams.
- 340 • Make the pre-class work short and straightforward. Ideally, the reading and quiz should take an
341 hour or less, and should be vocabulary and introductory material. The first time we used these we
342 had undergraduate students in our lab at similar levels do the exercise and report the time needed
343 to complete it. This information was used to provide an estimate for time that was noted at the
344 beginning of each pre-class activity. Students are more likely to do work that they know they can
345 accomplish the night before each class. Think also about notetaking, and whether you can provide
346 blank diagrams for students to fill in. Ideally, the pre-class reading will generate student notes like
347 lecture notes that they can use for study.
- 348 • Provide accountability with an assignment or quiz. An online quiz is common, but you can also
349 request students to summarize what they've learned in an online writing assignment. The
350 assignment should be worth a small amount of points. Answer sharing between friends can be
351 reduced by question randomizing. The goal here is to provide the motivation to do the work, so

15
352 the quiz should be basic enough that anyone who has taken notes on the reading can receive full
353 credit.

354 • Do not cover that material in class. If it is clear to a student that you are assuming they have done
355 the reading and know the basics, they are more likely to do the reading and know the basics. We
356 know instructors who use the effective technique of keeping their old introductory slides in their
357 slide deck but with a different background color, and deliberately clicking past the slides at the
358 start of class, saying, “here is the material you have already learned,” before starting the lecture
359 with the more advanced material. This reinforces to students that the pre-class reading is required
360 and important (and will be tested).

361 Why we like it: It was initially difficult for us to believe that we could completely let go of lecturing on
362 very important biological concepts. We measured the effect of pre-class preparation in our own class [11]
363 and found that extra activities in class on more difficult concepts improved student performance on exams
364 compared to when we lectured on the material.

365

366 **Example: Encourage students with pre-class videos**

367 Foundation paper: Stockwell, B. R., Stockwell, M. S., Cennamo, M., & Jiang, E. (2015). Blended
368 learning improves science education. *Cell*, 162(5), 933-936. [26]

369 Message: Creating videos as pre-class assignments can improve student interest and exam scores
370 compared to text-based pre-class assignments.

371 Implementation and discussion:

372 Creating pre-class reading guides is an effective tool to prepare students for active learning in class. But if
373 an instructor finds that the textbook is not an ideal source, making simple pre-class videos can be even
374 more effective. Designing a video can provide a precise focus on content important to you, and can
375 increase the connection students feel with you that the text does not provide. It has been our experience
376 that making videos does not need to be overwhelming if approached with clear boundaries. We
377 recommend:

- 16
378
- Create a video if you want students to understand a more difficult concept. Reading guides for
379 basic content are generally accepted by students, but if they need to learn about a complex topic
380 before class, they find it helpful to hear their instructor explain the information with
381 accompanying visuals.
 - Add only a few videos per term. Unless there is a sudden worldwide pandemic, you do not need
382 to have all your course content as immediately available as videos. A colleague of ours decided to
383 first only make pre-class videos for her Friday classes (“Flipped Friday”), which reduced the
384 workload.
 - Videos do not need to look professional. You do not need to edit out your “ums” or pauses. We
386 find students would rather have three helpful-but-imperfect videos than one high-quality video.
387 One practice run-through can reveal gaps in your planned explanations that should be fixed before
388 recording, but do not practice multiple times.
 - Simple screen capture software and a mouse is generally sufficient. You do not need to get the
390 ‘premier” version of software or a digital tablet. If you want to handwrite or draw, you can rig
391 your phone to be above a pad of paper and record your writing using your phone. Contact your
392 campus teaching center to ask for recommended software.
 - Speak at your normal pace and move quickly through the content. Students can slow or re-watch
394 a video if they need to, and brisk videos are more engaging to watch.
 - Do not videotape slides with lots of text. Have the text as your notes, and instead show the
396 relevant image, or your face.
 - Give students notetaking instructions for your videos. Not all students will recognize that you
398 intend your video to be content that needs to be captured and studied, just like lecture with its
399 lecture notes. Provide guiding questions, or a notetaking sheet with matching images, to remind
400 your students that they will be held accountable for the material.
- 402 Why we like it: There are many concepts in biology that benefit from visuals and animations, that are
403 difficult to reproduce in a textbook. Using videos has allowed us to create short, solid “lectures” about

17
404 concepts that used to take up class time. Students like being able to re-watch the videos, and students for
405 whom English is not their first language find captions that go with the video to be extremely helpful. With
406 content moved outside of class time, we are able to create engaging activities that get students closer to
407 the work of actual scientists - reading figures, solving problems, and designing experiments.

408 Additional resources: Brame 2016 [27]

410 Conclusion

411 Often faculty members are interested in making their classes more active and inclusive, but aren't sure
412 how to efficiently make changes with the limited time they have available. In this short review, we have
413 presented evidence-based techniques to make space for active learning and then implement it. Some
414 techniques require a significant amount of time to implement, but others are very quick to use. It is our
415 view that to be effective the science education environment should be as dynamic, intellectually
416 stimulating, and evaluative as the scientific research environment. Therefore, the time we spend updating
417 our classes will benefit us as well as our students.

418 We have intended this to be a standalone article with sufficient details to implement the techniques, but
419 each of our recommendations comes with a full history of research and resources. Faculty members who
420 wish to learn more about evidence-based teaching in the biological sciences are encouraged to explore the
421 following:

- 422 ● CBE-Life Science Education (Journal): <https://www.lifescied.org/>
- 423 ● SABER (Society for the Advancement of Biology Education Research): <https://saberbio.org/>
- 424 ● The books Small Teaching and Small Teaching Online for additional ideas for small changes to
425 increase student engagement in the college classroom [28, 29]
- 426 ● The book Teaching and Learning STEM, for a more thorough, step-by-step guide to
427 incorporating active learning in STEM classes [30].

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