2021 Active Learning Initiative Competition

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Call for proposals from departments

The Vice Provost for Academic Innovation, together with the college deans, invite departments across the university to submit proposals to Cornell University's Active Learning Initiative (ALI) for funds to substantially improve teaching and learning for significant dimensions of their undergraduate courses. Grants are available to facilitate the implementation of high-impact active-learning practices, technology-enhanced learning, and other innovative teaching methods. Our aim is to facilitate vibrant, challenging, and reflective undergraduate learning experiences at Cornell.

This is the fourth iteration of a project launched in 2013 in response to calls from the White House, the National Academies, the Association of American Universities, and an array of professional societies to improve college-level teaching [i]. These organizations were motivated by a large and growing body of new research (many hundreds of papers), from both cognitive psychology and college classrooms, identifying a variety of pedagogical approaches that are significantly more effective than the traditional lecture-based format still used in most college teaching today [ii]. The previous projects at Cornell have delivered impressive results in sixteen departments encompassing humanities, social sciences, and STEM courses. This new round is an opportunity to extend that effort into an even wider variety of disciplines across the university — placing Cornell in the vanguard of an emerging national movement.

The ALI is grateful for the generous funding from Alex and Laura Hanson that has supported it from its inception. This competition is funded by a gift from the Hansons, together with funds from the University Provost and the colleges.

Funding and schedule

Grants of up to $750K, spread over three years, are available to departments with projects starting in the summer/fall of 2022. The average grant in previous competitions has been around $500K. These one-time investments are spent largely on people in term positions (e.g., teaching postdocs in two/three-year positions) who help the faculty research, develop and implement new teaching materials and approaches. Grants should support the redesign or design of between 2–6 undergraduate courses and involve teams of faculty who are scheduled to teach these courses in the next three years. Proposals may include courses of all sizes and undergraduate level from large introductory courses to smaller senior capstone courses (please indicate average student enrollment numbers and level). For large courses, we are also interested in proposals for online active learning as an alternative to high-attendance classes in large auditoriums.

Grant applications are submitted by department chairs after projects have been reviewed and endorsed by the departments' faculty. Department chairs and their faculty teams should meet with Peter Lepage, Director of the ALI (g.p.lepage@cornell.edu), early in the process of developing their proposals. They can also consult teaching specialists from the Center for Teaching Innovation (CTI) for advice on pedagogical strategies, assessment design, and approaches to teaching with technology; contact Carolyn Aslan, Associate Director of the ALI, in CTI for more information (crc1@cornell.edu).

Important dates for this competition are:

> ***October 15, 2021:*** **Pre-proposals are due.** Departments should prepare five-page (max) pre-proposals outlining their major ideas, the relevance of proposed changes, and the names of the courses and faculty members who would participate in the project.

> ***October - November, 2021***: **Department team meetings.** Peter Lepage and Carolyn Aslan will meet with each department team after their pre-proposal is submitted to discuss and help develop the proposed innovations, implementation plans, and strategies for sustaining changes. This meeting should include all the instructors who are interested in teaching a transformed active learning course and participating in the project.

> ***December 3, 2021:*** **Final proposals are due.** These should be five–ten pages long, describing innovations and rationale, a schedule for faculty involvement and implementation, a plan for assessment of efficacy and outcomes, budget, and a plan for sustaining the changes beyond the end of the project (without additional funding). See discussion below for more information.

> ***January, 2022:*** **Proposal awards will be announced.** Winning proposals will be selected by the Vice Provost for Academic Innovation, with input from internal and external

reviewers and in consultation with the college deans. Departments can begin the hiring process for postdocs, who typically start in the summer of 2022 to begin work on fall courses.

Proposals and pre-proposals should be submitted electronically to Carolyn Aslan at ali-admin@cornell.edu. If you would like to see examples of previous successful proposals, please e-mail us.

Section 1. Context and rationale

Extensive research from the last 20–30 years, much of it "discipline-based education research" in college classrooms, has led to new, highly effective pedagogies that are quite different from conventional lecturing. The new pedagogies emphasize active learning, with much more interaction among students, and between students and instructors than in the traditional format, even when applied to large classes in lecture halls. These methods emphasize building a course backwards from carefully articulated learning outcome goals for both the course as a whole and also broken down into specific sub-goals for every lecture. The goals are less about the acquisition of particular facts, and more about imparting an expert's facility with the subject through "deliberate practice" of expert thinking/performance [iii]. These methods generally incorporate time in class for students to process what they are learning, discuss it with others, and practice or apply their knowledge. Opportunities are provided for fine-grained, real-time assessment and feedback (multiple times in every class) — information that is essential to the students themselves as they grapple with the course material.

The new pedagogies go far beyond simply adding clicker questions to a traditional lecture. In one design for an active-learning class, for example, students are assigned material to read ahead of class. They complete an online (graded) quiz the night before each class, which motivates a large majority of the students to do the preparation. In class, the professor typically lectures for several minutes at the start, but then challenges the class with a problem or question. Students work on it on their own, and then in conversation with students sitting next to them in the auditorium. After several minutes, students report their results to the professor, using an audience response system, and the professor responds to what these results show about the students' grasp of the concept. A few minutes of further lecturing is followed by another question for students to work through, and so on throughout the class. While students are working on questions or problems, the teaching staff circulates among the students, offering advice to individual groups as needed, and listening in on student conversations, to assess where students are in their understanding. In some active learning courses at Cornell, students are assigned to permanent teams throughout the semester, while others use more informal pairs of students that change each session.

Controlled experiments have shown that this format can be spectacularly successful [iv], without significant loss in subject coverage. Students learn the easier material from the readings and

homework on their own. Class time is reserved for the most confusing and/or interesting aspects of the material, allowing students to practice their new understandings, again and again, with immediate feedback.

This form of active learning was introduced in both of the projects funded by the first ALI competition. The winning proposals came from the Physics Department, who wanted to transform the 3-course introductory physics sequence taken by all engineering students at Cornell, and from a consortium of biology departments, who wanted to transform 4 of the 5 introductory biology courses taken by biology majors and students who wish to pursue medical careers. Each of these sequences teaches about a thousand students a semester. Both groups proposed to convert their courses from a traditional lecture format, with typically 100–300 students at a time in large auditoriums, to an active-learning format, still in large auditoriums with 100–300 students.

The results from both projects were impressive. The figure below shows the distributions of student grades on (matched) final exams before (2012, black) and after (2014-15, red) introducing active learning in the first ALI physics course.
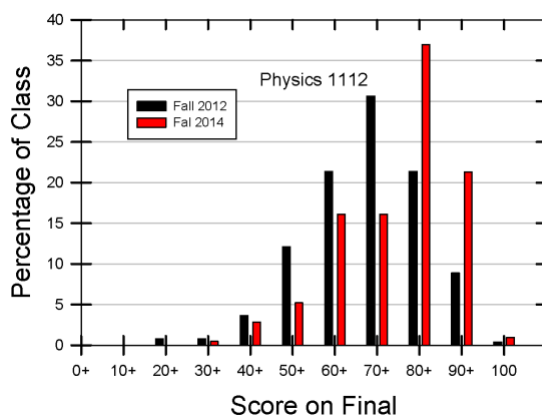
The entire grade distribution, covering everyone from the weakest to the strongest students, moved up by more than half a letter grade. This resulted in a three-fold reduction in the number of students with failing or marginal grades. Student evaluations were also significantly higher: overall ratings increased to 4.50 (out of 5) from 3.85.

The introductory evolution course (BioEE 1780) demonstrated that a learning gap of almost a letter grade between underrepresented groups and others was eliminated by active learning. Their research, now published, showed that active learning increases students' sense of self-efficacy, and that this increase is correlated (for underrepresented groups) with increased performance. They also saw a dramatic reduction (factors of 3–7) in the number of marginal and failing grades. Student learning, as measured using a concept-inventory exam, doubled in the introductory ecology course (BioEE 1610); they also saw a four-fold increase in students' confidence in their ability to deal with science in their daily lives. Introductory neurobiology (BioNB 2220) has both a 3-credit version, and a 4-credit version, with an extra recitation section each week. Traditionally students in the 4-credit version have outperformed the rest of the class

by almost a letter grade. With active learning, the 3-credit students have reduced the gap by a factor of three.

These successful results in Biology and Physics motivated the expansion of the initiative to the humanities, social sciences as well as other STEM disciplines. Students now use active learning strategies to debate the impact of social inequality (Sociology), explore ancient societies through hands-on experience of their material cultures (Classics), probe the structure of music using electronic keyboards in class (Music), and practice modeling dynamic systems in the life sciences (Math). In addition to common active learning strategies (classroom polling, think-pair-share, structured worksheets, small-group discussions), ALI instructors at Cornell have been designing innovative projects and assignments that give students more agency over their learning through student-directed lab experiments (Physics), semester-long projects (Natural Resources, Economics, Engineering, Classics), video assignments (Plant Sciences, Engineering), and at-home lab kits (Engineering, Classics). This current ALI competition is open to undergraduate departments across the university. More information about the variety of previous grant projects can be found on the Provost's website.

Section 2. Faculty collaborations with postdocs on course transformations

Creating an active-learning course is time consuming. Faculty need to develop clear learning goals for the course, absorb often large amounts of research on how to teach their topics, design large amounts of new pedagogical material (for example, the in-class questions, problems, or activities), and create or revise tools for assessing the impact of the new instructional methods. The major cost of the current and earlier ALI projects has been in hiring teaching postdocs who make it possible for the faculty to do this work.

Teaching postdocs assigned to work closely with the faculty on course transformations greatly facilitate contributions from the faculty. They have PhDs in the appropriate discipline and a strong interest in teaching. Experience at Cornell and elsewhere indicates that there is a large supply of capable and interested candidates for such jobs in most disciplines, and good jobs for them afterwards. The Center for Teaching Innovation (CTI) trains teaching postdocs to be education specialists embedded within departments. Projects typically hire postdocs for two or three years, so they can work on multiple iterations of two or three courses through several semesters. Postdocs are expected to work in-person in Ithaca and attend and assist faculty during the in-person classes (unless circumstances require a return to remote teaching). Part of the responsibility of the lead faculty member on the grant is to help supervise and mentor the postdocs.

More information about the roles of teaching postdocs can be found in Appendix C. We also recommend a handbook developed for similar initiatives at UC Boulder and the University of British Columbia https://open.ubc.ca/the-science-education-initiative-handbook/, which guides faculty on starting a course transformation project and effectively collaborating with embedded teaching specialists (postdocs)

Active learning course transformation projects work best when instructors are both enthusiastic about transforming their course and also realistic about the time commitment that is needed to effectively collaborate with a teaching postdoc. We recommend that department chairs draft a letter to each participating faculty member outlining the expectations and incentives in detail for faculty to sign to signal their commitment. When discussing this project among your department, all of the involved faculty should be willing to commit to the following within the time period of the project.

- Spending at least two semesters implementing significant revisions to an undergraduate course or designing a new course. Preparatory work needs to happen in the summer or semester before teaching.
- Collaborating with a postdoc in clarifying learning outcomes, identifying where students are struggling, designing learning activities and assignments, and assessing student learning and experiences in their course. Often this involves meeting on a weekly basis.
- Being open to trying new teaching strategies.
- Getting feedback about their course by inviting an observer from the central ALI team to their class a few times a semester, meeting with the ALI team consultant before class begins and at least once during the semester and collecting student feedback through a mid-semester survey.

Section 3. Pre-proposal submission (deadline October 15, 2021)

The pre-proposal process is meant to provide departments feedback that helps them develop successful proposals. Department chairs and project lead(s) are strongly encouraged to meet with Peter Lepage before submitting their pre-proposals. Departments may also want to consult Carolyn Aslan and other CTI consultants for advice on design, assessment, and teaching strategies. The initiative has (limited) funds available for departments to bring other consultants to campus or to send faculty to visit programs elsewhere. Chairs should contact Peter Lepage with requests.

Pre-proposals should be sent electronically to Carolyn Aslan (ali-admin@cornell.edu) by October 15, 2021. They should be two to five pages long and include:
- A list of the targeted courses or course sequences.
- An outline of major ideas for new change(s) in the pedagogy of a course or course sequence.
- Discussion of relevance and/or importance of proposed changes to departmental or college curriculum.
- The names of faculty members leading the proposed work and the role(s) they've agreed to fill. Department chairs have ultimate responsibility for their departments' projects, but they should also designate faculty leads for the projects.

- Identification of new (term-appointed) staff positions, such as teaching postdocs or other disciplinary-based education specialists.
- Description of the process by which the department faculty as a whole will discuss and approve the proposal. A significant part of this discussion should precede the pre-proposal.

The ALI is focused on pedagogy, so proposals should be more about changes in how courses are taught (teaching strategies) and less about what is being taught (curriculum design). Proposals can include the development and implementation of pedagogy training for faculty and TAs. Funds cannot be used for classroom renovation projects.

Section 4. Proposal submission (deadline December 3, 2021)

After the pre-proposals have been reviewed, a meeting that includes the department chair, the project lead(s), and all the faculty who will be working on a course redesign project should be arranged with Peter Lepage or Carolyn Aslan before the final proposal is submitted. Proposals should be sent electronically by department chairs to Carolyn Aslan (ali-admin@cornell.edu) by December 3, 2021. They should be five to ten pages long and address:

Courses: Identify the targeted courses or course sequence. Include information about the courses and their context, such as: course numbers and titles, numbers/levels of students affected, numbers of cross-college student enrollments or cross-departmental enrollments, inter-connection with existing college or university initiatives, impact on majors/minors, relation to distribution requirements and/or department/college learning goals and curriculum, etc.

Changes and rationale: Describe the changes being made to the courses and the rationale for those changes. List any specific learning challenges that are being addressed.

Faculty and incentives: Identify the faculty lead(s) for the project, and the other faculty who will be working on courses in the project. Discuss how faculty will be involved, what incentives will be provided to them (e.g., teaching relief, summer salary) and what is expected in order to receive the incentive. Discuss any plans for faculty or TA training (e.g., department workshops).

Assessment: Describe plans for assessing the proposed pedagogical changes and their impact on students (and faculty). A robust assessment plan is essential for improving and refining initial instructional designs, and also for convincing students, faculty, and others that the project is/was worthwhile; see Appendix B for some ideas.

Sustainability: Discuss the long-term sustainability of the proposed changes, the role of assessment in monitoring future performance, archives of course materials, and faculty

succession plans that will allow innovations to out-live the original team of innovators. Note that ALI funds are one-time; they cannot be used to cover ongoing expenses after the project.

Timeline and detailed work plan: Include a project timeline for changing/creating courses that identifies specific courses, critical milestones, and participating faculty names, roles, and schedules. It is best to include at least two iterations of a transformed course in the grant timeline to allow time to revise and improve the course. In our experience, each postdoc can effectively work with one, sometimes two, courses each semester depending on the size of the teaching team and the extent of the transformation.

Budget: Provide a budget, by expense category. Include a budget narrative that explains the elements of the budget. Postdoc salaries should be similar to other postdocs within your discipline. Remember to include expenses for postdoc computers, travel, conference fees, and publication expenses.

Department review process: Proposals must be submitted by the department chair, after review by the department faculty. Describe the process used for departmental review. This typically involves discussion at one or two faculty meetings, followed by a vote.

Proposals will be reviewed by internal and external reviewers with experience in active learning and higher education initiatives. These reviews will be shared with the college deans, who will review and prioritize projects from their colleges. Final funding decisions will be made by the Vice Provost for Academic Innovation based on information from the reviewers and the colleges, as well as university priorities.

Section 5. Project support from CTI

The ALI's support services are provided by the Center for Teaching Innovation (CTI). A central ALI team within the CTI consults with ALI departments on proposal development, course design, research-based teaching methods, and strategies for assessment and sustainability. They help train ALI faculty and, especially, teaching postdocs, and provide education technology support, as needed. CTI organizes ongoing activities that encourage faculty and postdocs from different ALI projects to interact with each other and share ideas. CTI helps departments measure their progress, and the impact of their redesigned courses on student learning and experiences, through methods such as class observations, mid-semester student surveys, and data from student learning assessments. CTI can also connect departments with national networks of experts in discipline-based education research, course design, and assessment.

Section 6. Project reporting and dissemination

Chairs of ALI departments submit annual (in June) progress reports to the ALI, for review by the Vice Provost for Academic Innovation and the relevant college deans. Reports detail changes that have been made to courses, assessments of their effectiveness, and plans for further improvement, as well as impacts on teaching and discussions within the department as a whole. Updated budget reports are due each year (due in March). Postdocs also submit end-of-semester progress reports on their work to the ALI director and associate director. Chairs submit a final report after their projects conclude.

ALI faculty are invited to discuss and explain their course redesign projects to other Cornell faculty at university events such as the Provost's Seminar for Teaching Excellence, or college events such as the CALS Learning Experience. ALI faculty also meet together at least once a semester to discuss their projects and share ideas and resources. ALI faculty and postdocs are encouraged to disseminate teaching resources and research results from their projects through publications, and presentations at disciplinary conferences. Presentations and teaching workshops within your department are also highly encouraged and grant money can be used to support such events.

Appendix A. Resources to ground pre-proposal discussions

The ALI was inspired by Carl Wieman's science education initiatives at the University of British Columbia (CWSEI) and at the University of Colorado at Boulder (SEI): see, http://www.cwsei.ubc.ca/ and http://www.colorado.edu/sei, as well as Wieman's book Improving How Universities Teach Science (Harvard, 2017). Having helped more than 250 faculty members introduce active learning into their teaching across several disciplines, the CWSEI and SEI have created rich online resources to help departments and faculty members redesign courses. While targeted at STEM teaching, much of this material is directly applicable in other disciplines. Useful links include:
- https://open.ubc.ca/the-science-education-initiative-handbook/: this handbook guides faculty on starting a course transformation project and effectively collaborating with embedded teaching specialists (postdocs)
- http://www.cwsei.ubc.ca/resources/course_transformation.htm: a collection of documents offering detailed advice for departments and faculty members on how to redesign courses.
- http://www.cwsei.ubc.ca/resources/instructor_guidance.htm : a collection of short guides for instructors—on assessment, clicker use, student engagement, etc.—that illustrates in concrete terms the pedagogical philosophy (active engagement of students) underlying these initiatives. The advice is highly practical.
- http://www.cwsei.ubc.ca/resources/SEI_video.html: a collection of videos that show, among other things, what active learning looks like.
- http://www.cwsei.ubc.ca/resources/papers.htm: an annotated bibliography of papers on the research behind many aspects of active learning.

Appendix B. Creating a course assessment plan

Structured assessment is essential when redesigning a course. It provides information about what is working well and what could be improved. Assessment methods can help to target the development of teaching materials and methods by identifying which topics or skills student struggle to learn well. Assessment data is also essential for a department to document its progress for their dean and for the ALI.

The Center for Teaching Innovation (CTI) can work with each department to develop a customized assessment plan. CTI can also assist departments through the process of obtaining permissions for human research studies from the Institutional Research Board.

Possible assessment strategies include:

> *Grades, scores, tracker questions, and concept inventories:* Direct measures of learning are important when evaluating a new pedagogy. This data might include final grades, scores on exams or assignments, scores on components of a rubric, or points given to individual exam questions (such as tracker questions reused, in disguise, from one semester to another). Tests, often called concept inventories, can be given to students at the beginning of a course or a unit, and the same questions asked again at the end of the course or unit to measure how much students have learned.

> *Mid-semester feedback:* Mid-semester feedback from students allows instructors to address and resolve issues with a course before the semester ends. CTI administers a mid-semester feedback program and can distribute survey questions to students and then report and discuss the information with faculty. Other options for mid-semester feedback include minute papers or polling questions asking for anonymous responses to questions.

> *Class observations using COPUS (Course Observation Protocol for Undergraduate STEM):* With the COPUS protocol for class observations, a trained observer from CTI comes to class several times a semester and records the type of activity happening during two-minute intervals (for example: lecturing, group work, class discussion, polling question, students writing etc.). COPUS observations can help instructors find the right balance between time spent on different activities. They also document changes in the course over time.

> *Student attitudes, motivation, confidence, and sense of belonging:* Surveys, focus groups, or interviews can assess factors such as student mindset, motivation, confidence, and attitudes towards the subject material and learning experiences in your course. For example, some initial findings indicate that Cornell ALI courses improve students' sense of self-efficacy and confidence in science. Other ALI departments are researching student motivation and attitudes towards the discipline. Awareness of metacognitive strategies has been another area of interest for some departments in the

initiative. Some departments are also using structured interviews to learn more about student misconceptions about course material and their experiences in learning.

Long-term studies (various options): 1) A longitudinal study can be designed to retest students and assess how much knowledge they retain after six months, a year, or in upper level courses; 2) one could survey or interview faculty and TAs teaching upper level courses within the major to ask them about the level of student preparation for their courses; 3) one could also examine trends in enrollment numbers, students majoring or minoring in the department, or taking a second or third class in the department.

Student reflections about their own learning: Reflection can take the form of "minute papers" (short responses to a prompt, for example "what was the most interesting concept you learned today?"). Other options include reflective responses on an online class forum after a discussion, or a reflective essay at the end of the semester. Instructors can also ask students the same reflection question at the beginning of the course and the end of the course (for example: "what relevance do you think this course will have for your life outside of this class?").

Faculty development and engagement with active learning: Faculty can measure and document changes in their teaching practices by completing the [Teaching Practices Inventory](#) survey before and after a project. Other options include documenting faculty perceptions and experiences implementing active learning, how their attitudes towards teaching have changed, and what changes they have noticed in their classes and with students. Surveys, interviews, and focus groups with faculty and TAs are possible.

Course evaluations: Consider adding specific questions about active learning activities to the end-of-course evaluation.

Appendix C. Working with an Active Learning Initiative fellow

Active Learning Initiative department grants give you the opportunity to work with an ALI fellow (postdoc) to improve your course and develop active learning questions, activities, assignments, and other materials. Based on many conversations with previous ALI faculty, we've distilled the following advice.

Five tips to make it a positive experience:
- *Set up regular weekly meetings* with the ALI fellow.
- *Identify the trouble spots* in the course – i.e., which topics or assignments do students struggle with the most? Focus on improving these areas.
- *Enjoy the intellectual and creative process.* In the best collaborations, ALI faculty and fellows bounce ideas off each other to develop engaging, innovative, and enjoyable activities that foster interaction and create a positive learning experience for students.

- *Choose one or two active learning strategies* and become comfortable with incorporating them into each class. Set up a routine in class so students become accustomed to what is expected.
- *Allow enough time for activities in class.* Be willing to shorten parts of your lecture and let go of some content. Consider asking students to read ahead of time or complete other pre-class work to learn some of the basics so that there is more time for them to practice, discuss, and get feedback during the class time.

A few things that can cause difficulties:
- *Don't wait until the last minute* to make changes and design activities with the ALI fellow. Start planning and meeting during the summer or the semester before you are teaching the course.
- *Design learning activities that can be easily implemented* and updated by yourself and other instructors in the future. Remember that the ALI fellow will eventually leave, and the changes should be sustainable.
- *Take time to involve and train TA′s* if they are expected to implement or help with active learning activities. TA's can also help design and give feedback on learning activities.

Generally, within a department, ALI fellows will:
- *Collaborate with faculty* on course transformation projects to implement active learning. Typically, an ALI fellow will focus on one course each semester, with secondary work for one or two other courses.
- *Serve as a resource* within their departments (consult with faculty, organize seminars or workshops about teaching)
- *Collect and analyze evidence* of student learning and experiences to guide course improvements

Typical timeline for a course transformation project:

Before the semester starts, an ALI postdoc can collaborate with faculty to:
- Refine or develop learning outcomes.
- Identify aspects of the course that most need improvement: i.e., areas where students tend to struggle.
- Decide on one or two main types of active learning strategies to implement throughout the semester (e.g., polling questions, think-pair-share, worksheet activities, group work, problem-solving etc.).
- Design learning materials (i.e., activities, worksheets, polling questions, assignments etc.)
- Develop assessments of student learning and experiences (pre/post quizzes, surveys, rubrics, revise prelims etc.)
- Review educational literature to identify best practices to implement
- Develop TA instructions and training materials

While the course is being taught the ALI fellow can:

- Sit in and observe the classes, take notes on student engagement, length of activities, reflections on how things are going, troubleshoot technology.
- Move around the class to help students during activities.
- Co-teach: some ALI fellows lead activities or teach parts of class sessions.
- Help train and mentor TAs in implementing active learning in sections, labs etc.

After the semester ends:
- Analyze student data to inform educational changes and course revisions.
- Make improvements to activities, assignments, assessments etc.
- Develop new materials for the next iteration of the course.
- Archive curricular materials for use in upcoming semesters.
- Author or co-author publications and/or presentations.

Appendix D. A research sampler on teaching

What follows is a small sample from the thousand plus research papers on active learning and teaching [v]. For the most part these are written by faculty from the disciplines being taught. The references themselves are links: click on them to read the articles.

S. Freeman et al, Active Learning Increases Student Performance in Science, Engineering and Mathematics, PNAS 111 (2014) 8410: Following meta-analysis practices familiar from medicine, these authors examined more than 200 articles, from 8 disciplines, on the impact of active learning. They find among other things that grades increased by half a letter grade with active learning (Fig. 2 in the paper), and failure rates decreased by a third (Fig. 1B). They question whether, in light of these results, it is ethical to use conventional lecturing as a control in education research given the damage it inflicts on students in the control group. Carl Wieman's commentary on this article provides an accessible and interesting summary of the paper's results and their implications: PNAS 111 (2014) 8319.

Theobald et al. Active Learning Narrows Achievement Gaps for Underrepresented Students in Undergraduate Science, Technology, Engineering, and Math, PNAS 117 (2020) 6476. This is another recent meta-analysis study that shows that classes in which students spend a high proportion of time in active learning activities reduced the exam and grade performance gaps of underrepresented minority and low-income students when compared with traditional lecture classes. The authors argue that courses that combine opportunities for deliberate practice within an intentionally inclusive environment can increase equity in higher education attainment by improving the learning and retention of minority students.

S. Wineburg et al, What is Learned in College History Classes?, Journal of American History 104 (2018) 983: Much discipline-based education research is in STEM fields, but similar research is available in other disciplines. This paper is part of a multi-year study of differences between novice and expert historians in their interpretations of historical sources. The study identifies

analysis skills central to the discipline that are reflexive for experts but almost nonexistent for novices (i.e., undergraduates); and it provides tools for addressing these shortcomings through repeated deliberate practice, with immediate feedback, in history courses. For information about how this research is done (and another interesting example) see: [S. Wineburg, Cognitive Science 22 (2010) 319](). For a similar study, about reading poetry, see: [J. Peskin, Cognition and Instruction 16 (1998) 235]().

[L. Deslauriers et al, Improved Learning in a Large-Enrollment Physics Class, Science 332 (2011) 862:]() This paper describes an experiment where a large introductory physics class was split in two for a week in mid-semester, with one group taught conventionally and the other using active learning. Student learning was assessed with an in-class test given after the intervention but designed beforehand. The entire grade distribution was shifted up two letter grades in the active-learning group (Fig. 1). The authors also measured student attention levels during class (using a standard protocol) and showed it doubled in the new format. This kind of improvement has long been apparent in introductory physics courses: see [R.R. Hake, Am. J. Phys. 66 (1998) 64](), for a famous early study of 62 introductory courses by 62 different instructors at 62 institutions (see Fig. 2).

[M.K. Smith et al, Combining Peer Discussion with Lecturer Explanation Increases Student Learning for In-Class Concept Questions, CBE—Life Sci. Ed. 10 (2011) 55:]() This semester-long controlled study, in two biology courses, compared the relative impacts of peer discussions (student-student) and instructor explanations on students 'ability to absorb new concepts in class. They found that peer discussion followed by an explanation from the instructor was twice as effective as either peer instruction or an instructor explanation alone (Fig. 4A). By itself, peer discussion was slightly more effective than instructor explanation, but the difference was not statistically significant except for the strongest students in the class—peer discussion was twice as beneficial for them as instructor explanation (Fig. 5A). These results indicate that lecturing can be very powerful provided the students are first engaged; and strong students benefit even more than the others from peer discussion. The benefits of having students struggle with a problem before they hear the expert solution (i.e., the lecture) is a theme in many other studies from a variety of disciplines: for example, [D.L. Schwartz et al, A Time for Telling, Cognition and Instruction 16 (1999) 475]() shows how having students analyze "contrasting cases" and then hear a lecture substantially improved their learning in psychology (Fig. 5). Lead author of the biology paper, Michelle Smith is associate professor at Cornell in Ecology and Evolutionary Biology, the editor of [CourseSource](), a journal with active learning activities for courses, and the Senior Associate Dean for undergraduate education in the Arts&Sciences College. Smith also provides advice on writing effective questions for student learning through peer discussion ([ch. 10 in Active Learning in College Science]()).

[N.G. Holmes et al, Teaching Critical Thinking, PNAS 112 (2015) 11199:]() This controlled study, in a freshman-level physics lab, shows how directed practice taught students to make expert-like decisions about data: Do the data prove anything? How should the experiment be changed to improve the data? Do the data disprove the model? How must the model be changed? And so on. The directed practice was phased out during the semester. By the end, students in the

experimental group were outperforming the control group by factors of 5-10, and they continued to outperform in a subsequent course (Figs. 1 and 2). Lead author, Natasha Holmes, has been redesigning Physics laboratory classes as part of an ALI project in the Cornell Physics department. The redesigned labs provide students with more authentic experiences in scientific inquiry and discovery where they have agency to make decisions about their experiments (ch. 18 in Active Learning in College Science).

i See, for example: the 2012 report Engage to Excel from the White House and the President's Council of Advisors on Science and Technology (PCAST, Peter Lepage was a co-chair of their working group); the 2012 report from the National Academies on Discipline-Based Education Research (DBER); the 2016 Call to Action from the White House; the 2017 report from the Association of American Universities (AAU, Peter Lepage is a member of their Technical Advisory Committee); and the 2017 report on The Future of Undergraduate Education from the American Academy of Arts and Sciences.

ii For a short overview see the articles by Carl Wieman and Sarah Gilbert in Microbe, Vol. 10(4), 152 (2015) and 203 (2015). For a curated (and annotated) set of links to a wide variety of research articles see http://www.cwsei.ubc.ca/resources/papers.htm. Past research has focused mostly on STEM areas, but there is also work in other disciplines: see, for example, S. Wineburg et al, Journal of American History 104 (2018) 983.

iii The emphasis on deliberate practice stems from recent research indicating that the extent to which students engage in such practice is more important to their ultimate success than any innate talent for a subject. This is contrary to much conventional wisdom about teaching, especially in STEM subjects where teaching in the past has often functioned mostly as a filter for selecting people with a priori talent. For popular accounts of the research see P. Ross's article in Scientific American 295 (2006) 64, and K. Ericsson's book Peak: Secrets of The New Science of the Expertise (Houghton Mifflin Harcourt, 2016). For ideas about how to use these insights in courses see the short guide at http://www.cwsei.ubc.ca/resources/files/Teaching_Expert_Thinking.pdf.

iv See, for example, Deslaurier et al, Science 332 (2011) 862 where active learning shifted the entire grade distribution upwards by more than two letter grades (Fig. 1 in the paper). For a meta-study of 225 papers on active learning see S. Freeman et al, PNAS 111 (2014) 8410.

6 Books that offer more systematic surveys include: D. Schwartz et al, The ABCs of How We Learn (Norton, 2016); S. Ambrose et al, How Learning Works (Wiley, 2010); and J. Bransford et al, How People Learn, (National Academies Press, 2000).