

Not simply “active”: identifying types of active-learning tasks in introductory biology

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ABSTRACT Active learning is a phrase that lacks clear definition, which has hampered researchers’ efforts to investigate the nuances of effectiveness and instructors’ efforts to capitalize on potential benefits for students. One way to advance our understanding of “active learning” is assessing by the type of intellectual work that in-class activities require of students. We systematically analyzed in-class work opportunities created for students in 55 introductory biology courses around the United States, each of which used active learning. We did so by adapting an observation approach grounded in the ICAP framework and analyzing classroom videos in 15-s segments. Instructors devoted about a quarter of class time to student work time, on average, but this varied widely. About half of these student work opportunities focused on recall, and half required students to generate answers beyond what had been presented to them, which can foster deeper learning and better transfer than recall alone. The ratio of these levels of intellectual work varied considerably across courses. We also tested whether course- and instructor-level factors predicted the amount and level of active-learning opportunities and found no significant relationships. This work provides a striated definition of active learning that will be useful to researchers studying active-learning outcomes and instructors aiming to harness learning benefits for their students.

KEYWORDS ICAP, active learning, undergraduate, biology education, STEM education, higher-order cognitive skills

“Active learning” is a term with multiple definitions, and this lack of clarity impedes educators and education researchers alike. Active learning can refer to a wide range of independent instructional strategies (1–3), a broader, holistic approach to instruction (4–6), or anything that is not didactic lecture (7, 8). Given this lack of consensus, it is unsurprising that what happens in undergraduate active-learning classrooms varies widely (9). This creates challenges for studying the benefits of active learning, and existing evidence of effectiveness leaves unanswered questions about when and how active learning supports student success (7, 8, 10). These issues have led to calls for more attention to how we characterize active-learning instruction (11, 12).

One team of cognitive scientists developed the ICAP framework to better operationalize active learning (13–15). This framework aims to explain observed differences in student learning across active-learning activities by linking learning to the intellectual work asked of students. This has the potential to help educators and researchers differentiate between types of active learning and the learning we can expect to result from these opportunities. The letters in ICAP refer to the level of intellectual work undertaken by students: *Interactive*, *Constructive*, *Active*, and *Passive*. The base level, *passive*, involves students listening to a lecture or watching a video and is the only ICAP level that is not considered active learning. The next level, *active*, includes students recalling material that has already been presented to them, carrying out algorithmic processes, or manipulating materials. Next, *constructive* intellectual work

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involves students making inferences and generating ideas beyond what has been presented to them. The final level is *interactive*, in which students work *constructively* in dialog with others, each generating ideas beyond what has been presented to them or shared by their learning partner(s), and do so with repeated turn-taking (14, 16). *Interactive* and *constructive* work can collectively be referred to as *generative*, as students generate ideas that go beyond what they have been taught for each. These levels are hierarchical, with *interactive* intellectual work requiring *constructive* work and *constructive* work requiring *active* work.

Students benefit from engaging in higher levels of intellectual work. Students learn more deeply and are better able to transfer their knowledge after engaging in *constructive* and *interactive* active learning compared to *active* and *passive* opportunities (17, 18). For example, students who engaged in *constructive* intellectual work more successfully transferred knowledge to contexts they had not yet considered than students who engaged in *active* or *passive* work (17). Students who completed learning activities at the *active* level performed better on examinations than those who had only engaged in *passive* intellectual work, and students who had worked at either *constructive* or *interactive* levels had higher scores still (18). Importantly, students working on *interactive* activities may see even higher learning gains than those working on *constructive* activities, though gains may be restricted to questions requiring more inference (18) and vary depending on the extent to which students engage in back-and-forth dialog (16). With more detailed characterizations of active learning, and evidence of how this relates to student learning, we can ask: what types of active-learning opportunities exist in introductory biology courses?

Introductory courses are important because they lay the groundwork for upper-division coursework and are particularly impactful in students' decisions to stay or leave STEM majors (19, 20). Existing evidence suggests that introductory biology courses may fall short of expecting students to engage in higher-level intellectual work. Prior work has investigated this using Bloom's Taxonomy (21), and we propose that *active* intellectual work in the ICAP framework is essentially equivalent to the two lowest Bloom's levels, recall and comprehension. In 77 introductory biology courses from 44 institutions around the United States, 93% of exam questions required only *active* work, though just 69% of stated learning objectives focused on memorization or comprehension (22, 23). Similarly, in a study of 111 introductory biology instructors from 100 institutions, at least 85% of exam questions required only intellectual work at the *active* level (24). Though exam questions requiring *constructive* work tended to be worth a greater percentage of the total score (4.0% per question compared to 2.4% for active questions), the vast majority of exam scores depended only on *active* work. Though introductory biology courses predominantly assess students' abilities to engage in *active* intellectual work, instructors may create more opportunities for *constructive* and *interactive* intellectual work in class. Active-learning instructors in one small study used 34% of class time for active learning, including 18% that created opportunities for *generative* work (i.e., *constructive* or *interactive*) (25).

In this study, we took a large-scale look at the opportunities for intellectual work created in active-learning courses, using an analysis grounded in the ICAP framework. We studied the opportunities for intellectual work created in introductory biology courses taught by 55 instructors at 43 institutions around the country, by addressing this question: How much class time do instructors dedicate to opportunities for *active*, *constructive*, and *interactive* intellectual work? We also investigated whether particular course- and instructor-level variables predicted the opportunities that instructors created for students.

In addition to advancing knowledge about the current state of active learning in introductory biology, this study offers two methodological advancements. First, we adapted an ICAP observation approach from K12 settings to the context of higher education. Second, we analyzed classroom practices at a finer resolution than prior work, using 15-s rather than the standard 2-min time segment for observation protocols—an

important refinement for capturing the precise time dedicated to different types of learning opportunities (e.g., COPUS) (26). Therefore, this work provides proof of concept for new and refined approaches to systematically analyzing classroom instructional practices.

METHODS

Participants

We conducted this work within a larger study of instructors and students in introductory biology courses. We studied 55 instructors from 43 institutions (Table S1), including 30 Historically White Institutions (69.7%), 13 Minority Serving Institutions (30.3%), 37 public institutions, and 6 private institutions. According to Carnegie classifications, 23 are very high research activity institutions (R1), and 20 are high research activity (R2) or master's granting institutions. We recruited participants by emailing introductory biology instructors across the United States. We invited participants who (i) taught an introductory biology course with 50 or more students, (ii) self-reported using active learning, and (iii) taught specific topics. We offered monetary incentives for participation. Participants shared information about their background and identity through an online survey (see the supplemental material). 61.8% of instructors identified as women, and 76.4% identified as White (Table 1). Instructors taught classes with a mean enrollment of 161 (SD = 97). Instructors held positions with an average of 72% (SD = 23%) of their time formally dedicated to teaching, ranging from 20% to 100%. On average, they had taught college courses for 26.4 terms (SD = 18.4), ranging from 0 to 70 terms. Most (78.2%) had participated in 40 or more hours of teaching professional development, and many had participated in other forms of training or development for teaching (Table S2).

Data collection

We aimed to video record three class periods for each instructor and collected all associated class materials (e.g., slides and handouts). We met this goal for 91% of participants ($n = 50$) and included recordings for at least two full class periods for the remaining participants, for a total of 160 videos analyzed. For instructors with only two class periods, we also included any partial recordings from a third class period. In some instances, missing data in the form of audio blips or class materials prevented coding opportunities for work in part of a recorded lesson. We excluded these time segments from quantification. This never exceeded half a class period, typically being limited to less than 20% of a class period.

TABLE 1 Instructor's self-reported gender and race/ethnicity ($n = 55$)^a

	<i>n</i>	%
Gender		
Woman	34	61.8%
Man	21	38.2%
Race/ethnicity		
White: European	48	87.2%
Latiné: South American	4	7.3%
Latiné: Mexican	2	3.6%
Asian: Indian	2	3.6%
Jewish	1	1.8%
Asian: Korean	1	1.8%
Asian: Chinese	1	3.7%
White: North African	1	1.8%
White: Middle Eastern	1	1.8%
Decline to state	1	1.8%

^aSix instructors reported multiple racial/ethnic identities. To honor their identities, we include them in counts for each identity reported. This results in counts exceeding 100%.

Data analysis

Analyzing classroom video and materials

We analyzed classroom video to identify opportunities for intellectual work created for students using a modified coding scheme from Morris and Chi (15) (supplemental material). We altered their approach in a few ways to meet our goals. First, we quantified the time that instructors gave students to engage in opportunities for intellectual work, rather than counting the number of tasks assigned (e.g., questions, problems, and cases). We made this change because it offers more information about the opportunities created for students. We coded tasks in 15-s time blocks, rather than the 2-min time blocks standard in most classroom observation protocols (26–28) to provide greater resolution regarding the opportunities for intellectual work created for students. We worried that 2-min segments would obscure key differences. For example, an *active* task might take 15 s to complete compared to a *constructive* task that took 2 min, yet these would be coded identically using a standard 2-min block. Second, we did not code *passive* questions. *Passive* questions are rhetorical, with no expectations of students answering, or simple enough to be answered with a head nod (supplemental material). As such, *passive* questions did not align with our goal of characterizing active-learning instruction. Third, we coded *interactive* tasks differently to more comprehensively capture the intellectual work opportunities created for students. Morris and Chi (15) considered every opportunity for group work that involved *constructive* tasks to be *interactive time*. However, students do not necessarily engage in *interactive* intellectual work when they discuss tasks (13, 14), though they can learn more when they do (16). We opted to set a higher bar, expecting instructors to specifically prompt students to engage in *interactive* dialog about a *constructive* task using specific verbal cues (e.g., debate, agree upon, and evaluate; see full protocol in supplemental material) (29). Instructor cues influence the specific intellectual work students undertake in groups (30). Therefore, we honored the demonstrated value of *interactive* dialog by limiting this code to instructions that explicitly directed students to build on each other's ideas.

A team conducted this analysis, including B.D.J., C.D., and two undergraduate researchers. We first refined the protocol using practice videos, with each coder independently applying the protocol before discussing all disagreements to reach consensus. When two researchers struggled to come to consensus, we invited a third researcher's judgment. Once researchers were comfortable with the protocol and had addressed consistent disagreements, we coded 25% of the data set in pairs and determined interrater reliability (IRR) using Cohen's kappa, discussing all disagreements to consensus. The average kappa across pairs was 0.84 (SD = 0.02). We then coded the rest of the data set independently, with two key exceptions. First, two researchers always independently analyzed and discussed to consensus segments of class in which students worked on more than one task within the same time frame (see details in supplemental material). This was important because these instances often spanned several minutes, and therefore inconsistencies in how we coded them could have large impacts on the results. When students worked on multiple tasks in one time frame, we had to make assumptions to quantify the length of time dedicated to *active* versus *constructive* tasks. We assumed tasks at the same level demanded equal time, whereas tasks at a higher ICAP level demanded twice as much time. For example, if an instructor asked students to work on three tasks in 10 min, including two active and one constructive task, we assumed that each active task spanned 2.5 min and the constructive task spanned 5 min. Second, researchers regularly reconvened to code one class period to consensus and determine IRR. In total, two or more coders analyzed 33.5% of the data set (56 complete videos). This approach ensured high and consistent IRR over time and across coders, with each coding pair achieving Cohen's Kappa > 0.80 (mean IRR for all coder pairs [$n = 56$ videos] = 0.86, SD = 0.01).

Statistical analysis

We used descriptive statistics to characterize the opportunities that instructors created for students to engage in intellectual work. We identified the proportion of time across all recorded class sessions that an instructor provided opportunities for students to work on *active*, *constructive*, and *interactive* tasks by dividing the number of 15-s segments at each level by the total number of 15-s class segments recorded. We determined means, medians, 95% confidence intervals (CIs), and ranges for each level of work and total active-learning time (*active* + *constructive* + *interactive* time). We considered total time because it facilitates comparisons that readers might want to make to previous studies that have considered the proportion of class given to active learning (10, 25). Due to the rarity of *interactive* time in the data set, we collapsed *constructive* and *interactive* time into *generative* time, which describes the two highest ICAP levels (15, 25). We created plots to visualize the data, including violin plots and stacked bar charts.

We also examined the relationship between class time used for *generative* and *active* work. We explored whether the data suggested that instructors might use more or less of both (positive correlation) or trade out time spent on one for the other (negative correlation). Relatedly, we considered the ratio of class time spent in *generative* versus *active* work, and how this varied across classes, to start to understand how instructors might be allocating their active-learning time. This exploration recognizes a critique of the ICAP framework—namely, that classes will not neatly adhere to solely *active* or *generative* tasks, but rather include a mix (31), and that the most effective lessons might involve a mix of levels of intellectual work.

We also considered five factors that could be related to the use of active learning in undergraduate classrooms, including course- and instructor-level factors. First, at the course level, class size commonly enters discussions of active learning use. Prior work suggests that instructors of large classes spend more time lecturing (9, 32, 33). Second, peer learning assistants (LAs) have been proposed as a strategy for maximizing the impact of active learning. Students consider classes with learning assistants to be more interactive, fostering learning and peer discussion (34, 35). Third, teaching experience may relate to instructional practices, but the evidence is inconsistent. There may be an inverse relationship between teaching experience and active learning implementation (36) or no relationship at all (37). Fourth, the proportion of an instructor's appointment devoted to teaching may predict active-learning implementation, with teaching-centric faculty using more evidence-based practices and research-centric faculty using fewer (33, 36, 37). Finally, we examined teaching professional development experiences, as instructors who are involved in instructor communities focused on professional development may be more likely to implement student-centered teaching (38).

We fit simple linear regression models to examine the relationships between active-learning use and four of these factors. We tested for relationships between each factor and *generative* time, as well as total active-learning time. We conducted all analyses using Graphpad Prism (version 10.6.0, GraphPad Software, San Diego, CA, USA). For professional development, we conducted one-way analysis of variance (ANOVA) comparing the mean generative time and total time for instructors with three different professional development backgrounds: (i) instructors who had led teaching professional development, (ii) instructors who have completed 40+ h of teaching professional development, *but had not led teaching professional development*, and (iii) instructors who had done neither.

RESULTS

Every instructor in the study created opportunities in class for students to engage in *active* work (mean = 13.0% of class time, SD = 7.9%, range = 1.2–32.7%) and *constructive* work (mean = 13.4%, SD = 10.0, range = 2.1–41.7%), with considerable variability across the sample (Fig. 1 and 2). Only one instructor devoted time to *interactive* work, and this was limited to a single task (1.6% of total class time). Therefore, for subsequent reporting, we combine the opportunities created for *constructive* and *interactive* work

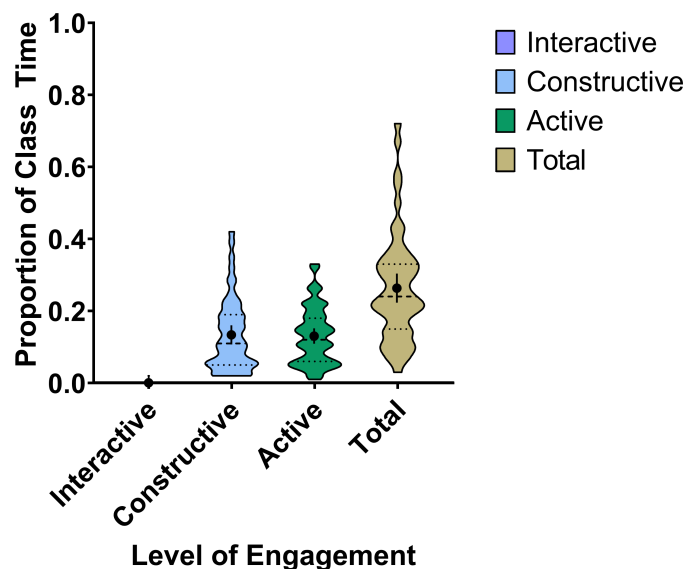


FIG 1 Proportion of class time in which students had opportunities for different levels of intellectual work. Violin plots show the distribution of class time that provided opportunities for students to engage in *interactive*, *constructive*, and *active* work. Total represents the sum of these (i.e., total proportion of class time in any active learning). Violin width indicates distribution, with wider areas representing values with more instructors. Dashed lines in violins represent quartiles, with the thicker dashes indicating the median. Black dots represent means, and black vertical bars represent 95% confidence intervals.

into *generative* work. Irrespective of intellectual work, instructors used 26.4% of class time (SD = 15.0%) for either *active* or *generative* work, ranging from 3.3% to 71.4% of class time (Fig. 2).

The proportion of class time dedicated to *active* opportunities significantly correlated with class time dedicated to *generative* opportunities ($\beta = 0.47$, 95% CI: 0.15, 0.79, $P = 0.0047$, Fig. 3). Thus, if an instructor gave an additional 10% of class time to *active* work, we would expect them to also give an additional 4.7% of class time to *generative* work, on average. Still, this association was modest, with only 14% of the variance in *generative* time predicted by *active* time ($R^2 = 0.14$). We also examined plots (Fig. 3; Fig. S1 and S2) and calculated the ratio of time that instructors provided for *generative* work compared to *active* work. This ratio ranged from 0.09 *generative* to *active* (i.e., 11 times as much time given to *active* work as *generative*) to 4.5 times as much *generative* time as *active*. The median ratio was 1.14, which corresponds to about 8 min of *generative* work for every 7 min of *active* work time. Sixty percent of instructors ($n = 33$) used ratios of 1.0 or higher, meaning equal or higher *generative* time than *active* time, and extreme ratios in either direction were rare (Fig. 2; Fig. S2).

We next considered whether course- and instructor-level factors predicted the opportunities created for *generative* work or total active-learning time. None of the factors that we investigated predicted instructors' use of *generative* work time nor total active-learning time (Table S3 and S4), including class size, teaching experience, position type, and the use of learning assistants.

DISCUSSION

Introductory biology courses in this study provided students with a range of opportunities for intellectual work. All participants identified as active-learning instructors, and each course devoted time to tasks requiring *active* and *generative* intellectual work. Some classes provided only rare active learning opportunities (i.e., 3.3% of 15-s intervals) and others provided extensive opportunities (i.e., 71.4% of 15-s intervals), with an average of about a quarter of class time for active learning (i.e., 26.4% of 15-s

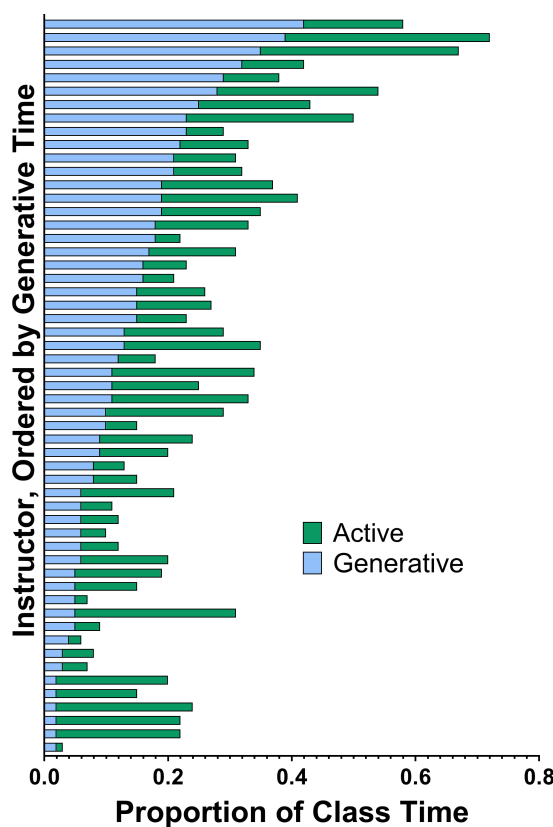


FIG 2 Total proportion of class time created for *generative* and *active* intellectual work, by instructor. Stacked bar plots of each participant's average proportion of class time that created opportunities for *generative* (blue) and *active* (green) intellectual work, ordered by time for generative work, from lowest to highest starting at the bottom of the y-axis. Generative encompasses both constructive and interactive intellectual work since the latter was so rare in the data set.

intervals). This is similar to a large-scale study, including 179 biology instructors, in which instructors lectured in roughly 75% of 2-min class intervals (9). Notably, we studied only instructors who identified as using active learning, whereas prior work did not (9). This suggests that instructors who consider themselves to be active learning instructors may not use appreciably more active learning than the average instructor who participates in education research.

One important question for the field and instructors to consider is how much active learning is enough to maximize gains for students. Is 25% of class time, the average in this sample, sufficient? Few studies have examined active learning dosage, but one carefully designed study tested doses of 10%, 15%, 20%, and 36% of class time devoted to active learning and determined that each dose significantly outperformed lower doses (39). If that finding generalizes to other classrooms, many of the active-learning instructors in this study could further enhance student learning by expanding active-learning time. The same study established that doses of misconception-focused instruction—in which instructors directly attend to common student ideas that differ from canonical scientific knowledge—enhanced learning gains even more than active-learning alone, and this was true at each dose of active learning (39).

Applying the ICAP framework allows researchers to make further distinctions about the intellectual work opportunities available to students. In this study, courses varied widely in the relative time dedicated to *active* versus *generative* work, which means that the learning opportunities varied considerably for students. The chance to engage in more generative work can translate into deeper learning and better ability to transfer knowledge (17, 18)—both of which college faculty commonly aspire to promote

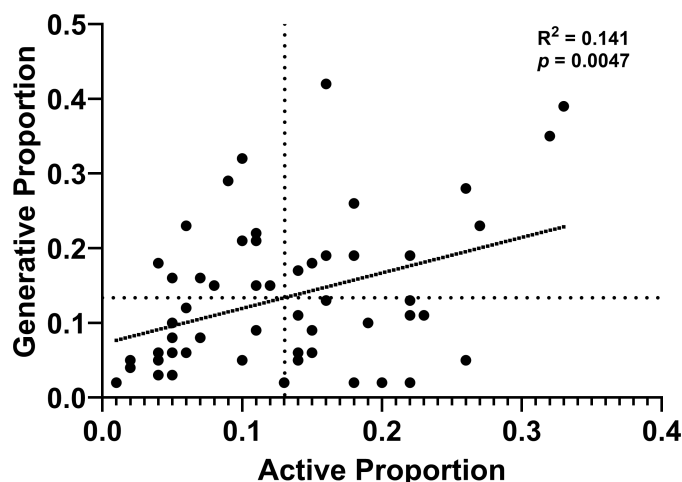


FIG 3 Relationship between proportion of class time in which instructors created opportunities for *generative* and *active* intellectual work. A scatter plot demonstrates the time given to opportunities for intellectual work at the *active* level on the X-axis and the *generative* on the Y-axis. A single point represents the proportion of class time a single instructor gave to intellectual work at each level. Vertical and horizontal dotted lines represent the mean proportion of class time for *active* and *generative* time, respectively. This creates quadrants representing above- and below-average class time dedicated to active and generative opportunities. For example, instructors in the top right quadrant dedicated a higher-than-average proportion of class time to both *active* and *generative* work. A diagonal line represents a simple linear regression between proportion of class time dedicated to active and generative time (linear regression equation: $y = 0.47x + 0.0072$, $P = 0.0047$).

through their teaching. Given the observed variation, characterizing these courses as “active learning” obscures important differences in the learning opportunities students likely experienced. Therefore, we propose that the field of biology education is ready to move beyond discussing active learning, instead characterizing the opportunities students have for intellectual work, how these opportunities impact student learning, in what sequences and contexts, and for whom. Together, our findings and prior research challenge the field to continue to critically consider the quantity and quality of active-learning opportunities that best serve students.

Classrooms that engage students solely in a single ICAP level are likely to be rare (31), but the field currently lacks sufficient empirical evidence to determine what ratios and sequences of different levels of intellectual work best support learning and in what scenarios. It is possible that introductory biology students need both *active* and *generative* learning opportunities. For example, *active* tasks may be effective at helping students memorize foundational information and processes that they could not infer, whereas *generative* tasks are likely to be more effective at developing conceptual understanding that equips students to successfully reason through questions they have not yet encountered (40–43). Thus, *active* tasks may serve an important role in scaffolding students toward *generative* tasks. Instructors could devote time at the beginning of class to *active* work or hold students accountable for completing *active* work prior to class to allow class time for students to work on more challenging *constructive* tasks and engage in *interactive* work together (44–47). Future work is needed to determine how combinations and sequences of *active*, *constructive*, and *interactive* opportunities help biology students meet different learning objectives.

The *interactive* code was exceptionally rare in our study, yet we see promising avenues for increasing *interactive* opportunities in biology courses. Even instructors who were exposed to the ICAP framework and asked to create *interactive* in-class activities struggled to do so. They tended to ask students to “work together” and “collaborate,” which can prompt group work but falls short of fostering *interactive* work (48). However, students respond to specific instructions, so small changes to the directions that

instructors provide to students could create more *interactive* opportunities. For example, when an instructor intentionally directed students to “focus on the reasons for your answers” instead of just asking them to “discuss your answers” before they worked on challenging clicker questions in groups, students had more discussions that contained reasoning connected to evidence (30). Specific language to cue *interactive* work could include “challenge or confirm your partner’s ideas” and “debate this question to see if you come to consensus or feel committed to different ways of thinking about it” (48, 49). Many of the courses that we studied were poised to increase the level of intellectual work because students spent time working in groups on *constructive* tasks. Therefore, we see potential for relatively small instructional change (i.e., different instructions) to enhance students’ learning opportunities.

This work has a few implications for future research. First, it demonstrates the potential of an ICAP-focused observation protocol to characterize the quality of learning opportunities in undergraduate classrooms. Future research can generate novel and actionable insights by studying how the level of intellectual work relates to student outcomes. Existing evidence establishes the potential positive impacts of active learning (8, 10) and advancing our collective knowledge requires that we next explore the nuance of active learning. Second, this work suggests that obvious instructor- and course-level variables cannot reliably predict the intellectual work opportunities created for students. Instructors with a range of class sizes, work effort dedicated to teaching, and experience with teaching and teaching professional development created extensive—and not so extensive—opportunities for *active* and *generative* work. These factors are therefore unconvincing as an excuse or a solution for the amount and type of active learning that instructors use.

For instructors, we propose that the ICAP framework, as defined in the introduction, is a useful heuristic for designing and adapting active-learning activities. We propose that which active-learning strategy you use (i.e., clickers and group work) (3) is less important to student learning than the opportunities for intellectual work created by the strategy (14, 48). We offer two questions that instructors could ask themselves as they design and implement active learning. (i) Does this task (e.g., problem, question, and case) require students to produce something beyond what has been presented to them (e.g., an explanation, interpretation, prediction, and visual representation)? (ii) Have I specifically directed students to engage in back-and-forth dialog to build on each other’s ideas, using verbs like “debate” and “build upon”? Importantly, open-ended exam questions much more often assessed higher level intellectual work than closed-ended questions (e.g., multiple choice) (24), suggesting that implementing more open-ended questions in class activities is likely to provide more opportunities for higher levels of ICAP work. The supplemental materials include example activities at multiple ICAP levels for topics commonly taught in introductory biology courses (Table S5) and a self-evaluation resource as an aid to instructors who want to design or adapt activities to provide opportunities for higher levels of intellectual work (Appendix C).

We hope the reader will carefully consider the limitations of this work. First, participants all taught courses with 50 or more students. Though we observed no relationship between class size and active-learning opportunities, instructors of smaller classes may devote class time differently. Second, participants volunteered to be a part of an involved study with multiple forms of data collection, a decision that may reflect particular interest in teaching. As further support of this, 78% of participants reported that they had completed over 40 h of teaching professional development. These instructors may be more likely than average to use evidence-based teaching practices in the classroom, limiting our ability to generalize these findings to the broader population of instructors. Third, we analyzed three class periods per participant, which may not fully represent the opportunities their course created for intellectual work at different levels. For example, an instructor could devote time early in a semester to providing guidance in support of *interactive* group work, which students quickly learned to enact, and therefore the instructor provided only sporadic reminders later in the semester (50). In that case,

students may frequently engage in *interactive* intellectual work on *constructive* questions, and this would not be captured by our analysis.

Conclusions

The potential—and considerable—benefits of active learning were demonstrated over a decade ago in a meta-analysis by Freeman et al. (8), and yet our operationalization of active learning has advanced little since that time. We propose, drawing on the work of others and these findings, that “active learning” is no longer a useful concept in biology education research and that we can better serve students by distinguishing between the passive, active, constructive, and interactive opportunities for intellectual work in college classrooms. Only with finer demarcations can we hope to advance knowledge of how to best support our students in developing deep disciplinary expertise. We hope this work offers one step toward more clearly defining and operationalizing active learning.

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Benjamin D. Jackson, Formal analysis, Methodology, Project administration, Visualization, Writing – original draft, Writing – review and editing | Cristine Donham, Conceptualization, Methodology, Writing – review and editing | Tessa C. Andrews, Conceptualization, Funding acquisition, Project administration, Supervision, Writing – review and editing

ETHICS APPROVAL

This work was determined by the Institutional Review Board at the University of Georgia to be exempt (PROJECT00000297).

ADDITIONAL FILES

The following material is available [online](#).

Supplemental Material

Supplemental material (jmbe00284-25-S0001.docx). Appendices A to C, Tables S1 to S5, and Fig. S1 and S2.

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