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Implementing Active Learning: A Critical Examination of Sources of Variation in Active Learning College Science Courses

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To investigate the variation in active learning used in college science courses, the authors analyzed 57 comparison studies published in three prominent science education journals. Focusing on three sources of variation—(a) the active learning activities, (b) other pedagogical features, and (c) course structure/design—they found that most courses contained a significant lecture component despite the "active learning and lecture" dichotomy and that courses varied widely in terms of the intensity of the active learning strategies, the time students engaged with the content, and where other activities were added. A taxonomy for active learning is also presented to help guide the design of an active learning course.

The predominant mode of instruction in science courses (and other STEM disciplines) continues to be the lecture method, where instructors delve into specified topics as students listen to and potentially take notes on what is presented (Freeman et al., 2014; Stains et al., 2018). However, lecture has been criticized for promoting passive learning, lower student performance, and eventual "fatigue" (that is, lack of enthusiasm/motivation) and attrition (for example, dropped courses, change of majors to non-STEM areas, and even dropping out of college) (Freeman et al., 2014; Gasiewski, Eagan, Garcia, Hurtado, & Chang, 2012; Reimer et al., 2016).

Calls to abandon the lecture method are accompanied by questions as to why it has "refused to go away" (Pickles, 2016, para. 4).

An approach that has gained momentum in science courses as an alternative to traditional lecture is *active learning*. Bonwell and Eison (1991) defined active learning as "activities involving students in doing things and thinking about what they are doing" (p. iii). Besides being implemented in practice, active learning has been the subject of considerable educational research (for example, Chin, Chi, & Schwartz, 2016; Crimmins & Midkiff, 2017; Shattuck, 2016). For example, a prominent meta-analysis was conducted by Freeman et al. (2014) in which active learning was compared to lecture in terms of the effects on student learning and course performance. The researchers asked, when it comes to STEM instruction, "should we ask or should we tell?" (p. 8410). Their findings showed that student performance was, on average, almost half a standard deviation higher with active learning methods compared to lecture and that failure rates were about 1.5 times higher in traditional lecture courses compared to those with active learning.

Wieman (2014) noted that the Freeman et al. (2014) meta-analysis makes a powerful case for adopting active learning in our teaching practice as well as for redirecting our research focus on active learning (for example, dropping traditional lecture as the standard for comparison). However, an open question remains that has serious implications for pursuing the goal of either increased adoption of active learning or more targeted research: What do we mean by "active learning" in terms of the instructional intervention(s) involved? Freeman et al. (2014) acknowledged that "the active learning interventions [in their meta-analysis] varied widely in intensity and implementation" (p. 8410). Similarly, in a research review and illustrative case study on effective teaching approaches in a large introductory biology course, Martella and Demmig-Adams (2018) reported that the use of active learning required further specification and study given the spectrum of possible approaches, ranging from traditional lecture with a few clicker questions to student-centered group work with little instructor guidance. Furthermore, a large observational study of STEM classes conducted by Stains et al. (2018) found seven distinct instructional profiles, five of which involved active learning of some kind. Consistent with the notion that active learning can be implemented in many different ways, instructors across these five active learning profiles could be observed lecturing, asking questions, working with students, posing clicker questions, administering worksheets, and/or implementing group work.

Other empirical and theoretical analyses of active learning have similarly highlighted the breadth of possible activities while analyzing different activities in terms of learning theory. For example, Arthurs and Kreager (2017) identified four categories of in-class active learning activities reported in college science courses: individual non-polling (for example, 1-minute papers), in-class polling (for example, clickers), whole-class discussion (for example, ask and answer questions), and in-class groups (for example, jigsaws). In another example, Chi and Wylie (2014) proposed the Interactive Constructive Active Passive (ICAP) theoretical framework that posits four progressive levels of learner engagement: *passive* (for example, simply listening), *active* (for example, taking notes), *constructive* (for example, generating solutions), and *interactive* (for example, collaboratively solving problems).

Given the array of ways in which active learning can be implemented in practice and analyzed by theory, it is not surprising that Freeman et al. (2014) called for "second-generation experiments" to explore *which types* of active learning and instructor behaviors are most effective in promoting student learning. However, before conducting the recommended second-generation research on active learning, researchers should be aware of the variation that exists in active learning courses so that these sources of variation can be studied systematically. In addition, before encouraging faculty members to incorporate active learning into their courses, it would be helpful to have a taxonomy of the interventions currently in use to help tame the space of active learning options and make instructors' selection processes more concrete.

There were two primary goals of our systematic review. First, we wanted to sample from the discipline-based education research (DBER) science literature to examine the sources of variation in active learning college science classrooms and to provide a more detailed depiction of how active learning is actually being implemented. Thus, we sought to discover a taxonomy of active learning course features based on empirical practice. We did not conduct a meta-analysis, but rather a systematic review of how active learning is implemented in practice. Second, we wanted to provide researchers with a framework for systematically investigating not only *how and why* active learning is more effective than lecture but also *how and why* particular active learning course features are more effective than others. With clear instructor knowledge of the ways in which active learning courses are similar to and different from their corresponding comparison conditions, specific course features can be systematically varied and studied across contexts.

To gather a comprehensive list of sources of variation in active learning science courses, we investigated the types and intensities of active learning activities as well as other course-wide features in a representative sample of active learning science courses. To date, no examination of the research literature in science domains has been conducted that investigates the sources of variation in active learning courses beyond in-class active learning activities. This research project expands on the work of Arthurs and Kreager (2017) by identifying and quantifying three sources of variation in active learning science courses: (a) active learning activities employed in and outside the classroom, (b) other pedagogical features of active learning courses, and (c) course structure/design. We collected a set of active learning studies in discipline-based education research, allowing us to conduct qualitative and quantitative analyses to address our goal of critically examining the sources of variation in active learning implementations.

Method

Search Procedure

Given that the Freeman et al. (2014) meta-analysis was published in 2014, we were interested in studies published beyond this date (that is, 2014-2018). Our search terms were obtained by (a) using the search terms from the Freeman et al. (2014) meta-analysis and (b) adding search terms we came across in active learning articles. Due to the fine-grained analyses we aimed to conduct, we obtained a representative sample of active learning studies in science disciplines. We based our decision on which journals to review on three factors. First, we investigated active learning in discipline-based education research (DBER). DBER has been recognized by the National Science Foundation as an important area of research that draws on the expertise of scientists and the learning sciences and has the potential to improve science education (Singer et al., 2012). We chose to focus on three science disciplines—biology, chemistry, and physics—because of their status as "parent disciplines" for DBER and their longer history in education research than other science disciplines (Singer, Nielsen, & Schweingruber, 2012). Second, we included journals that are considered primary DBER journals (see Singer et al., 2012) (that is, they are the main journals in which researchers publish DBER studies). Finally, to choose between/among the primary DBER journals, we included the journals most frequently publishing comparison studies involving active learning. To determine these journals, the second author identified those journals used in Freeman et al. (2014) and tallied how many articles came from each. Based on all of these factors, we reviewed three journals: *CBE—Life Sciences Education* for biology, the *Journal of Chemical Education* for chemistry, and the *American Journal of Physics* for physics.

The studies were located using an electronic search of the Web of Science database. We used the advanced search option to enter the three journals and the specific publication years and to search 27 key terms related to active learning (for example, *student-centered*, *group activity*, *engaged learning*). The results were exported to Rayyan, a free web application to help researchers manage and code articles to be used in their systematic reviews (Ouzzani, Hammady, Fedorowicz, & Elmagarmid, 2016), using a BibTech file; 463 results were found for the years "2014 to 2017." We repeated this process for the year "2018," and 107 results were found. The total number of results across the years "2014 to 2018" was, thus, 570.

Inclusion Process and Criteria

The third author reviewed the titles and abstracts of the 463 articles pulled from the Web of Science search for the years 2014-2017. An additional research assistant (Research Assistant A) reviewed the titles and abstracts of the 107 articles pulled from the Web of Science for the year "2018." Both reviewers also reviewed the Method section of an article if the title and abstract did not provide sufficient information for inclusion or exclusion. The following inclusion criteria were assessed across the five-year period: (a) the participants in the studies had to be undergraduate college students, and (b) the research design had to be an experimental or quasi-experimental investigation of "active learning versus lecture" or "active learning versus active learning" or a comparison to past implementations where student learning was measured quantitatively (for example, pre/posttest). We ensured that each course labeled as active learning met the definitional and theoretical criteria for active learning previously discussed. Rayyan (Ouzzani et al., 2016) was used to include or exclude articles; each article that was excluded was labeled with the reason(s) for exclusion. With our first inclusion criterion, the number of articles was narrowed to 406 (28.8%, or 164, eliminated). With our second criterion, the number of articles was narrowed to 57 (86.0%, or 349, eliminated). Thus, a large proportion of active learning studies did not include comparisons of active learning conditions to other conditions.

To verify that our inclusion/exclusion criteria were being accurately applied, the first author applied the inclusion criteria to a random 20% of the 570 articles, resulting in an agreement level of 91%. Any discrepancies were discussed between the first and third author and/or the first author and Research Assistant A, and a resolution was achieved for each. The first author also examined every excluded article to ensure the exclusion reasons were accurate; the resulting agreement level was 98%. Any further discrepancies were discussed and resolved between the first and third author and/or the first author and Research Assistant A.

Study Information

Based on our primary research goals, we developed 10 categories to code the 57 included articles (and 59 studies across the 57 articles); for analysis purposes, we called the active learning *courses* in each study active learning *conditions* (there were 88 active learning conditions in total). Our categories were as follows: (1) Comparison (which conditions were being compared?), (2) Condition (what features were included in each condition?), (3) Change Location (did the change to an active learning course occur in the main class, recitation and/or lab, or both?), (4) Average Class[1] Time Spent on Lecture (what percentage of the class period and time per week were used for an instructor-led lecture in the condition?), (5) Average Recitation Time Spent on Lecture (what percentage of recitation time was used for lecture in the condition?), (6) Average Lab Time Spent on Lecture (what percentage of lab time was used for lecture in the condition?), (7) Average Home Time Spent on Lecture (what was the duration of lecture/instructional videos required for students to watch at home in the condition?), (8) Equal Time-on-Task in the Course (were students in class and recitation and/or lab for the same amount of time in the conditions being compared?), (9) Equal Time-on-Task at Home (were students given assignments that took roughly the same amount of time in the conditions being compared?), and (10) Treatment Fidelity (was each condition observed to ensure the fidelity of treatment?).

We utilized the work of Freeman et al. (2014), Reimer et al. (2016), and Stains et al. (2018) to develop our categories because we wanted to investigate the types and intensities of active learning as well as other features (for example, lecture) that can be present in active learning courses.

Our second category (Condition) required the development of specific codes for the course features identified in each active learning condition (as well as for each lecture/control/traditional condition, hereby referred to as *lecture conditions*). To develop relevant codes, the first author analyzed 10 of the included articles (~18%) and created codes based on the course features. Using these codes, the first author coded the 57 included articles, creating additional codes as necessary. To ensure that any newer codes did not apply to previously coded articles, the first author reexamined the 57 articles. There were 55 codes developed for the 57 articles (and 59 studies across the 57 articles). These codes fell under two general areas: (a) active learning activities and (b) other pedagogical features. Active learning activities were determined based on prior categorizations of active learning activities (see, for example, Arthurs & Kreager, 2017). Other pedagogical features were considered separately due to their association with traditional lecture courses. After reviewing the codes (see Table 1), we combined several course features due to their similarity, resulting in 14 main features: nine active learning activity features and five other pedagogical features (see Table 2).

Interrater Reliability

The first author coded each article (100%), and the third author coded 25% of the included articles based on the 10 categories. We computed Cohen's Kappa and Gwet's AC for three categories, "Equal Time-on-Task in the Course," "Equal Time-on-Task at Home," and "Comparison," as well as for six of the 14 features that fell under the "Condition" category. The overall coding reliability for those categories and features for which we computed both Cohen's Kappa and Gwet's AC was .83 ("substantial" category for agreement level). We did not compute the interrater reliability for the other seven categories and eight features within "Condition," because both raters had a perfect match for codes and/or the base rate of one of the codes was virtually 100%.

Results

Basic Study Details

Before analyzing the specific features present in each active learning condition and comparing the conditions included in each study, we developed a full reference for each article, which we coded for the specific journal in which the article was published and for which types of conditions were compared in each study.

Journal

Our initial search through the Web of Science database resulted in 570 articles, with 93 (16.3%) articles from *CBE—Life Sciences Education*, 436 (76.5%) articles from *Journal of Chemical Education*, and 41 (7.2%) articles from *American Journal of Physics*. After applying our inclusion criteria to these articles, we obtained our sample of 21 articles from *CBE—Life Sciences Education* (22.6% remained from the initial 93 articles), 31 articles from *Journal of Chemical Education* (7.1% remained from the initial 436), and five articles from *American Journal of Physics* (12.2% remained from the initial 41).

Table 1
Identified Course Features

Area	*Code*
Active Learning Activities	**PS**: Problem Sets; **WA**: Worksheet Activity; **GO**: Graphic Organizer; **CS**: Case Study; **SP**: Student Presentation; **SG**: Student Guide; **SW**: Software System for Active Learning; **Game**: Game-Based Instruction; **WA**: Worksheet Activity; **PT**: Purposeful Tutoring; **IB**: Instructional Booklet; **GIQ**: Guided Inquiry Questions; **TBR**: Textbook Reading; **PQfp**: Post Questions for Points; **PQnfp**: Post Questions for No Points; **GW**: Group Work; **PD**: Peer Discussion; **GP**: Group Project; **FP**: Final Project; **WCD**: Whole Class Discussion; **R/V A**: Reading or Video Assignment; **RG**: Reading Guides; **OD**: Online Discussion; **WCS**: Write Content Summary; **OT/Tut**: Online Tutorials; **CQ**: Clicker Questions; **LP**: Active Learning Lesson Plan Created; **KWCCN**: Key Word Created Class Notes; **PLTL**: Peer Led Team Learning; **ALA**: Active Learning Activities; **TBL**: Team-Based Learning; **CPR**: Calibrated Peer Review System; **IFATsc**: Immediate Feedback Technique Scratch Cards
Other Pedagogical Features *Lecture*	**RL**: Recorded Lecture; **CL**: Class Lecture; **GS**: Guest Speakers; **TAP**: TA Presentation; **IML**: Interactive Mini Lecture; **ML**: Mini Lecture; **SL**: Socratic Lecture; **JITT**: Just in Time Teaching; **RTW**: Real Time Writing; **MC**: More Content Taught; **DCS**: Different Content Sequence; **CTF**: Concepts Taught First
Tasks	**GHW**: General Homework Assignment (and any code from activity list); **QZ**: Quizzes; **ST**: Self-Tests
Learning/ Exam Preparation	**WEC**: Written Exam Corrections; **GDE**: Group Discussion of Exam; **EQZ**: Exam Quiz; **SS**: Study Strategies; **PE**: Practice Exams; **LO**: Learning Objectives; **RV**: Exam/Content Review

Comparison Conditions

Among the 59 studies we reviewed (across the 57 articles), six studies (10.2%) compared two active learning conditions. Thirty-seven studies (62.7%) compared one active learning condition to one lecture condition.

Table 2
Identified Course Features and Subsequent Codes

Active Learning Activities	*Codes*
Activities	
1. Activity sheets	WA, PS, GO, KWCCN, SG
2. Clicker questions	CQ
3. Case studies	CS
4. Class projects	GP, FP
5. Group Tasks	GW, PD
6. Purposeful tutoring	PT
7. Student presentations	SP
8. Tutorials and games	OT/Tut, Games, SW
9. Whole-class discussions	WCD, OD
Other Pedagogical Features	*Codes*
Lecture	
10. Class lecture component	CL, GS, TAP, IML, ML, SL, JITT, RTW
11. Home lecture component	RL
Tasks	
12. Homework	GHW and any code from Activities in Table 1 when it was completed as homework
13. Student Quizzes	QZ, ST
Learning/Exam Preparation	
14. Learning and exam preparation	SS, LO, PE, RV, EQZ, GDE, WEC

Three studies (5.1%) compared three or more active learning conditions. Eleven studies (18.6%) compared two or more active learning conditions to one lecture condition. Finally, two studies (3.4%) compared at least one active learning condition to two or more lecture conditions. Thus, in total, there were 88 active learning conditions and 52 lecture conditions (140 total conditions).

Sources of Variation

We focused our critical examination of active learning on three sources of variation: (a) active learning activities, (b) other pedagogical features, and (c) course structure/design.

Source 1: Variation in Active Learning Activities

We quantified the variation in active learning activities by calculating the frequencies of the nine active learning activities across all 88 active learning conditions (see Figure 1, which also includes frequencies of the five other pedagogical features). The prevalence and implementation details for each of these nine activities are described below; they are ordered from most frequent to least frequent. The location of where these activities occurred is shown in Figure 1 as well.

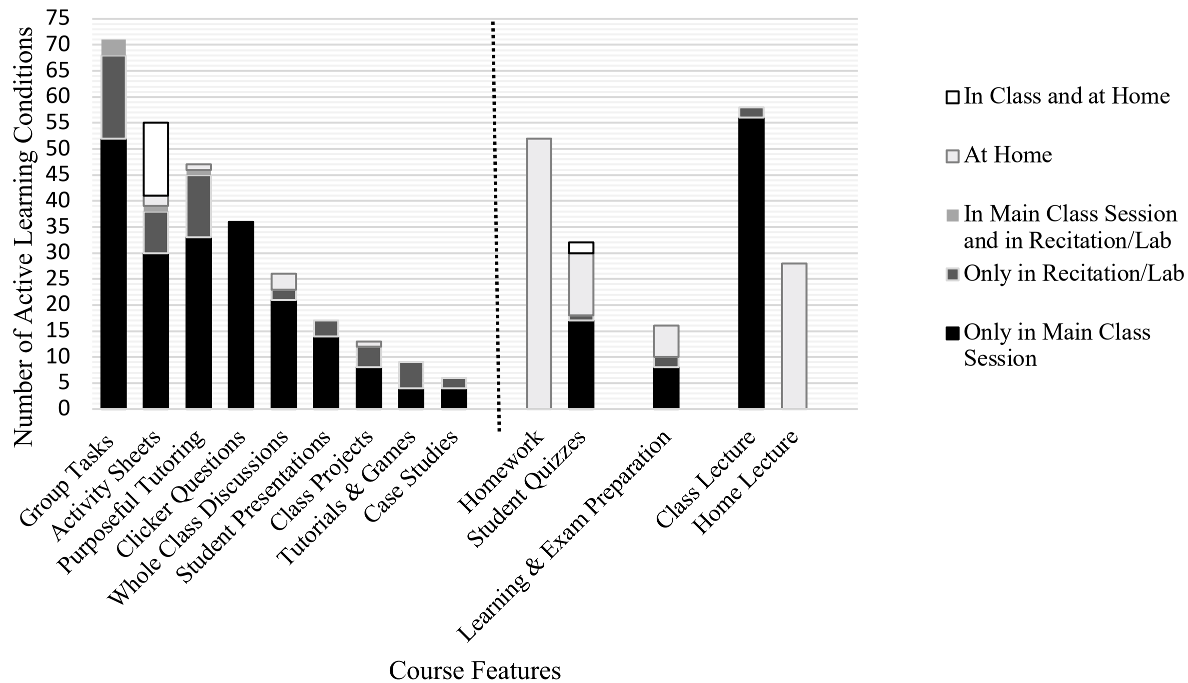
Group tasks. We identified the use of group tasks in 71 of the 88 (80.7%) active learning conditions. These group tasks included group work and/or peer discussion where students had the opportunity to engage in the reciprocal transfer of knowledge (collaborative learning). Group tasks varied in the number of students per group, the types of tasks on which students worked together (for example, clicker questions), and the length of time students were given to work together.

Activity sheets. We identified the use of activity sheets in 55 of the 88 (62.5%) active learning conditions. These activity sheets included problem sets, worksheet activities, graphic organizers, student guides, and guided notes; the activity sheets varied in form, duration, and number and types of tasks.

Purposeful tutoring. We identified the use of purposeful tutoring in 47 of the 88 (53.4%) active learning conditions. Purposeful tutoring included students receiving intentional guidance and feedback from learning or teaching assistants (undergraduate or graduate students) and /or instructors during course activities, typically while working on group tasks.

Clicker questions. We identified the use of clicker questions in 36 of the 88 (40.9%) active learning conditions. These clicker questions could occur at the beginning, during, or end of the class period and gave students the opportunity to practice applying or solidifying their knowledge and skills; the number and duration of clicker questions varied. Students often had time to discuss the clicker questions with their peers in a think-pair-share format; some clicker questions were answered without student discussion.

Figure 1
Frequency of Course Features



Note. Active learning features to the left of vertical dotted line, and other pedagogical features to the right: homework and quizzes; learning and exam preparation; and course and home lecture) present in the 88 active learning conditions and the location of where these course features occurred in the course.

Whole-class discussions. We identified the use of whole-class discussions in 26 of the 88 (29.5%) active learning conditions. These discussions included online discussion boards and in-class, whole-class discussions where students had the opportunity to engage in the reciprocal transfer of knowledge (collaborative learning). There are two main differences between peer discussions (categorized under "group tasks") and whole-class discussions. First, peer discussions typically occur in small groups where all students have the chance to participate. Second, peer discussions are not typically led or guided by the instructor.

Student presentations. We identified the use of student presentations in 17 of the 88 (19.3%) active learning conditions. These presentations often had students present a problem on which they were working to the class (either individually or as a group), providing them an opportunity to learn by teaching.

Class projects. We identified the use of class projects in 13 of the 88 (14.8%) active learning conditions. These projects were individual or group projects and provided students with the opportunity to deepen their knowledge through real-world tasks that varied in format, topic, and other requirements.

Tutorials and games. We identified the use of tutorials and games in nine of the 88 (10.2%) active learning conditions. These activities included online tutorials, games, and software systems for online activities where students could practice applying their knowledge and skills. Tutorials and games varied in format, duration, number of tasks, and types of tasks.

Case studies. We identified the use of case study activities in six of the 88 (6.8%) active learning conditions. These activities required students to use problem-solving and inquiry skills to analyze real-world scenarios, helping to extend or deepen their knowledge through real-world tasks.

Source 2: Variation in Other Pedagogical Course Features

In addition to active learning activities, we identified and quantified other pedagogical features that were also present in the active learning conditions (see Figure 1). As previously stated, we categorized these features as "other" based upon their presence in many traditional lecture courses and the fact that they were not directly related to the active learning activities *per se*. Although homework, student quizzes, and learning/exam preparation can be used to promote active learning (for example, Cook & Babon, 2017), these course features are often included in traditional lecture courses and are not necessarily unique to active learning courses. In addition, we also analyzed the amount of time instructors spent lecturing in the active learning conditions.

Homework. We identified the use of assigned homework in 52 of the 88 (59.8%) active learning conditions. Assigned homework included general homework assignments (through the digital tool *Mastering Biology*, for example), problem sets, reading and video assignments/guides, textbook readings, projects, online discussions, and quizzes. Assigned homework often included several different forms and lengths of assignments/tasks with varying types and numbers of questions that were inconsistent across conditions. For the active learning conditions that had assigned homework (that is, 52 conditions), eight of these conditions had recorded lecture as the only form of homework; the other 44 conditions had one or more other assignments/tasks.

Student quizzes. We identified the use of student quizzes in 32 of the 88 (36.4%) active learning conditions. These quizzes occurred online, through clicker questions, or on paper and were primarily given to ensure that students (a) watched the recorded lectures and (b) understood the course content. The quizzes varied in length, format, number of points, and types of questions.

Learning and exam preparation. We identified the use of learning and exam preparation in 16 of the 88 (18.2%) active learning conditions. Learning and exam preparation included providing learning objectives, practice exams, exam/content review, study strategies, and written exam corrections.

Lecture. We examined whether the active learning conditions included a lecture component (see Figure 1) and divided our analysis into (a) lecture included in main class session (see Footnote 1), in recitation, and/or in lab and (b) recorded lecture viewed at home.

Class lecture. We identified a class lecture component in 58 of the 88 (65.9%) active learning conditions. These lecture components included just-in-time teaching; Socratic lecturing, interactive mini lectures, mini lectures, real-time writing, guest speaker presentations; teaching-assistant presentations; and traditional lecture using PowerPoint slides, a white board, and/or lecture notes.

Home lecture. We identified a home lecture component (also known as recorded lecture) in 28 of the 88 (31.8%) active learning conditions. These lecture components included instructional videos, recorded class lectures, and condensed recordings of class lectures. The home lecture videos varied in length and in the number assigned. Video watching ranged from 15 minutes to 3 hours (videos typically did not exceed 1 hour, however).

Class and home lecture. We identified both class and home lecture components in 16 of the 88 (18.4%) active learning conditions.

Average time in main class session spent on lecture. The active learning conditions with a lecture component varied according to how much time in the main class session (see Footnote 1) was dedicated to lecture versus active learning activities. We quantified (a) the percentage of the main class session spent on lecture and (b) the average amount of time per week spent on lecture in the main class session to provide a relative and absolute metric for how much lecture was included in the main class session. Having both metrics is important, because active learning conditions varied in how much total time students spent per week in class in addition to how much class time was dedicated to different class features. For example, active learning conditions in two studies could devote 50% of the main class session to lecture, but students in one condition met for two class periods per week, whereas students in another condition met for three class periods per week. Thus, the percentage of time devoted to lecture would be the same for the two conditions, but the amount of time spent on lecture per week would differ between conditions. The "average time in main class session spent on lecture" information was primarily acquired from the reporting of this information in the Method sections of the articles we analyzed. If this information was not reported, we utilized two main approaches: (a) reading the descriptions of the course structure provided in the Introduction or Method section and determining into which category the amount of lecture would fit and (b) searching for the course described in the article on the university's website and identifying the length of the main class session and additional information about the course structure in the description of the course (if provided).

Percentage of time spent on lecture in the main class session. We conducted our analyses by investigating active learning conditions that devoted (a) 0-19% of the main class session to lecture; (b) 20-49% of the main class session to lecture; (c) 50-99% of the main class session to lecture; (d) 100% of the main class session to lecture; and (e) difficult to determine[2], but at least 20% of the main class session devoted to lecture. Although our sample included 88 active learning conditions, 12 (13.6%) of these conditions were lab courses/lab-only interventions or had only recitation and, thus, did not have a main class session that was included as part of the course. Thus, we investigated 76 (86.4%) active learning conditions that had a main class component. Thirty-one (40.8%) active learning conditions devoted 0-19% of the main class session to lecture, six (7.9%) devoted 20-49% of the main class session to lecture, 17 (22.4%) devoted 50-99% of the main class session to lecture, and five (6.6%) devoted 100% of the main class session to lecture. The courses with 100% of class time devoted to lecture were considered active learning courses because they also included a recitation and/or lab that included active learning activities. Finally, for 27 (22.4%) of the active learning conditions it was difficult to determine the precise percentage of the main class session devoted to lecture (that is, percentage not reported in the study), but they were deemed to devote at least 20% of the main class session to lecture. Thus, 55 of the 76 (72.4%) active learning conditions investigated devoted at least 20% of the main class session to lecture.

Average class time per week in main class session spent on lecture. We analyzed active learning conditions that had an average of (a) 0-29 minutes of class time per week devoted to lecture; (b) 30-49 minutes of class time per week devoted to lecture; (c) 50-99 minutes of class time per week devoted to lecture; (d) 100 minutes or more of class time per week devoted to lecture; and (e) difficult to determine[3], but at least 30 minutes of class time per week devoted to lecture. Although our sample included 88 active learning conditions, 12 (13.6%) of these conditions were lab courses/lab-only or had only recitation and, thus, did not have a main class session for us to examine. In addition, 12 (13.6%) of these conditions focused only on the teaching of one specific topic or testing a specific active learning approach over one or two class periods and, thus, did not have a "per week" component. Thus, we examined 64 (72.7%) active learning conditions. Twenty-three (35.9%) active learning conditions devoted an average of 0-29 minutes of weekly class time to lecture, four (6.3%) devoted an average of 30-49 minutes of weekly class time to lecture, seven (10.9%) devoted an average of 50-99 minutes of weekly class time to lecture, and 15 (23.4%) devoted an average of 100 minutes or more of weekly class time to lecture. Finally, for 15 (23.4%) of the conditions it was difficult to determine the amount of weekly class time devoted to lecture (that is, minutes not reported in the study), but they were deemed to devote at least 30 minutes of class time per week to lecture. Thus, 41 of the 64 (64.1%) active learning conditions investigated devoted at least an average of 30 minutes of weekly class time to lecture.

Lab courses, lab-only courses, and recitation-only courses. Although 12 active learning conditions were lab-only or recitation-only courses, it should be noted that 10 (83.3%) of these conditions also had an associated lecture period as part of the course, and two (16.7%) had an optional lecture period that students could take concurrently. Although these conditions did not include the lecture period as part of the active learning condition, students were exposed to a significant amount of lecture.

Average recitation and/or lab time spent on lecture. There were 24 active learning conditions that had at least one new active learning recitation and/or lab. Four of these 24 (16.7%) active learning conditions had a small lecture component in the recitation or lab. However, the average time spent on lecture in recitations and/or labs was near 0% due to the focus of these sections being on conducting lab experiments, engaging in discussions, and working on activity sheets. Lecture components were typically included in the main class period.

Average home time spent on lecture. As reported previously, there were 28 active learning conditions that had home lecture (also known as recorded lecture). The duration for watching videos per week typically ranged from 10 minutes to 3 hours.

Source 3: Variation in Structure/Design

For the third source of variation in active learning courses, we examined the structure/design of active learning conditions based on where active learning activities were added to the course (that is, in class, in recitation, and/or in lab) and the time students were required to spend in class and at home engaging with the content (that is, time on task). To determine the time students were required to spend engaging with the content in class and at home, we used information provided either in the articles (some articles reported time required for homework or the amount of homework given) or on the course websites (to determine the course duration and if students were assigned homework). We also examined the number of course features present in each active learning condition and the number of course features that differed between/among the conditions compared in each study.

New active learning course component. We examined if the active learning conditions included a new active learning main class session or a new active learning recitation and/or lab that was not included in the lecture condition. We also examined how many active learning conditions had both a new active learning main class session and a new active learning recitation and/or lab.

New active learning main class component. We identified a new active learning main class session in 67 of the 88 (76.1%) active learning conditions. These conditions changed what students were doing during class time (for example, engaging in activities during class and watching lecture videos at home).

New active learning recitation and/or lab component. As previously stated, we identified a new active learning recitation and/or lab in 24 of the 88 (27.3%) active learning conditions. These additional course sections varied in the activities presented to students during this time and in the amount of time students spent in the section per week. We also found that three of the 24 conditions had two or more new active learning recitations and/or labs added to the course.

Both a new active learning main class component and at least one new active learning recitation and/or lab component. We identified a new active learning class and at least one new active learning recitation and/or lab in eight of the 88 (9.1%) active learning conditions. These conditions changed what students were doing in the main class session and in their recitation and/or lab.

Equal time-on-task in class and at home. We also examined the time students were required to spend in class and at home to quantify how conditions from each study compared with regard to time-on-task. Thus, for the time-on-task variables below, our unit of analysis was each study in our sample rather than the specific conditions within each study.

Equal time-on-task in the class. We were interested in determining if the two or more conditions being compared in each study differed on the amount of time students spent in the class (including the main class session, recitation, and/or lab). We found that 40 of the 59 (67.8%) studies contained conditions requiring students to be in the main class session, recitation, and/or lab for the same amount of time as students in the other condition(s) (five of these 40 were not reported but were deemed equal).

Among the remaining studies with unequal time-on-task in the course, we found that 12 of the 59 (20.3%) studies contained conditions requiring students to be in the main class session, recitation, and/or lab for a different amount of time than students in the other condition(s) (one of these 12 was not reported but was deemed unequal). Of these 12 studies, (a) three studies had students in the active learning condition (or one of the active learning conditions if there was more than one) spend more time in the class than students in the lecture and/or the other active learning condition(s). Finally, seven of the 59 (11.9%) studies did not provide enough information to determine if there was equal time-on-task in the course.

Equal time-on-task at home. We were also interested in determining if the two or more conditions compared in each study differed on the amount of time students spent preparing for the course at home. This time measure was determined by (a) the number of activities assigned to do at home or (b) the specific length of videos or homework assignments. We found that 19 of the 59 (32.2%) studies contained conditions that were designed for students to prepare for the course at home for the same amount of time as students in the other condition(s). Twelve of these 19 conditions were not reported but were deemed equal.

We also found 26 of the 59 (44.1%) studies contained conditions that were designed for students to prepare for the course at home for a different amount of time than students in the other condition(s) (four of these 26 were not reported but were deemed unequal). In each of these 26 studies, the active learning condition (or one of the active learning conditions if there was more than one) was designed for students to spend more time at home on assignments than students in the lecture and/or the other active learning condition(s). Students in the active learning conditions typically spent more time at home on the course due to assigned recorded lectures to watch before class and longer/more numerous homework assignments. Finally, 14 of the 59 (23.7%) studies did not provide enough information to determine if there was an equal time-on-task at home for students in the conditions.

Equal time-on-task in the class and at home. We examined if the two or more conditions compared in each study differed on the amount of time students spent in the class (including the main class session, recitation, and/or lab) and at home. We found that 14 of the 59 (23.7%) studies contained conditions requiring students to be in the main class session, recitation, and/or lab for the same amount of time and that were designed for students to prepare for the course at home for the same amount of time as students in the other condition(s) (nine of these 12 conditions were not reported but were deemed equal).

We also found that eight of the 59 (13.6%) studies contained conditions requiring students to be in the main class session, recitation, and/or lab for a different amount of time and were designed to have students prepare, at home, for a different amount of time than students in the other condition(s) (two of these eight were not reported but were deemed unequal). Of these eight studies, (a) five studies had students spend more time in the lecture condition in the class but had students in the active learning condition(s) spend more time at home on the course, and (b) three studies had resulted in students in the active learning condition spending more time working on course material at home than students in the lecture condition and/or other active learning condition(s). Additionally, 21 of the 59 (35.6%) studies either had conditions that resulted in students spending an equal amount of time in the class and a different amount of time at home or a different amount of time in the class and a seemingly equal amount of time at home. Although a question arises as to whether the difference in course time between/among conditions was equated through the difference in home time (and vice versa), the studies did not precisely quantify the time students spent on homework for us to make this determination. Finally, for 16 of the 59 (27.1%) studies, it was not possible to determine if there was equal time-on-task spent in the class and at home for students in the conditions.

Number of course features present in each active learning course. The 88 active learning conditions had features that were categorized under two general areas: (a) active learning activities and (b) other pedagogical features. In total, these conditions could have up to 14 features present in the course (see Figure 1). The most common number of features present in the active learning conditions were 4, 5, and 6 (36/88 total conditions; 40.9%), resulting in an average number of 5 course features. Only four active learning conditions had just one feature, and no active learning conditions had more than 10 features (see Figure 2).

Number of differences between/among conditions. Due to the average number of course features being 5, we investigated if a conclusion could be made about *which* of the (likely) multiple features led a particular condition to be more or less effective than its comparison condition(s). Thus, we examined if only one difference existed between/among the conditions being compared in each study, specifically looking at the 14 course features in Figure 1. For there to be more than one difference between/among conditions, the conditions had to differ on more than one of the 14 course features.

We identified seven of the 59 (11.9%) studies where only one feature differed between/among the conditions and an additional five (8.5%) studies where two of the three conditions being compared had only one difference. Thus, the majority of studies (79.7%) included comparison groups that differed on more than one feature.

Treatment fidelity. Given the numerous features implemented in each active learning condition, we quantified the number of studies that included a measure of the fidelity of implementation. Our unit of analysis for this category was the study itself rather than the specific features in each condition. We found that only 10 of the 59 (16.9%) studies included fidelity checks for the active learning conditions and that three of these 10 (30.0%) studies did not include a complete fidelity check (that is, a fidelity check was not conducted across all conditions or years of the study). Among those studies that included a fidelity check, a common method was the use of the Classroom Observation Protocol for Undergraduate STEM (COPUS), where course features were documented during 2-minute segments throughout the class period (see Smith, Jones, Gilbert, & Wieman, 2013).

Taxonomy

We developed a taxonomy (see Figure 3) as a practical guide to support (a) instructors in creating an active learning course or to revise a course to include active learning and (b) researchers in doing systematic investigations of active learning. There are three main dimensions of our taxonomy, each of which maps to a source of variation we identified from the active learning courses in our review. The first dimension is "location," based

Figure 2
Frequency of Active Learning Conditions That Had 1-to-14 Course Features

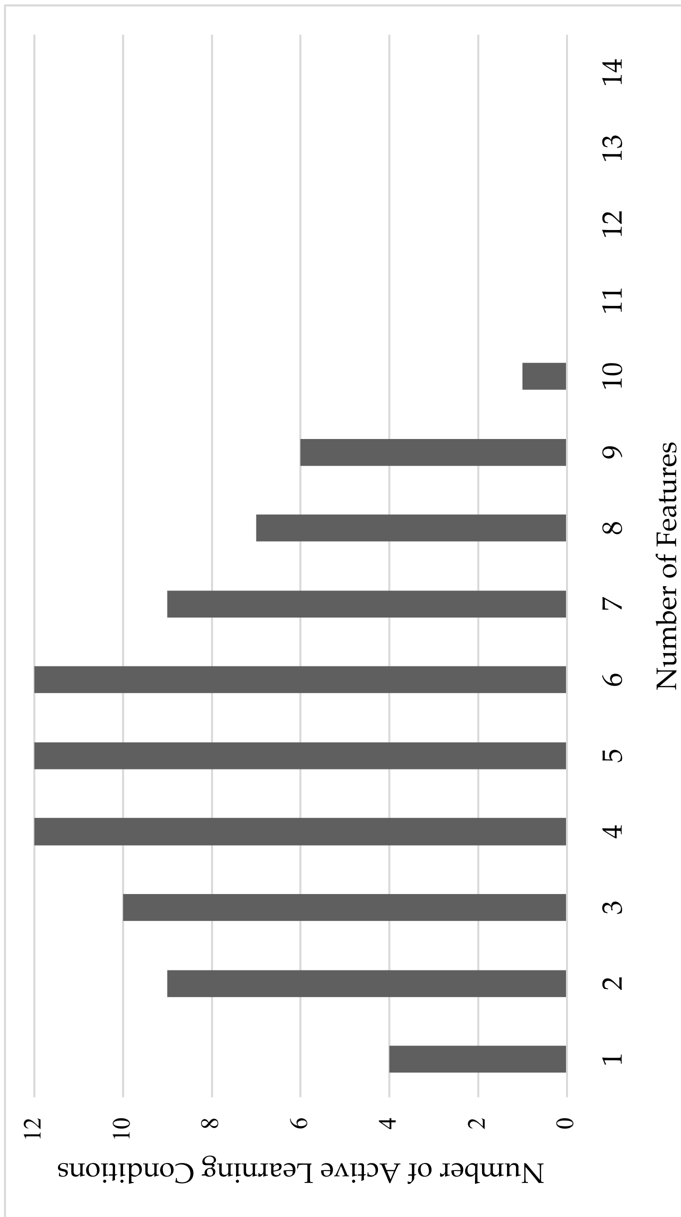
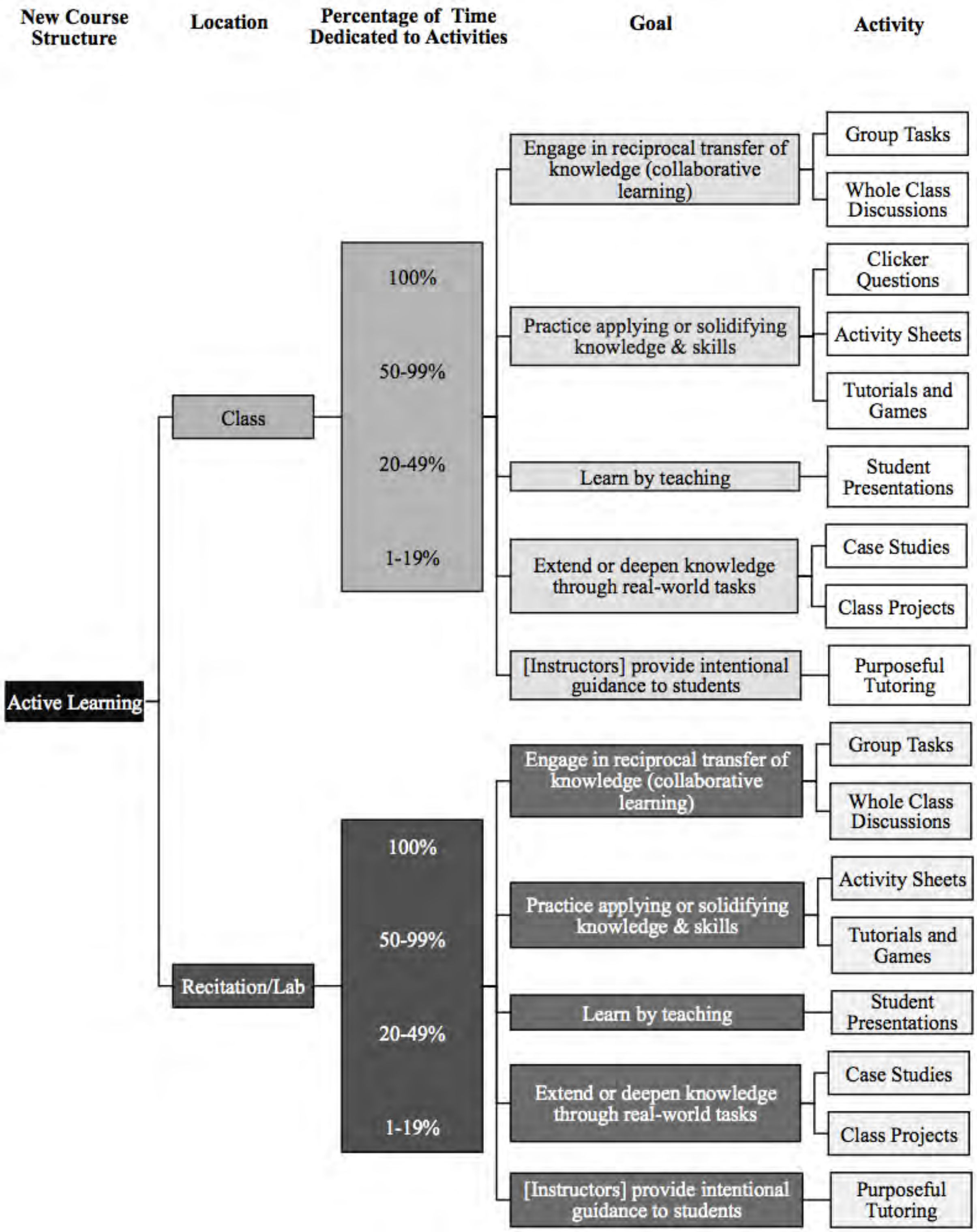


Figure 3
Taxonomy of Elements of Active Learning Courses to Be Considered in Course Design/Restructure

See page 88 for Figure 3.


New Course Structure
Location
Percentage of Time Dedicated to Activities
Goal
Activity
Active Learning
Class
100%
50-99%
20-49%
1-19%
Engage in reciprocal transfer of knowledge (collaborative learning)
Group Tasks
Whole Class Discussions
Practice applying or solidifying knowledge & skills
Clicker Questions
Activity Sheets
Tutorials and Games
Learn by teaching
Student Presentations
Extend or deepen knowledge through real-world tasks
Case Studies
Class Projects
[Instructors] provide intentional guidance to students
Purposeful Tutoring
Recitation/Lab
100%
50-99%
20-49%
1-19%
Engage in reciprocal transfer of knowledge (collaborative learning)
Group Tasks
Whole Class Discussions
Practice applying or solidifying knowledge & skills
Activity Sheets
Tutorials and Games
Learn by teaching
Student Presentations
Extend or deepen knowledge through real-world tasks
Case Studies
Class Projects
[Instructors] provide intentional guidance to students
Purposeful Tutoring

on *Source 3: Variation in Structure/Design*. Here, the taxonomy branches based on where active learning will be deployed in the course—in the lecture session, recitation, or lab. The second dimension is "percentage of time dedicated to activities," based on *Source 2*: V*ariation in Other Pedagogical Course Features*. Because this is a continuous dimension, the taxonomy does not explicitly show different branches, but we highlight in Figure 3 a few different levels of percentage of time that could be dedicated to active learning (based on our analysis of that feature). The third dimension is "goal of the activity," based on *Source 1*: *Variation in Active Learning Activities*.

To determine the goals corresponding to the active learning activities identified in our analyses, we looked to the ICAP Framework and other prior research for how cognitive engagement activities are defined and categorized (Arthurs & Kreager, 2017; Chi & Wylie, 2014). We also based our goals and categorization of the activities on the results of our own analyses, wherein similarities and differences in the nature and purpose of the activities led to the grouping of activities or the creation of different features (see Table 2). Then, for each goal, the taxonomy branches to one (or more) active learning activities. It is worth noting that the activities are, in multiple cases, repeated across "leaf nodes" in the upper and lower branch of the taxonomy's tree diagram. This highlights that the taxonomy is not designed to create mutually exclusive conditions under which different active learning activities can be applied. Instead, many of the active learning activities identified in our review can be deployed across multiple locations and for varying percentages of time. This means that instructors are not limited in their choices even after they have considered the dimensions of this taxonomy.

Discussion

When examining the conditions compared in each study, we found the most common comparison was between one active learning condition and one lecture condition (62.7%). This was surprising, given that we examined articles published *after* the Freeman et al. (2014) meta-analysis that, like Wieman (2014), called for subsequent research to move beyond "active learning versus lecture." We expected a higher number of studies comparing two or more active learning conditions. However, it may be that the studies in our set were already designed or implemented when the meta-analysis was published.

When examining the specific features found in each of the 88 active learning conditions, we identified nine active learning activities and five other pedagogical features. The most common active learning activity (see Figure 1) across these conditions was group tasks (80.7%). The second most common active learning activity across these conditions was activity sheets (62.5%). Other highly frequent activities (that is, > 40%) included purposeful tutoring (active learning activity) (53.4%), homework ("other" activity) (59.8%), and clicker questions (active learning activity) (40.9%). Our results are consistent with Stains et al. (2018) in that they found clicker questions, group work, and group activities to be prevalent in the classrooms observed in their study. Our findings are also consistent with Arthurs and Kreager's (2017) analysis of 127 articles from 1994-2014, in that they found individual non-polling, in-class polling, and in-class group activities to be prevalent in active learning science courses.

Although we expected active learning conditions to differ from lecture conditions in terms of providing students with active learning activities such as activity sheets, clicker questions, group work, and purposeful tutoring, we did not expect active learning conditions to more often provide students with other pedagogical features as well, such as quizzes, homework, and learning/exam preparation. We found that 36.4% of active learning conditions had quizzes, compared to 5.8% of lecture conditions; 59.8% of active learning conditions had homework assignments, compared to 25.0% of lecture conditions; and 18.2% of active learning conditions had learning/exam preparation, compared to 3.8% of lecture conditions.

Several researchers have examined the effects of frequently assessing students and have found that weekly quizzes improve students' performance on tests and exams (McDaniel & Agarwal, 2011), that repeated testing leads to greater retention than studying (Roediger & Karpicke, 2006), and that "testing potentiates further study" (Brame & Biel, 2015, p. 8). Relatedly, for learning/exam preparation, practice exams that mirror actual exams allow students to actively retrieve information from their long-term memory, strengthening their memory for this information in the process (Dunlosky, 2013). Learning objectives, like study strategies, can also be used to guide student learning (Crimmins & Midkiff, 2017). Finally, research on the impact of homework assignments has also shown there to be positive effects on student learning when students solidify their skills through practice (Archer & Hughes, 2011) and store information in long-term memory (Dunlosky, 2013). It should be noted that exactly how these strategies are implemented can affect their effectiveness. However, given the general benefits of assessing for learning, providing students with homework assignments, and including learning/exam preparation in a course, questions arise: Do students in active learning courses outperform students in lecture courses due to the inclusion of these other course features rather than the active learning features *per se*? Could lecture courses be as effective as active learning courses if students were given more frequent assessments and homework assignments (the same number and type as their active learning peers)? Or, are the activities included in active learning courses and the reduced lecture time driving improved student performance? A future line of research could investigate these and related questions.

We also found that despite the "active learning versus lecture" dichotomy, 79.5% of active learning conditions contained a lecture component (in the class, at home, or both). In fact, when analyzing the percentage of lecture time students spent in the main class session, 72.4% of the active learning conditions devoted at least 20% of class time to lecture. Similarly, when measured in terms of absolute time per week spent on lecture in the main class session, 64.1% of the active learning conditions spent at least 30 minutes of class time per week on lecture. Thus, active learning courses can and often do incorporate elements of the lecture method. The important question to consider is "How does the proportion/amount of lecture as compared to the time spent on active learning activities impact student learning?"

When looking across the 14 course features identified in active learning conditions, we found variation to exist within each of the features shown in Figure 1. Activity sheets, for example, took many forms, required differing levels of cognitive skills, and varied in length. This pattern was found for every feature identified in the active learning conditions. As evidenced by the lecture results, students in active learning conditions listened to lectures of varying lengths and structure, resulting in class time for activities to vary across conditions as well. Thus, active learning conditions differed not only on the types and number of features present in the course but also on *how* these features were designed and implemented. Given the ICAP framework (Chi & Wylie, 2014) and its predictions, it is clear that some implementation differences *even for the same activity* can lead to significant effects on student learning. Unfortunately, only 16.9% of the studies included a fidelity check, leaving us to speculate if the intervention was implemented as described.

With active learning conditions involving several components, both in the class and at home, we also examined whether the comparison conditions in each study were designed to require equal time-on-task. We found that 20.3% of the studies did not create conditions that were equal in how much time students spent in the class, and 44.1% of the studies did not create conditions that were equal in how much time students spent on the course at home. Those conditions that typically required more time in class were primarily lecture conditions, whereas those conditions that typically required more time at home were primarily active learning conditions. The amount of time students are engaged in a course (for example, the time students put into a course through longer classes, recitations and/or labs, and pre/post class assignments) is significantly predictive of their achievement (Gettinger & Walter, 2012). Students in active learning conditions who spent equal time in class but more time at home than their peers in the comparison condition(s) were given more numerous homework assignments to solidify the content knowledge (the benefits of homework are briefly described above). Students in active learning conditions who spent less time in class than their peers in the comparison condition(s) were expected to study for the course and complete assignments during the "free" class period. A question remains as to whether students in active learning courses tended to experience greater academic success than their peers in lecture courses due to more time to study and work on assignments for the course and/or due to more opportunities to practice the course content.

We also conducted an additional investigation of the structure of active learning courses by examining in which part of the course students experienced active learning. Active learning conditions typically involved redesigning the main class to involve active learning (76.1%), followed by redesigning/adding a new recitation or lab (27.3%, with 9.1% involving a new class *and* a new recitation or lab). If active learning activities can occur either at the class level or at the recitation or lab level, then it is important to investigate if features occurring in one location are more or less effective than those occurring in another location.

Finally, by utilizing and building on the taxonomy of active learning activities identified in this study, researchers should be better positioned to follow the Freeman et al. (2014) recommendation and conduct second-generation research that analyzes which types of active learning and instructor behaviors are the most effective for student learning, especially in particular contexts. This research may include devising carefully constructed comparisons of active learning conditions, investigating whether the effect sizes for different comparisons are correlated with specific features present in the active learning conditions, and investigating whether or how those correlations change across course contexts.

Two open questions highlighted by our review are worth promoting to researchers. First, given that the majority of active learning conditions included a lecture component, it is important to determine how much lecture, if any, is necessary for students to learn the course content at the highest level possible. For example, future research could address whether the most effective active learning courses are those that have (a) more than 75% of the class period dedicated to active learning activities and the rest dedicated to lecture, (b) between 50% and 75% of the class period dedicated to active learning activities, or (c) less than 50% of the class period dedicated to active learning activities. Of course, in order to draw valid and generalizable conclusions when making comparisons about time spent with active learning, other variables (for example, location of the active learning, goal of the active learning, type of active learning activity, and details of its implementation) should either be held constant or more systematically varied. Second, *which* active learning strategies are most effective and whether that result depends on various contextual factors (for example, location of the active learning, amount of time spent, discipline under study, student population) are important factors to consider. For example, are activity sheets more or less effective compared to clicker questions or case studies or whole-class discussions? The only way to achieve this specificity of research questions (and conclusions) is to isolate variables and systematically study their effects on student learning and motivation.

Footnotes

[1]"Class" refers to the main part of the course where all enrolled students meet together (typically in a large lecture hall). "Recitation" and "lab" refer to the smaller sections associated with the course. Thus, an undergraduate science *course* may include the main class, a recitation, and/or a lab.

[2]These conditions did not have a specified percentage of class time spent on lecture. However, based on the details provided in the studies (e.g., lecture was stopped every 20 minutes in a 60-minute period for short clicker questions); these conditions were deemed by the first author (and the third author) to have devoted at least 20% of class time to lecture—thus representing a significant amount of the class period being dedicated to lecturing.

[3]These conditions included lecture as an important component of the class; that is, these conditions relied on lecture or integrated lecture and activities throughout the class periods.

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