

1. Andrews, T., M. Leonard, et al. (2011). "Active learning not associated with student learning in a random sample of college biology courses." CBE-Life Sciences Education **10**(4): 394-405.

Previous research has suggested that adding active learning to traditional college science lectures substantially improves student learning. However, this research predominantly studied courses taught by science education researchers, who are likely to have exceptional teaching expertise. The present study investigated introductory biology courses randomly selected from a list of prominent colleges and universities to include instructors representing a broader population. We examined the relationship between active learning and student learning in the subject area of natural selection. We found no association between student learning gains and the use of active-learning instruction. Although active learning has the potential to substantially improve student learning, this research suggests that active learning, as used by typical college biology instructors, is not associated with greater learning gains. We contend that most instructors lack the rich and nuanced understanding of teaching and learning that science education researchers have developed. Therefore, active learning as designed and implemented by typical college biology instructors may superficially resemble active learning used by education researchers, but lacks the constructivist elements necessary for improving learning.

2. Armbruster, P., M. Patel, et al. (2009). "Active learning and student-centered pedagogy improve student attitudes and performance in introductory biology." CBE-Life Sciences Education **8**(3): 203-213.

We describe the development and implementation of an instructional design that focused on bringing multiple forms of active learning and student-centered pedagogies to a one-semester, undergraduate introductory biology course for both majors and nonmajors. Our course redesign consisted of three major elements: 1) reordering the presentation of the course content in an attempt to teach specific content within the context of broad conceptual themes, 2) incorporating active and problem-based learning into every lecture, and 3) adopting strategies to create a more student-centered learning environment. Assessment of our instructional design consisted of a student survey and comparison of final exam performance across 3 years—1 year before our course redesign was implemented (2006) and during two successive years of implementation (2007 and 2008). The course restructuring led to significant improvement of self-reported student engagement and satisfaction and increased academic performance. We discuss the successes and ongoing challenges of our course restructuring and consider issues relevant to institutional change.

3. Barrows, H. S. (1996). "Problem-based learning in medicine and beyond: A brief overview." New directions for teaching and learning **1996**(68): 3-12.

This chapter reviews the motivation for the change to problem-based learning, its definition, and the educational objectives it can serve. It discusses changing

an established curriculum to problem-based learning and asks whether problem-based learning is worth the trouble.

4. Beatty, I. D., W. J. Gerace, et al. (2006). "Designing effective questions for classroom response system teaching." American Journal of Physics **74**(1): 31-39.  
Classroom response systems (CRSs) can be potent tools for teaching physics. Their efficacy, however, depends strongly on the quality of the questions used. Creating effective questions is difficult, and differs from creating exam and homework problems. Every CRS question should have an explicit pedagogic purpose consisting of a content goal, a process goal, and a metacognitive goal. Questions can be engineered to fulfil their purpose through four complementary mechanisms: directing students' attention, stimulating specific cognitive processes, communicating information to instructor and students via CRS-tabulated answer counts, and facilitating the articulation and confrontation of ideas. We identify several tactics that help in the design of potent questions, and present four "makeovers" showing how these tactics can be used to convert traditional physics questions into more powerful CRS questions.
5. Beichner, R. J. and J. M. Saul (2003). "Introduction to the SCALE-UP (student-centered activities for large enrollment undergraduate programs) project." Proceedings of the International School of Physics "Enrico Fermi," Varenna, Italy. <http://www.ncsu.edu/per/scaleup.html> (accessed 7 June 2005).  
The SCALE-UP Project has established a highly collaborative, hands-on, computer-rich, interactive learning environment for large-enrollment courses. Class time is spent primarily on hands-on activities, simulations, and interesting questions as well as hypothesis-driven labs. Students sit in three groups of three students at round tables. Instructors circulate and work with teams and individuals, engaging them in Socratic-like dialogues. Rigorous evaluations of learning have been conducted in parallel with the curriculum development effort. Our findings can be summarized as follows: Ability to solve problems is improved, conceptual understanding is increased, attitudes are improved, failure rates are drastically reduced (especially for women and minorities), and performance in follow up physics and engineering classes is positively impacted. In this paper we will describe the studio-style classroom environment and discuss how its features promote the desired interactions. We will also show results of a variety of assessments of student learning.
6. Blumenfeld, P. C., R. W. Marx, et al. (1996). "Learning with peers: From small group cooperation to collaborative communities." Educational researcher: 37-40.
7. Borrego, M., S. Cutler, et al. (2011). "Faculty use of research based instructional strategies."  
Over the last 20 years, significant investments (individual, institutional, state, and federal) have been made to improve engineering education. Multiple Research Based Instructional Strategies (RBIS) have been developed and shown to improve student learning. In order to assess engineering faculty members'

awareness and use of these strategies, a survey was developed and distributed through chemical and electrical engineering professional societies targeting academic staff teaching core required courses. Just over 200 electrical and chemical engineering faculty in the US completed the survey. Results show that faculty members most commonly learn about RBIS from colleagues (18%). 98.6% of faculty report knowledge about one or more of the 12 RBIS asked about in the survey. 82.1% of faculty report use of one or more of these RBIS. The most common reason given for non-use was the fear that these strategies would take up too much class time.

8. Boyle, J. T. and D. J. Nicol (2003). "Using classroom communication systems to support interaction and discussion in large class settings." Research in Learning Technology **11**(3).  
Teaching methods that promote interaction and discussion are known to benefit learning. However, large class sizes make it difficult to implement these methods. Research from the United States has shown that an electronic classroom communication system (CCS) can be used to support active discussion in large lecture classes. This investigation extends that research and it evaluates students' and teachers' experiences of CCS technology in the context of two different modes of discussion — peer-group and classwide discussion. With CCS technology, students' answers to multiple-choice concept tests are collated in real time with the class results fed back as a histogram. This information serves as the trigger for each mode of discussion. This paper explores the unique contribution of CCS technology, the relative strengths of peer- and class-wide discussion and some practical implementation issues.
9. Bruck, A. D. and M. H. Towns (2009). "Analysis of classroom response system questions via four lenses in a General Chemistry course." Chemistry Education Research and Practice **10**(4): 291-295.  
General Chemistry lecture questions used in an electronic classroom response system (CRS) were analyzed using three theoretical frameworks and the pedagogical context in which they were presented. The analytical lenses included whether students were allowed to collaborate, Bloom's Taxonomy, a framework developed by Robinson and Nurrenbern, and an expanded framework discussed by Bretz, Smith and Nakhleh. Analysis via these frameworks allowed faculty to reflect upon question types used in the course, and to modify instruction by decreasing the number of lower order cognitive skill questions, and emphasizing higher order cognitive skill questions in subsequent semesters.
10. Caldwell, J. E. (2007). "Clickers in the large classroom: Current research and best-practice tips." CBE-Life Sciences Education **6**(1): 9-20.  
Audience response systems (ARS) or clickers, as they are commonly called, offer a management tool for engaging students in the large classroom. Basic elements of the technology are discussed. These systems have been used in a variety of fields and at all levels of education. Typical goals of ARS questions are

discussed, as well as methods of compensating for the reduction in lecture time that typically results from their use. Examples of ARS use occur throughout the literature and often detail positive attitudes from both students and instructors, although exceptions do exist. When used in classes, ARS clickers typically have either a benign or positive effect on student performance on exams, depending on the method and extent of their use, and create a more positive and active atmosphere in the large classroom. These systems are especially valuable as a means of introducing and monitoring peer learning methods in the large lecture classroom. So that the reader may use clickers effectively in his or her own classroom, a set of guidelines for writing good questions and a list of best-practice tips have been culled from the literature and experienced users.

11. Cooper, J. L. and P. Robinson (2000). "Getting started: informal small group strategies in large classes." New directions for teaching and learning **2000**(81): 17-24.

Through brief in-class discussions that begin, end, or punctuate a lecture, students can prepare for the lecture, check their understanding, or refocus on the material presented. Faculty or teaching assistants can check for understanding as well.

12. Cortright, R. N., H. L. Collins, et al. (2005). "Peer instruction enhanced meaningful learning: ability to solve novel problems." Advances in Physiology Education **29**(2): 107-111.

Students must be able to interpret, relate, and incorporate new information with existing knowledge and apply the new information to solve novel problems. Peer instruction is a cooperative learning technique that promotes critical thinking, problem solving, and decision-making skills. Therefore, we tested the hypothesis that peer instruction enhances meaningful learning or transfer, defined as the student's ability to solve novel problems or the ability to extend what has been learned in one context to new contexts. To test this hypothesis, our undergraduate exercise physiology class of 38 students was randomly divided into two groups: group A (n=19) and group B (n=19). A randomized crossover design in which students either answered questions individually or during peer instruction was used to control for time and order effects. The first factor that influences meaningful learning is the degree of mastery of the original material. Importantly, peer instruction significantly enhanced mastery of the original material. Furthermore, the student's ability to solve novel problems was significantly enhanced following peer instruction. Thus pausing two to three times during a 50-min class to allow peer instruction enhanced the mastery of the original material and enhanced meaningful learning, i.e., the student's ability to solve novel problems.

13. Couch, B. A., T. L. Brown, et al. (2015). "Scientific Teaching: Defining a Taxonomy of Observable Practices." CBE-Life Sciences Education **14**(1): ar9.

Over the past several decades, numerous reports have been published advocating for changes to undergraduate science education. These national calls inspired the formation of the National Academies Summer Institutes on

Undergraduate Education in Biology (SI), a group of regional workshops to help faculty members learn and implement interactive teaching methods. The SI curriculum promotes a pedagogical framework called Scientific Teaching (ST), which aims to bring the vitality of modern research into the classroom by engaging students in the scientific discovery process and using student data to inform the ongoing development of teaching methods. With the spread of ST, the need emerges to systematically define its components in order to establish a common description for education researchers and practitioners. We describe the development of a taxonomy detailing ST's core elements and provide data from classroom observations and faculty surveys in support of its applicability within undergraduate science courses. The final taxonomy consists of 15 pedagogical goals and 37 supporting practices, specifying observable behaviors, artifacts, and features associated with ST. This taxonomy will support future educational efforts by providing a framework for researchers studying the processes and outcomes of ST-based course transformations as well as a concise guide for faculty members developing classes.

14. Crossgrove, K. and K. L. Curran (2008). "Using clickers in nonmajors-and majors-level biology courses: student opinion, learning, and long-term retention of course material." CBE-Life Sciences Education 7(1): 146-154.  
Student response systems (clickers) are viewed positively by students and instructors in numerous studies. Evidence that clickers enhance student learning is more variable. After becoming comfortable with the technology during fall 2005–spring 2006, we compared student opinion and student achievement in two different courses taught with clickers in fall 2006. One course was an introductory biology class for nonmajors, and the other course was a 200 level genetics class for biology majors. Students in both courses had positive opinions of the clickers, although we observed some interesting differences between the two groups of students. Student performance was significantly higher on exam questions covering material taught with clickers, although the differences were more dramatic for the nonmajors biology course than the genetics course. We also compared retention of information 4 mo after the course ended, and we saw increased retention of material taught with clickers for the nonmajors course, but not for the genetics course. We discuss the implications of our results in light of differences in how the two courses were taught and differences between science majors and nonmajors.
15. Crouch, C. H. and E. Mazur (2001). "Peer instruction: Ten years of experience and results." American Journal of Physics 69(9): 970-977.  
We report data from ten years of teaching with Peer Instruction ~PI! in the calculus- and algebra-based introductory physics courses for nonmajors; our results indicate increased student mastery of both conceptual reasoning and quantitative problem solving upon implementing PI. We also discuss ways we have improved our implementation of PI since introducing it in 1991. Most notably, we have replaced in-class reading quizzes with pre-class written responses to the reading, introduced a research-based mechanics textbook for

portions of the course, and incorporated cooperative learning into the discussion sections as well as the lectures. These improvements are intended to help students learn more from pre-class reading and to increase student engagement in the discussion sections, and are accompanied by further increases in student understanding.

16. Crouch, C. H., J. Watkins, et al. (2007). "Peer instruction: Engaging students one-on-one, all at once." Research-Based Reform of University Physics **1**(1): 40-95. Peer Instruction is an instructional strategy for engaging students during class through a structured questioning process that involves every student. Here we describe Peer Instruction (hereafter PI) and report data from more than ten years of teaching with PI in the calculus-and algebra-based introductory physics courses for non-majors at Harvard University, where this method was developed. Our results indicate increased student mastery of both conceptual reasoning and quantitative problem solving upon implementing PI. Gains in student understanding are greatest when the PI questioning strategy is accompanied by other strategies that increase student engagement, so that every element of the course serves to involve students actively. We also provide data on gains in student understanding and information about implementation obtained from a survey of almost four hundred instructors using PI at other institutions. We find that most of these instructors have had success using PI, and that their students understand basic mechanics concepts at the level characteristic of courses taught with interactive engagement methods. Finally, we provide 2 a sample set of materials for teaching a class with PI, and provide information on the extensive resources available for teaching with PI.
17. Demetry, C. (2010). Work in progress-An innovation merging "classroom flip" and team-based learning. Proceedings, 40th ASEE/IEEE Frontiers in Education Conference. This work in progress compares two versions of a "classroom flip" instructional strategy in which lectures are moved from inside class to outside class. Class time is then spent on problem solving and feedback. In previous offerings of this materials science course, students were asked to read instructor-supplied lecture notes and complete an on-line warmup assignment prior to class. Informal cooperative learning activities such as think-pair-share were used during class, and clickers provided a mechanism for probing understanding and providing feedback. In the most recent offering, students viewed instructor-prepared multimedia microlectures and took an individual quiz as homework, then repeated the quiz and completed a problem set with an assigned team during class. Thus, the redesigned course delivered multimedia rather than text lectures, and utilized a structured team-based learning strategy rather than informal cooperative learning structures. Moreover, higher level "material selection challenges" were added to the redesigned course. This paper summarizes the planned assessment and evaluation methods to compare the two classroom flip models; results and analysis are not yet complete.

18. Fagen, A. P., C. H. Crouch, et al. (2002). "Peer instruction: Results from a range of classrooms." The Physics Teacher **40**(4): 206-209.
19. Farrell, J. J., R. S. Moog, et al. (1999). "A Guided-Inquiry General Chemistry Course." Journal of Chemical Education **76**(4): 570.  
A first-year general chemistry course based on constructivist principles and the learning cycle has been developed. Through the use of cooperative learning techniques, students are active participants in the learning process. No lectures are given; students follow guided inquiry worksheets to develop and understand the course concepts. Groups of about four students are formed and the instructor moves among the groups, serving as a facilitator. The laboratory is designed in the same way as the classroom component of the course.
20. Giuliadori, M. J., H. L. Lujan, et al. (2006). "Peer instruction enhanced student performance on qualitative problem-solving questions." Advances in Physiology Education **30**(4): 168-173.  
We tested the hypothesis that peer instruction enhances student performance on qualitative problemsolving questions. To test this hypothesis, qualitative problems were included in a peer instruction format during our Physiology course. Each class of 90 min was divided into four to six short segments of 15 to 20 min each. Each short segment was followed by a qualitative problem-solving scenario that could be answered with a multiplechoice quiz. All students were allowed 1 min to think and to record their answers. Subsequently, students were allowed 1 min to discuss their answers with classmates. Students were then allowed to change their first answer if desired, and both answers were recorded. Finally, the instructor and students discussed the answer. Peer instruction significantly improved student performance on qualitative problemsolving questions (59.3+/-0.5% vs. 80.3+/-0.4%). Furthermore, after peer instruction, only 6.5% of the students changed their correct response to an incorrect response; however, 56.8% of students changed their incorrect response to a correct response. Therefore, students with incorrect responses changed their answers more often than students with correct responses. In conclusion, pausing four to six times during a 90-min class to allow peer instruction enhanced student performance on qualitative problem-solving questions.
21. Gosser, D. K. and V. Roth (1998). "The Workshop Chemistry Project: Peer-Led Team-Learning." Journal of Chemical Education **75**(2): 185.  
The Workshop Chemistry model embraces dimensions of student experience that are essential for learning: the freedom to discuss and debate chemistry in a challenging but supportive environment, the connection to mentors, and the power of working as part of a team. The workshop model calls for the traditional recitation, or a modest amount of lecture, to be replaced by a new curricular structure: a two-hour student-led workshop. In the first two and a half years of the project, more than 6000 students have participated in workshop courses in allied health, general, and organic chemistry, conducted by 27 faculty and more than 800 workshop leaders.

22. Handelsman, J., D. Ebert-May, et al. (2004). "Scientific teaching." Science **304**(5670): 521-522.

23. Hung, W., D. H. Jonassen, et al. (2008). "Problem-based learning." Handbook of research on educational communications and technology **3**: 485-506.

Problem-based learning (PBL) is perhaps the most innovative instructional method conceived in the history of education. PBL was originally designed to respond to the criticism that traditional teaching and learning methods fail to prepare medical students for solving problems in clinical settings. Instead of requiring that students study content knowledge and then practice context-free problems, PBL embeds students' learning processes in real-life problems. After its successful implementation in various fields of medical education, PBL is now being implemented throughout higher education as well as in K–12 education. The purpose of this chapter is to inform researchers and practitioners about research findings and issues in PBL that may be used to inform future studies. In this chapter, we review PBL research from the past 30 years. We first describe the history of development and implementation of PBL in various educational settings and define the major characteristics of PBL. We then review the research on PBL. First, we examine the effectiveness of PBL in terms of student learning outcomes, including basic domain knowledge acquisition and applications, retention of content and problem-solving skills, higher order thinking, self-directed learning/lifelong learning, and self-perception. Second, we look at implementation issues, such as tutoring issues, curriculum design issues, and use of technology. Finally, we provide recommendations for future research.

24. James, M. C. and S. Willoughby (2011). "Listening to student conversations during clicker questions: What you have not heard might surprise you!" American Journal of Physics **79**(1): 123-132.

When instructors provide time for students to discuss their ideas in Peer Instruction, instructors minimally expect that the conversation partners will discuss their opinions relating to the physical attributes posed in a question and submit clicker responses that coincide with individual opinions. We defined conversations that met these two criteria as "standard conversations." In our study of 361 recorded Peer Instruction conversations from large introductory astronomy classrooms taught by experienced instructors, we found that 38% of student conversations were standard conversations. Of the remaining 62%, we identified three broad categories consisting of ten types of "nonstandard" conversations. The first category of conversations describes student ideas that were not reflected in any of the given multiple choice answers. The second category includes issues related to the interpretation of the statistical feedback provided by electronic classroom response systems. The third category describes common pitfalls experienced by students during conversations that led to unproductive interactions. Our analysis of nonstandard Peer Instruction conversations will be useful to practitioners and researchers seeking to improve the implementation of Peer Instruction.



25. Johnson, D. W., R. T. Johnson, et al. (1998). "Cooperative learning returns to college what evidence is there that it works?" Change: The Magazine of Higher Learning **30**(4): 26-35.

26. Knight, J. K. and W. B. Wood (2005). "Teaching more by lecturing less." Cell biology education **4**(4): 298-310.

We carried out an experiment to determine whether student learning gains in a large, traditionally taught, upper-division lecture course in developmental biology could be increased by partially changing to a more interactive classroom format. In two successive semesters, we presented the same course syllabus using different teaching styles: in fall 2003, the traditional lecture format; and in spring 2004, decreased lecturing and addition of student participation and cooperative problem solving during class time, including frequent in-class assessment of understanding. We used performance on pretests and posttests, and on homework problems to estimate and compare student learning gains between the two semesters. Our results indicated significantly higher learning gains and better conceptual understanding in the more interactive course. To assess reproducibility of these effects, we repeated the interactive course in spring 2005 with similar results. Our findings parallel results of similar teaching-style comparisons made in other disciplines. On the basis of this evidence, we propose a general model for teaching large biology courses that incorporates interactive engagement and cooperative work in place of some lecturing, while retaining course content by demanding greater student responsibility for learning outside of class.

27. Kothiyal, A., R. Majumdar, et al. (2013). Effect of Think-Pair-Share in a large CS1 class: 83% sustained engagement. Proceedings of the ninth annual international ACM conference on International computing education research, ACM.

Think-Pair-Share (TPS) is a classroom-based active learning strategy, in which students work on a problem posed by the instructor, first individually, then in pairs, and finally as a classwide discussion. TPS has been recommended for its benefits of allowing students to express their reasoning, reflect on their thinking, and obtain immediate feedback on their understanding. While TPS is intended to promote student engagement, there is a need for research based evidence on the nature of this engagement. In this study, we investigate the quantity and quality of student engagement in a large CS1 class during the implementation of TPS activities. We did classroom observations of students over a period of ten weeks and thirteen TPS activities. We determined patterns of student engagement in the three phases using a real-time classroom observation protocol that we developed and validated. We found that 83% of students on average were fully or mostly engaged. Predominant behaviors displayed were writing the solution to the problem (Think), discussing with neighbor or writing (Pair), and following class discussion (Share). We triangulated results with survey data of student perceptions. We find that students report being highly engaged for 62% during Think phase and 70% during Pair phase.

28. Lasry, N., E. Mazur, et al. (2008). "Peer instruction: From Harvard to the two-year college." American Journal of Physics **76**(11): 1066-1069.  
We compare the effectiveness of a first implementation of peer instruction PII in a two-year college with the first PI implementation at a top-tier four-year research institution. We show how effective PI is for students with less background knowledge and what the impact of PI methodology is on student attrition in the course. Results concerning the effectiveness of PI in the college setting replicate earlier findings: PI-taught students demonstrate better conceptual learning and similar problem-solving abilities than traditionally taught students. However, not previously reported are the following two findings: First, although students with more background knowledge benefit most from either type of instruction, PI students with less background knowledge gain as much as students with more background knowledge in traditional instruction. Second, PI methodology is found to decrease student attrition in introductory physics courses at both four-year and two-year institutions.
29. Lewis, S. E. and J. E. Lewis (2005). "Departing from Lectures: An Evaluation of a Peer-Led Guided Inquiry Alternative." Journal of Chemical Education **82**(1): 135.  
To improve a large-enrollment general chemistry course based on conventional lectures, we instituted a reform combining peer-led team learning with a guided inquiry approach, together called peer-led guided inquiry (PLGI). For one group of first-semester general chemistry students, a PLGI session was combined with two lectures per week, and this group was compared to a control group that had the usual three lectures per week. Students were compared based on performance on identical course exams and on a final exam from the ACS Examinations Institute given at the end of the semester. The experimental group was found to perform better than the control group overall, in spite of experiencing one fewer lecture each week. Also, attendance at the PLGI sessions was found to have a significant positive impact on student performance, even when controlling for students' SAT mathematics and verbal scores. This method of evaluating reform effects for institutions with several large sections of introductory chemistry courses is recommended.
30. Linton, D. L., J. K. Farmer, et al. (2014). "Is Peer Interaction Necessary for Optimal Active Learning?" CBE-Life Sciences Education **13**(2): 243-252.  
Meta-analyses of active-learning research consistently show that active-learning techniques result in greater student performance than traditional lecture-based courses. However, some individual studies show no effect of active-learning interventions. This may be due to inexperienced implementation of active learning. To minimize the effect of inexperience, we should try to provide more explicit implementation recommendations based on research into the key components of effective active learning. We investigated the optimal implementation of active-learning exercises within a "lecture" course. Two

sections of nonmajors biology were taught by the same instructor, in the same semester, using the same instructional materials and assessments. Students in one section completed in-class active-learning exercises in cooperative groups, while students in the other section completed the same activities individually. Performance on low-level, multiple-choice assessments was not significantly different between sections. However, students who worked in cooperative groups on the in-class activities significantly outperformed students who completed the activities individually on the higher-level, extended-response questions. Our results provide additional evidence that group processing of activities should be the recommended mode of implementation for in-class active-learning exercises.

31. Linton, D. L., W. M. Pangle, et al. (2014). "Identifying Key Features of Effective Active Learning: The Effects of Writing and Peer Discussion." CBE-Life Sciences Education **13**(3): 469-477.

We investigated some of the key features of effective active learning by comparing the outcomes of three different methods of implementing active-learning exercises in a majors introductory biology course. Students completed activities in one of three treatments: discussion, writing, and discussion+writing. Treatments were rotated weekly between three sections taught by three different instructors in a full factorial design. The data set was analyzed by generalized linear mixed-effect models with three independent variables: student aptitude, treatment, and instructor, and three dependent (assessment) variables: change in score on pre- and postactivity clicker questions, and coding scores on in-class writing and exam essays. All independent variables had significant effects on student performance for at least one of the dependent variables. Students with higher aptitude scored higher on all assessments. Student scores were higher on exam essay questions when the activity was implemented with a writing component compared with peer discussion only. There was a significant effect of instructor, with instructors showing different degrees of effectiveness with active-learning techniques. We suggest that individual writing should be implemented as part of active learning whenever possible and that instructors may need training and practice to become effective with active learning.

32. Lyman, F. (1987). "Think-pair-share." Unpublished University of Maryland paper.
33. Mazur, E. (1997). Peer instruction: getting students to think in class. AIP Conference Proceedings, IOP INSTITUTE OF PHYSICS PUBLISHING LTD.
34. Mazur, E. and M. D. Somers (1999). "Peer instruction: A user's manual." American Journal of Physics **67**(4): 359-360.
35. Michael, J. (2006). "Where's the evidence that active learning works?" Advances in Physiology Education **30**(4): 159-167.

Calls for reforms in the ways we teach science at all levels, and in all disciplines, are wide spread. The effectiveness of the changes being called for, employment of student-centered, active learning pedagogy, is now well supported by evidence. The relevant data have come from a number of different disciplines that include the learning sciences, cognitive psychology, and educational psychology. There is a growing body of research within specific scientific teaching communities that supports and validates the new approaches to teaching that have been adopted. These data are reviewed, and their applicability to physiology education is discussed. Some of the inherent limitations of research about teaching and learning are also discussed.

36. Miller, K., J. Schell, et al. (2015). "Response switching and self-efficacy in Peer Instruction classrooms." Physical Review Special Topics-Physics Education Research **11**(1): 010104.

Peer Instruction, a well-known student-centered teaching method, engages students during class through structured, frequent questioning and is often facilitated by classroom response systems. The central feature of any Peer Instruction class is a conceptual question designed to help resolve student misconceptions about subject matter. We provide students two opportunities to answer each question—once after a round of individual reflection and then again after a discussion round with a peer. The second round provides students the choice to “switch” their original response to a different answer. The percentage of right answers typically increases after peer discussion: most students who answer incorrectly in the individual round switch to the correct answer after the peer discussion. However, for any given question there are also students who switch their initially right answer to a wrong answer and students who switch their initially wrong answer to a different wrong answer. In this study, we analyze response switching over one semester of an introductory electricity and magnetism course taught using Peer Instruction at Harvard University. Two key features emerge from our analysis: First, response switching correlates with academic self-efficacy. Students with low self-efficacy switch their responses more than students with high self-efficacy. Second, switching also correlates with the difficulty of the question; students switch to incorrect responses more often when the question is difficult. These findings indicate that instructors may need to provide greater support for difficult questions, such as supplying cues during lectures, increasing times for discussions, or ensuring effective pairing (such as having a student with one right answer in the pair). Additionally, the connection between response switching and self-efficacy motivates interventions to increase student self-efficacy at the beginning of the semester by helping students develop early mastery or to reduce stressful experiences (i.e., high-stakes testing) early in the semester, in the hope that this will improve student learning in Peer Instruction classrooms.

37. Miller, S., C. Pfund, et al. (2008). "Scientific teaching in practice." Science **322**(5906): 1329-1330.

38. Nicol, D. J. and J. T. Boyle (2003). "Peer instruction versus class-wide discussion in large classes: A comparison of two interaction methods in the wired classroom." Studies in Higher Education **28**(4): 457-473.  
Following concerns about the poor conceptual understanding shown by science students, two US research groups (Mazur, 1997; Dufresne et al., 1996) have been experimenting with the use of 'classroom communication systems' (CCSs) to promote dialogue in large classes. CCS technology makes it easier to give students immediate feedback on concept tests and to manage peer and class discussions. Improvements in conceptual reasoning have been shown using these methods. However, these research groups have each piloted different discussion sequences. Hence little is known about which sequence is best and under what circumstances. This study compares the effects of each sequence on students' experiences of learning in engineering in a UK university. The research methods included interviews, a survey and a critical incident questionnaire. The results demonstrated that the type of dialogue and the discussion sequence have important effects on learning. The findings are discussed in relation to social constructivist theories of learning and in relation to the implications for teaching in wired classrooms.
39. Overton, T. L. and C. A. Randles (2015). "Beyond problem-based learning: using dynamic PBL in chemistry." Chemistry Education Research and Practice **16**(2): 251-259.  
This paper describes the development and implementation of a novel pedagogy, dynamic problem-based learning. The pedagogy utilises real-world problems that evolve throughout the problem-based learning activity and provide students with choice and different data sets. This new dynamic problem-based learning approach was utilised to teach sustainable development to first year chemistry undergraduates. Results indicate that the resources described here motivated students to learn about sustainability and successfully developed a range of transferable skills.
40. Parmelee, D., L. K. Michaelsen, et al. (2012). "Team-based learning: A practical guide: AMEE Guide No. 65." Medical teacher **34**(5): e275-e287.  
Team-based learning™ (TBL) is an instructional strategy developed in the business school environment in the early 1990s by Dr Michaelsen who wanted the benefits of small group learning within large classes. In 2001, a US federal granting agency awarded funds for educators in the health sciences to learn about and implement the strategy in their educational programs; TBL was put forward as one such strategy and as a result it is used in over 60 US and international health science professional schools. TBL is very different from problem-based learning (PBL) and other small group approaches in that there is no need for multiple faculty or rooms, students must come prepared to sessions, and individual and small groups of students (teams) are highly accountable for their contributions to team productivity. The instructor must be a content-expert, but need not have any experience or expertise in group process to conduct a successful TBL session. Students do not need any

specific instruction in teamwork since they learn how to be collaborative and productive in the process. TBL can replace or complement a lecture-based course or curriculum.

41. Porter, L., C. Bailey Lee, et al. (2011). Experience report: a multi-classroom report on the value of peer instruction. Proceedings of the 16th annual joint conference on Innovation and technology in computer science education, ACM.

Peer Instruction (PI) has a significant following in physics, biology, and chemistry education. Although many CS educators are aware of PI as a pedagogy, the adoption rate in CS is low. This paper reports on four instructors with varying motivations and course contexts and the value they found in adopting PI.

Although there are many documented benefits of PI for students (e.g. increased learning), here we describe the experience of the instructor by looking in detail at one particular question they posed in class. Through discussion of the instructors' experiences in their classrooms, we support educators in consideration of whether they would like to have similar classroom experiences. Our primary findings show instructors appreciate that PI assists students in addressing course concepts at a deep level, assists instructors in dynamically adapting their class to address student misunderstandings and, overall, that PI encourages students to be engaged in conversations which help build technical communication skills. We propose that using PI to engage students in these activities can effectively support training in analysis and teamwork skills.

42. Rania, N., S. Rebora, et al. (2015). "Team-based learning: Enhancing academic performance of psychology students." Procedia-Social and Behavioral Sciences **174**: 946-951.

43. Rao, S. P. and S. E. DiCarlo (2000). "Peer instruction improves performance on quizzes." Advances in Physiology Education **24**(1): 51-55.

Peer instruction is a cooperative-learning technique that promotes critical thinking, problem solving, and decision-making skills. Benson's think-pair-share and Mazur's peer-instruction techniques are simple cooperative exercises that promote student's participation in class and increase student's interaction with each other and with the instructor in a large classroom. We borrowed concepts from Benson and Mazur and applied these concepts to enhance student involvement during the respiratory component of the medical physiology class. The medical physiology class consisted of 256 first-year medical students. The peer-instruction technique was used for 10 classes. Each class of 50 min was divided into three or four short presentations of 12–20 min. Each presentation was followed by a one-question, multiple-choice quiz on the subject discussed. Questions ranged from simple recall to those testing complex intellectual activities. Students were given 1 min to think and to record their first answer. Subsequently, students were allowed 1 min to discuss their answers with their classmates and possibly correct their first response. The percentage of correct answers increased significantly ( $P < 0.05$ ) after discussion for both recall and intellectual questions. These data demonstrate that pausing three to four times

during a 50-min class to allow discussion of concepts enhanced the active learning; cooperative learning students level of understanding and ability to synthesize and integrate material.

44. Roediger III, H. L., P. K. Agarwal, et al. (2009). "1 Benefits of testing memory." Current issues in applied memory research: 13.
45. Smith, M., W. Wood, et al. (2011). "Combining peer discussion with instructor explanation increases student learning from in-class concept questions." CBE-Life Sciences Education **10**(1): 55-63.  
Use of in-class concept questions with clickers can transform an instructor-centered "transmissionist" environment to a more learner-centered constructivist classroom. To compare the effectiveness of three different approaches using clickers, pairs of similar questions were used to monitor student understanding in majors' and nonmajors' genetics courses. After answering the first question individually, students participated in peer discussion only, listened to an instructor explanation only, or engaged in peer discussion followed by instructor explanation, before answering a second question individually. Our results show that the combination of peer discussion followed by instructor explanation improved average student performance substantially when compared with either alone. When gains in learning were analyzed for three ability groups of students (weak, medium, and strong, based on overall clicker performance), all groups benefited most from the combination approach, suggesting that peer discussion and instructor explanation are synergistic in helping students. However, this analysis also revealed that, for the nonmajors, the gains of weak performers using the combination approach were only slightly better than their gains using instructor explanation alone. In contrast, the strong performers in both courses were not helped by the instructor-only approach, emphasizing the importance of peer discussion, even among top-performing students.
46. Smith, M. K., E. L. Vinson, et al. (2014). "A Campus-Wide Study of STEM Courses: New Perspectives on Teaching Practices and Perceptions." CBE-Life Sciences Education **13**(4): 624-635.  
At the University of Maine, middle and high school science, technology, engineering, and mathematics (STEM) teachers observed 51 STEM courses across 13 different departments and collected information on the active-engagement nature of instruction. The results of these observations show that faculty members teaching STEM courses cannot simply be classified into two groups, traditional lecturers or instructors who teach in a highly interactive manner, but instead exhibit a continuum of instructional behaviors between these two classifications. In addition, the observation data reveal that student behavior differs greatly in classes with varied levels of lecture. Although faculty members who teach large-enrollment courses are more likely to lecture, we also identified instructors of several large courses using interactive teaching methods. Observed faculty members were also asked to complete a survey

about how often they use specific teaching practices, and we find that faculty members are generally self-aware of their own practices. Taken together, these findings provide comprehensive information about the range of STEM teaching practices at a campus-wide level and how such information can be used to design targeted professional development for faculty.

47. Smith, M. K., W. B. Wood, et al. (2009). "Why peer discussion improves student performance on in-class concept questions." Science **323**(5910): 122-124.

When students answer an in-class conceptual question individually using clickers, discuss it with their neighbors, and then revote on the same question, the percentage of correct answers typically increases. This outcome could result from gains in understanding during discussion, or simply from peer influence of knowledgeable students on their neighbors. To distinguish between these alternatives in an undergraduate genetics course, we followed the above exercise with a second, similar (isomorphic) question on the same concept that students answered individually. Our results indicate that peer discussion enhances understanding, even when none of the students in a discussion group originally knows the correct answer.

48. Tolga, G. (2012). The effects of peer instruction on students' conceptual learning and motivation. Asia-Pacific Forum on Science Learning and Teaching.

This aim of this study was investigate the effects of peer instruction on college students' conceptual learning, motivation, and self-efficacy in an algebra-based introductory physics course for nonmajors. Variables were studied via a quasi-experiment, Solomon four-group design on 123 students. Treatment groups were taught by peer instruction. Control groups were taught by traditional didactic lecture method. To assess the effects of peer instruction, students were administered Force Concept Inventory and Motivated Strategies for Learning Questionnaire. Factorial analyses indicated that the treatment groups acquired significantly more conceptual learning, and were significantly more self-efficacious than students in the control groups. It was found that there were no significant differences in motivation between groups.

49. Vickrey, T., K. Rosploch, et al. (2015). "Research-Based Implementation of Peer Instruction: A Literature Review." CBE-Life Sciences Education **14**(1): es3.

Current instructional reforms in undergraduate science, technology, engineering, and mathematics (STEM) courses have focused on enhancing adoption of evidence-based instructional practices among STEM faculty members. These practices have been empirically demonstrated to enhance student learning and attitudes. However, research indicates that instructors often adapt rather than adopt practices, unknowingly compromising their effectiveness. Thus, there is a need to raise awareness of the research-based implementation of these practices, develop fidelity of implementation protocols to understand adaptations being made, and ultimately characterize the true impact of reform efforts based on these practices. Peer instruction (PI) is an example of an evidence-based instructional practice that consists of asking students conceptual questions



during class time and collecting their answers via clickers or response cards. Extensive research has been conducted by physics and biology education researchers to evaluate the effectiveness of this practice and to better understand the intricacies of its implementation. PI has also been investigated in other disciplines, such as chemistry and computer science. This article reviews and summarizes these various bodies of research and provides instructors and researchers with a research-based model for the effective implementation of PI. Limitations of current studies and recommendations for future empirical inquiries are also provided.