Classroom observations to characterize active learning within introductory undergraduate science courses

Supplemental Material

Pages 1-6: Example instructor report generated from Teaching Dimensions Observation Protocol (TDOP) data.

Pages 7-10: Additional information regarding participating courses, data collection, and statistical analyses for this study.

Figures and Tables

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Page 13: **Table 3.** Percentage of all two-minute intervals that a Teaching Dimensions Observation Protocol (TDOP) code was observed across all class periods for individual revised introductory science courses.

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Instructor Report
Spring 2014

Observation Process

The Teaching Dimensions Observation Protocol (TDOP) was chosen to observe instructional behaviors in classrooms. A web-based version of the TDOP was used for coding. With data collected over the next four years, researchers will be able to evaluate changing pedagogies in science classes at our institution.

When researchers entered a classroom, they first recorded the instructor name, date, course and department name, class size, and noted the physical layout of the room before coding the lesson. Once the class officially started, researchers began coding in two-minute intervals. As the codebook instructs: "The coding process involves marking a particular code when it is observed. A behavior needs to occur for more than 5 seconds to be coded. If a behavior lasts past the conclusion of one interval and runs into the next, make sure to code it twice" (Hora, Oleson, & Ferrare, 2013). For each interval, a note section also existed to record detailed notes of aspects that were pertinent but are not captured by the TDOP codes, or to explain a coding choice for future reference.

The TDOP includes four categories: Teaching Methods, Pedagogical Moves, Student-Teacher Interactions, and Cognitive Engagement of the students. In the following charts, percentages in each of the four categories do not add up to 100% because two behaviors from one category can occur in the same two-minute interval. For example, a professor has been lecturing with handwritten visuals on the chalkboard, and then gives the students small group work: the first activity can finish and the second activity begins within the same two-minute interval, leading to an overall percentage of two-minute intervals greater than 100%. Similarly, a behavior from each category does not have to occur, potentially causing the percentages to add up to less than 100%.

Reporting Results

This report provides the results from an individual professor's course observations as well as aggregate departmental data (e.g., chemistry, mathematics, biology) and summaries for all courses that were observed during the Spring 2014 semester. This approach allows faculty to contextualize their own pedagogical methods within the broader framework of other courses within the Natural Sciences Division. Although the TDOP collects data on a range of instructional behaviors, this report focuses on teaching methods, pedagogical moves, student-teacher interactions, and cognitive engagement.

Course Highlights

The most commonly observed instructor behaviors in this course included one-on-one interactions with the students (65% of all 2-min intervals) and moving among the students (39%).

During class, students were frequently observed doing small group work (75%), problem solving (74%), interacting with their peers (72%), and passive listening (33%).

Course Title: Chemistry	
Instructor	xxx
Term	Spring 2014
Course Type	Lecture
Course Level	Lower
Submitted Module?	Yes

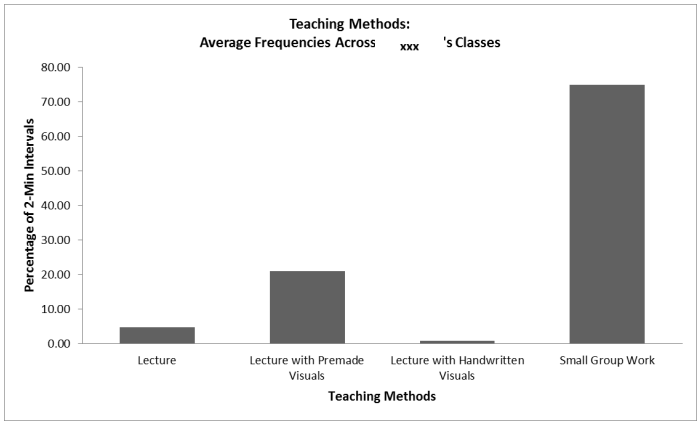
Classes Observed in Spring 2014

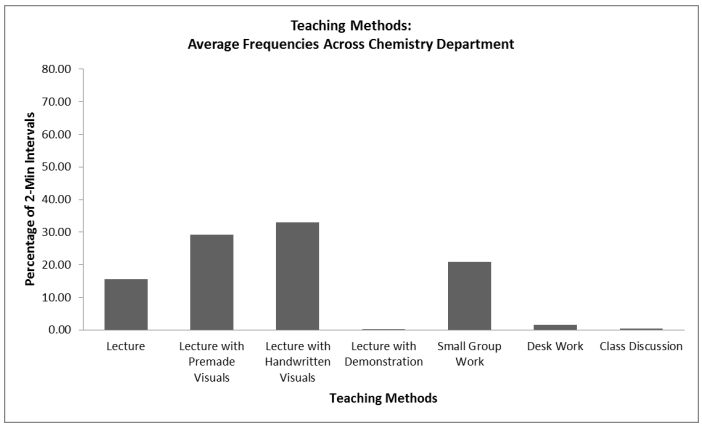
	Department	Level	Type
1	Biology	Upper	Lecture
2	Chemistry	Upper	Lecture
3	Chemistry	Lower	Lecture
4	Chemistry	Upper	Lecture
5	Mathematics	Lower	Lecture
6	Mathematics	Upper	Lecture

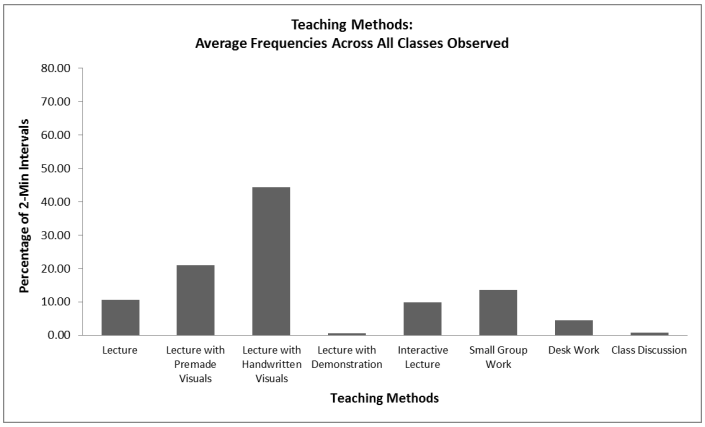
Major Findings for All Observed Classes

Different types of lecturing are the dominant teaching methods in use

- The most commonly observed teaching method was lecturing, with different types of lecturing occurring during 86% of class time. *Lecture with handwritten* (writing on the chalkboard) or *premade* (PowerPoint slides) *visuals* were the most common, occurring in 44% and 21% of class time, respectively. Traditional *lecturing* (without visuals or other methods of engaging the class), *interactive lecturing* (engaging the students in the lecture with an extended question and answer session), and *lecture with demonstration* (using equipment such as computer simulations, physical objects, or lab equipment) accounted for the additional 21% of lecturing time.
- The use of lecturing differs between departments, suggesting that some material is easier to present with lecture than other material or that pedagogical changes have already been incorporated into some departments to lessen the class time spent in lecture. Classes heavier in mathematical content were more likely to use *small group work* and *lecture with handwritten visuals* than those that were in the life sciences.
- For classrooms in which lecturing was not the singular method of instruction, *small group work* was the primary or secondary teaching method.



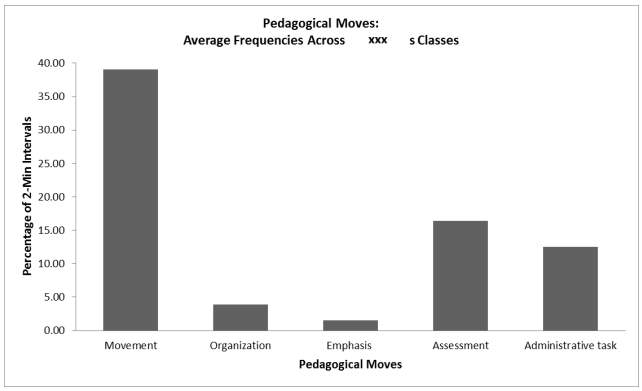


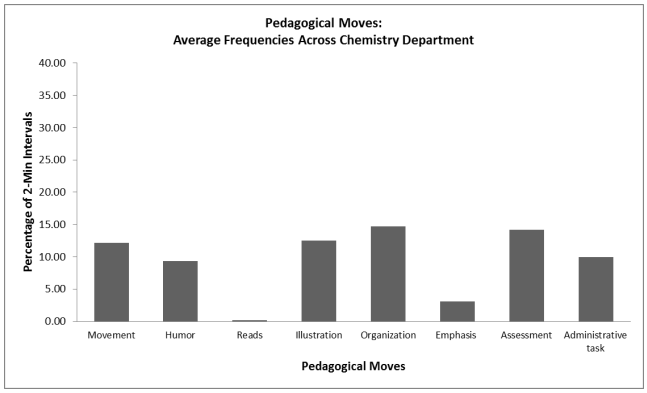


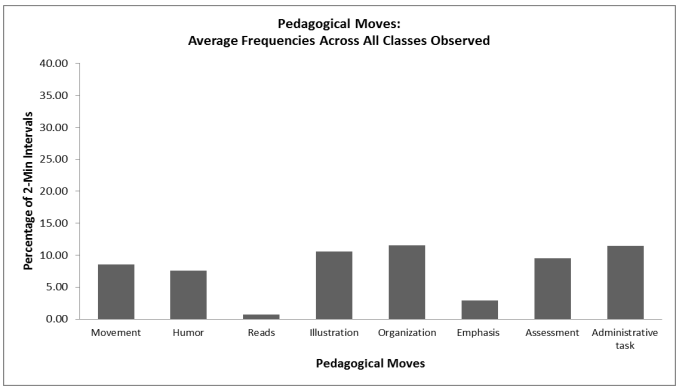
Different pedagogical strategies are being used

- Research suggests that teacher behaviors of *organization* and expressiveness (including *movement*, *humor*, and audible changes such as *emphasis*) are linked to increased and enhanced positive student scholastic behaviors (Schönwetter, Clifton, & Perry, 2002).
- *Organization*, coded when the instructor describes the outline of the class or indicates topic transition, was observed in similar frequencies across all three departments (i.e., biology, chemistry, and mathematics).

- *Movement*, which occurred in 9% of all two-minute intervals, frequently occurred with small group work, when the professor moved among the students while they worked. *Humor*, measured by student laughter to jokes or anecdotes, occurred in 8% of all two-minute intervals, on average. Instructor *emphasizing* course material by changes in tone or stating the importance of course material occurred in 3% of all two-minute intervals.
- *Illustrations* are real-world examples or pictures to further convey course material to students. *Illustrations* occurred more frequently in the Biology and Chemistry departments than in Mathematics. On average, this behavior occurred in 11% of all two-minute intervals.
- Though some *assessments* used to measure content-related knowledge from the students referred to quizzes, *clicker* questions make up the majority of the *assessments*. In general, the Chemistry Department used more assessments than Biology or Mathematics.

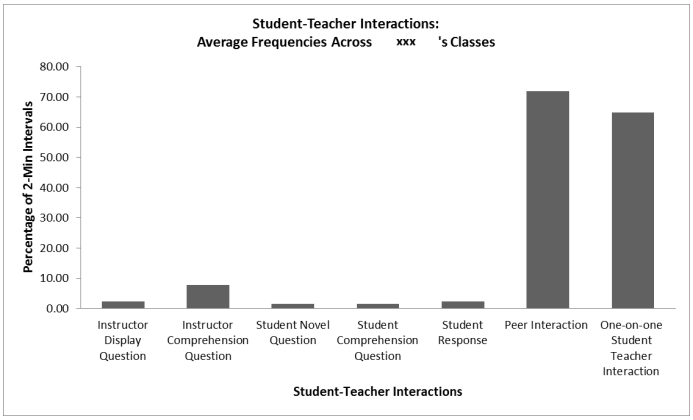


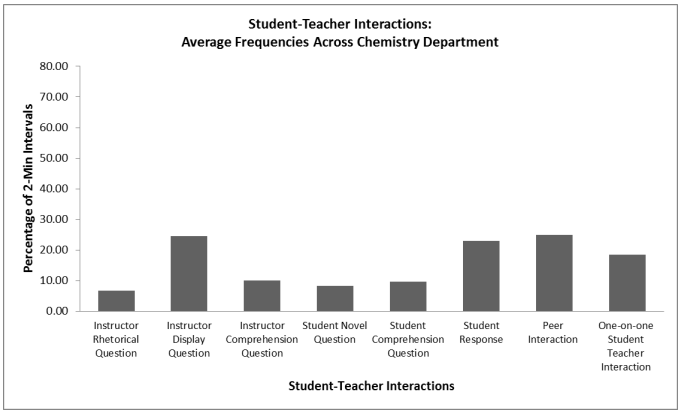


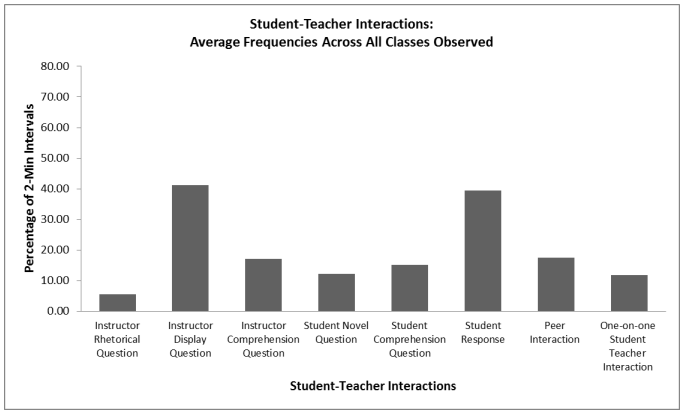


<u>Instructor questions and student responses embody student-teacher interactions</u>

- Instructors asked three different types of questions: *rhetorical* (where no answers are expected by the interlocutor), *comprehension* (checks for student understanding), and *display* (where original information is sought) *questions*. *Display questions* were the most commonly asked (41% of all two-minute intervals), followed by *comprehension questions* (17%), and *rhetorical questions* (6%).
- In response to the high number of *display questions* asked, the most common student interaction with instructors was *responding* to an instructor's question.
- Students asked questions to seek clarification on a concept covered in class (*comprehension question*) and to seek new information (*novel question*). On average, c*omprehension questions* (15%) occurred at about the same rate as *novel questions* (12%). Students in biology classes asked more *novel questions* (18%) than students in chemistry or math classes, whereas students in mathematics classes asked more *comprehension questions* (28%) then students in biology or chemistry classes.



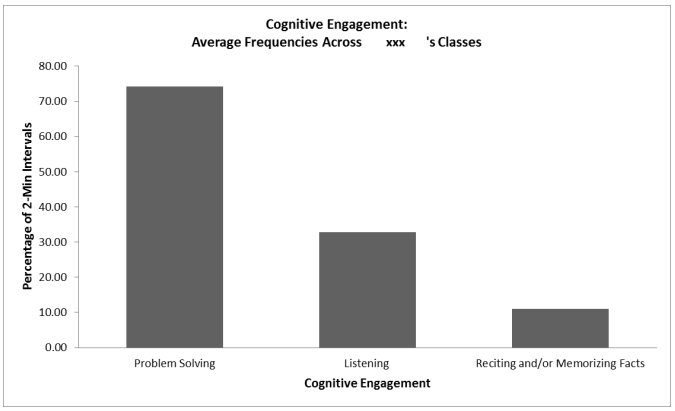


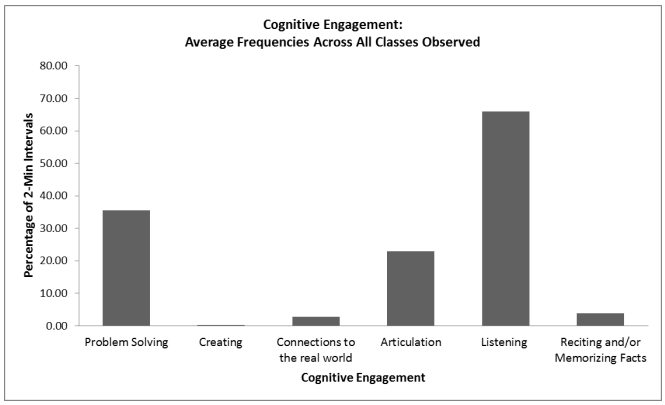


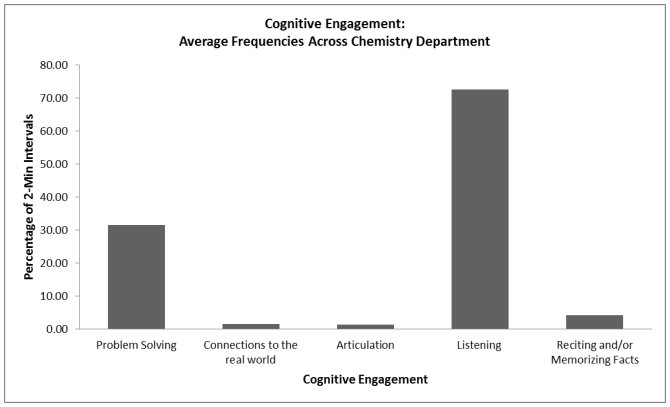
Cognitive engagement describes how students spend their time in class

This measure is inherently difficult, as observers cannot be certain how the students are engaging with the course material, such as during lecturing. Listening was a default mode of coding for this dimension, particularly during lecturing as the student is expected to listen silently and take notes, but observers cannot be sure if the students are listening or if they may be engaging in problem solving or connections silently. The dimension was measured by what students were observed engaging in, usually indicated by a physical action, such as speaking or writing, that could be observed.

- *Listening* occurred most often with lecturing, and was the most frequently observed student cognitive engagement, occurring, on average, in 66% of all two-minute intervals.
- *Problem solving* occurred when students apply, understand, and solve analytic processes, including computations and evaluations of conceptual dilemmas. *Problem solving* occurred frequently with lecture with handmade visuals and small group work, which all occurred most often in classes with mathematical content.
- *Connections to the real world* are when students make connections between course material and their daily lives. *Connections* were observed more frequently in biology classes (7% of all two-minute intervals) than in math (3%) or chemistry (1%) classes.
- Student *articulation*—verbally expressing their thoughts, ideas, solution, or opinions— occurred more often in biology classes (92% of all two-minute intervals) than in math (14%) or chemistry classes (1%).







Differences in teaching exist across departments

The aggregated percentages conceal variations in observation data between departments.

- Types of lecturing differed across departments. *Lecturing with premade visuals* was observed more frequently in biology (35% of all two-minute intervals) and chemistry (29%). *Lecturing with handwritten visuals*, in contrast, was more heavily utilized by math (70%). *Interactive lecture* was observed most in biology (41%).
- Chemistry was observed to most utilize *small group work* and *peer interaction* (21%, 25%), followed by math (11%, 17%).
- Pedagogical moves varied across disciplines as well. The use of *movement* occurred most often with *small group work*, and as such was observed most frequently in chemistry (12%). *Illustrations* and anecdotes were most frequently used by the Chemistry (13%) and Biology (12%) Departments.
- Questions seeking new information (*display question*) were most commonly asked by instructors in the Biology (66%) and Math (50%) Departments than in the Chemistry Department (25%). Questions checking understanding (*instructor comprehension questions*) were asked more in the Math Department (28%) than in Biology (15%) or Chemistry (10%).
- Biology students asked more questions seeking new information (*student novel question*) (18%), whereas math students asked more clarification questions (*student comprehension question*) (28%).
- Cognitive engagement varied by department also. *Passive listening* occurred more frequently in math (75%) and chemistry (73%) than in biology (34%). *Problem solving* was regularly observed in math (59%) and chemistry (32%), while *connection to the real world* (7%), and *articulating* (92%) were observed more frequently in biology.
- *Chalkboard* was observed to be the instructional technology of choice for math (60%) faculty, while *PowerPoint* was observed most in biology (41%). *Clicker* assessments were used more in chemistry (12%), and less frequently in math classrooms (3%). *Digital tablets* (primarily document cameras) were utilized by chemistry (39%) and math (23%).

Citations

Hora, M. T., Oleson, A., & Ferrare, J. J. (2013). Teaching Dimensions Observation Protocol (TDOP) user's manual. Wisconsin Center for Education Research.

Schönwetter, D. J., Clifton, R. A., & Perry, R. P. (2002). Content familiarity: differential impact of effective teaching on student achievement outcomes. *Research in Higher Education*, 43(6), 625-655.

Methods

Participating courses

Faculty were recruited by e-mail and self-selected into the study by allowing classroom observations within their introductory science courses. A summary of the courses included in this study is provided in Supplemental Material Table 1. Each course was classified as revised or unrevised with a course considered revised if the instructor had participated in a 2.5-day summer pedagogical workshop, created an active learning module for the class, and was using the module during the academic year when classroom observations were occurring. If a course did not meet these criteria, it was designated as unrevised.

The summer pedagogical workshop was facilitated by a nationally-recognized expert in active learning methods. Participants were provided with information about student-centered pedagogical techniques along with time and support to create active learning materials for one of their courses. Participants also had opportunities to discuss previous challenges and successes in using active learning and to present their initial course materials to other participants and the facilitator for feedback. Following the workshop, faculty completed their active learning course module and submitted it along with a short summary and written reflection on the experience. Modules varied in content but most contained components such as clicker questions, small group handouts, or videos and worksheets to "flip" the classroom. Submission of the module included a commitment by participants to integrate their materials into the designated course during the next academic year. Workshop participants were later surveyed to ensure they used the active learning module within their course.

Data collection using the Teaching Dimensions Observation Protocol (TDOP)

Two student observers participated in all suggested training outlined in the TDOP user's guide (Wisconsin Center for Education Research, 2014) to gain proficiency in the protocol. Following training, the research team observed two one-hour-and-15-minute class sessions to determine their inter-rater reliability (IRR). IRR was computed using Cohen's kappa, with values ranging from 0.86 for the Pedagogical Moves/Strategies TDOP category to 0.98 for the Instructional Technology category. One TDOP category, Student Cognitive Engagement, fell outside of that range with a Cohen's kappa value of 0.61. It has been

reported previously that IRR can be lower within this category of codes (Hora & Ferrare, 2013), particularly if observers do not have training in the disciplinary areas they are observing, which was the case here.

During a class period, observers sat toward the back of the classroom and used the online TDOP platform (Wisconsin Center for Education Research, 2010) to code behaviors and dialogue using predefined codes. Although the TDOP includes 57 possible codes, only 37 were used in this analysis. The observation data reported here were collected as part of a larger study, and numerous codes were omitted as the study progressed if they were seldom used or consistently had low inter-rater reliability.

Data analysis

Observation data were downloaded from the TDOP website then combined for individual courses within a spreadsheet. For a particular TDOP code, a "0" indicated that a behavior was not observed during a two-minute course interval, while a "1" indicated its presence. The proportion of two-minute intervals that a particular code was observed across all class periods for a given course was calculated and reported as a percentage. Results were compared among individual courses in the unrevised and revised categories then aggregated for further analysis (i.e., observations from Biology (ecology), Biology (cellular), and Computer Science courses were combined into a single "unrevised" category). The proportion of two-minute intervals that a particular code was observed across all class periods for a given course category (revised or unrevised) was subsequently calculated and reported as a percentage.

Statistical analyses were conducted using IBM SPSS Statistics, Version 24. A Pearson chi-square test examined whether there was an association between the type of course (revised or unrevised) and whether particular behaviors and dialogue were observed or not ($p < 0.05$). Two-proportion z-tests were used to determine whether the proportion of two-minute intervals that a code was observed in a revised course differed from the proportion observed in an unrevised course. Prior to conducting statistical analyses, two assumptions were met: samples were independent, and expected frequencies were greater than or equal to 5. If expected frequencies were less than 5, Fisher's exact test was used to determine if differences existed between proportions.

Hierarchical cluster analysis (HCA) was used to group student and faculty behaviors and dialogues based on similarities in the proportions of two-minute intervals observed within the classroom. Prior to the cluster analysis, nine TDOP Instructional Technology variables were removed, leaving 28 total variables. One HCA analysis was performed for revised introductory science courses and a second was conducted for unrevised courses. Between-groups linkage was used with Euclidian distance measurement intervals, and z-scores were used to standardize the variables. Results of the analyses were then visualized using dendrogram plots.

Following HCA analysis, dendrogram plots and TDOP code frequencies for revised and unrevised courses were compared to the instructional styles developed using the COPUS (Classroom Observation Protocol for Undergraduate STEM) by Stains et al. (2018): didactic, interactive, and student-centered (Figure S4; Stains et al., 2018, Supplemental Material). The TDOP and COPUS protocols both use 2-minute observation windows and share an 89% overlap between codes (Table S2; Stains et al., 2018, Supplemental Material) which facilitates application of the COPUS instructional profiles to TDOP data. COPUS instructional profiles are based on clustering of 2-minute interval frequencies for eight instructor and student codes. Frequencies for the corresponding TDOP codes in revised and unrevised courses were compared to average and boxplot values for the COPUS codes (Figure S4; Stains et al., 2018, Supplemental Material). Two COPUS codes, “group: worksheet” and “group: other”, have no corresponding TDOP code so frequencies of the TDOP “small group work” code for revised and unrevised courses were compared to those COPUS codes instead.

References

Hora, M. T., & Ferrare, J. J. (2013b). Instructional systems of practice: A multidimensional analysis of math and science undergraduate course planning and classroom teaching. *Journal of the Learning Sciences, 22*(2), 212–257.

Stains, M., Harshman, J., Barker, M.K., Chasteen, S.V., Cole, R., DeChenne-Peters, S.E.,…Young, A.M. (2018). Anatomy of STEM teaching in North American universities. *Science*, *359*(6383), 1468–1470.

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Supplemental Table 1
Summary of revised and unrevised introductory science courses observed using the Teaching Dimensions Observation Protocol (TDOP).

Status	Course	Term	Students enrolled	Professor[a]	Class periods observed	2-min intervals
Revised	Chemistry I	Fall 2013	27	A	7	171
	Chemistry I	Fall 2013	28	B	5	120
	Chemistry II	Spring 2014	25	B	5	128
				Revised total	17	419
Unrevised	Biology (ecology)	Fall 2013	25	C	5	131
	Biology (cellular)	Fall 2013	25	D	13	308
	Computer Science	Fall 2014	17	E	6	228
				Unrevised total	24	667

[a] Letters denote the course professor. The same letter across semesters indicates the course had the same instructor.

Supplemental Table 2
Percentage of all two-minute intervals that a Teaching Dimensions Observation Protocol (TDOP) code was observed across all class periods for individual unrevised introductory science courses.

Category	Unrevised Course 1[a]	Unrevised Course 2[a]	Unrevised Course 3[a]
Instructor-focused teaching methods			
Lecturing	9.9	5.5	26.3
Lecturing with pre-made visuals	71.8	81.5	11.4
Lecturing with handwritten visuals	5.3	7.8	51.3
Lecturing with demonstration	2.3	1.0	12.3
Interactive lecture	3.0	2.9	0.4
Assessment	0.0	8.4	7.5
Administrative task	18.3	14.0	14.5
Multimedia	9.2	2.0	0.0
Instructor-led dialogue			
Instructor rhetorical question	12.2	1.6	1.3
Instructor display question	37.4	30.5	29.8
Instructor comprehension question	9.2	15.6	23.7
Pedagogical strategies			
Humor	19.1	14.9	1.8
Illustration	41.2	32.5	7.0
Organization	23.7	15.3	33.3
Emphasis	8.4	4.9	16.2
Instructional technology			
Chalkboard	9.9	11.4	24.6
Overhead projector	0.0	0.0	11.0
Power Point	63.4	82.5	0.9
Clickers	0.0	6.8	0.0
Demonstration equipment	0.0	0.3	0.0
Digital tablet	0.0	0.0	64.9
Movie	8.4	1.9	0.0
Simulation	0.0	0.0	0.0
Student-focused teaching methods			
Small group work	9.2	0.3	1.8
Deskwork	0.0	0.0	86.8
Student presentation	0.0	4.6	0.0
Class discussion	1.5	0.0	0.0
Student-led dialogue			
Peer Interaction	9.9	0.3	27.6
Student response	38.2	30.2	32.9
Student question	19.8	35.7	25.9
Student cognitive engagement			
Articulation	10.7	3.2	4.8
Passive listening	93.1	96.8	90.8
Recitation/Memorization of facts	0.8	3.2	0.0
Problem solving	0.8	2.6	86.8
Creating	2.3	0.0	0.4
Making connections	15.3	4.6	80.7

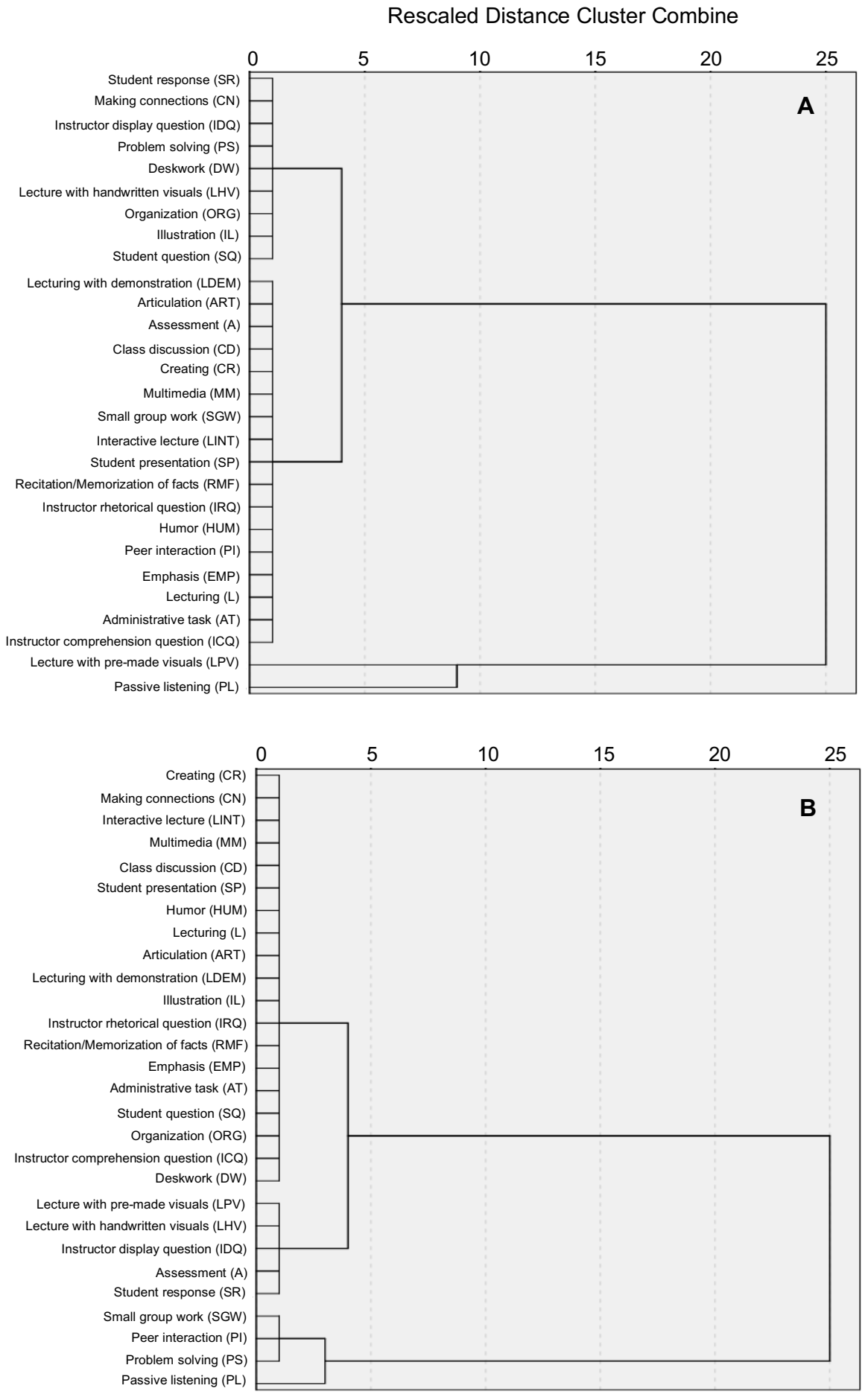
[a] Because more than one behavior may be observed during a two-minute interval, the sum of all percentages is greater than 100.

Supplemental Table 3
Percentage of all two-minute intervals that a Teaching Dimensions Observation Protocol (TDOP) code was observed across all class periods for individual revised introductory science courses.

Category	Revised Course 1[a]	Revised Course 2[a]	Revised Course 3[a]
Instructor-focused teaching methods			
Lecturing	2.3	3.3	4.7
Lecturing with pre-made visuals	35.1	10.0	21.1
Lecturing with handwritten visuals	39.8	25.0	0.8
Lecturing with demonstration	2.9	4.2	0.0
Interactive lecture	4.7	0.0	0.0
Assessment	19.3	30.8	16.4
Administrative task	11.7	11.7	12.5
Multimedia	0.0	0.0	0.0
Instructor-led dialogue			
Instructor rhetorical question	8.8	1.7	0.0
Instructor display question	46.8	12.5	2.3
Instructor comprehension question	8.2	10.8	7.8
Pedagogical strategies			
Humor	0.6	1.7	0.0
Illustration	4.7	0.0	0.0
Organization	13.4	14.2	3.9
Emphasis	9.4	4.2	1.6
Instructional technology			
Chalkboard	49.7	17.5	4.7
Overhead projector	0.0	0.0	0.0
Power Point	40.4	17.5	14.8
Clickers	15.2	6.7	5.5
Demonstration equipment	2.9	0.0	0.0
Digital tablet	11.1	22.5	18.8
Movie	0.0	0.0	0.0
Simulation	0.0	0.0	0.0
Student-focused teaching methods			
Small group work	49.1	71.7	75.0
Deskwork	5.8	18.3	0.0
Student presentation	0.6	0.0	0.0
Class discussion	0.0	0.0	0.0
Student-led dialogue			
Peer Interaction	49.7	68.3	71.9
Student response	43.3	10.0	2.3
Student question	9.9	25.8	3.1
Student cognitive engagement			
Articulation	7.6	0.0	0.0
Passive listening	68.4	37.5	32.8
Recitation/Memorization of facts	2.3	0.8	10.9
Problem solving	66.7	73.3	74.2
Creating	0.0	0.0	0.0
Making connections	0.0	0.0	0.0

[a] Because more than one behavior may be observed during a two-minute interval, the sum of all percentages is greater than 100.

Figure 1


Rescaled Distance Cluster Combine
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15
20
25
A
Student response (SR)
Making connections (CN)
Instructor display question (IDQ)
Problem solving (PS)
Deskwork (DW)
Lecture with handwritten visuals (LHV)
Organization (ORG)
Illustration (IL)
Student question (SQ)
Lecturing with demonstration (LDEM)
Articulation (ART)
Assessment (A)
Class discussion (CD)
Creating (CR)
Multimedia (MM)
Small group work (SGW)
Interactive lecture (LINT)
Student presentation (SP)
Recitation/Memorization of facts (RMF)
Instructor rhetorical question (IRQ)
Humor (HUM)
Peer interaction (PI)
Emphasis (EMP)
Lecturing (L)
Administrative task (AT)
Instructor comprehension question (ICQ)
Lecture with pre-made visuals (LPV)
Passive listening (PL)
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Creating (CR)
Making connections (CN)
Interactive lecture (LINT)
Multimedia (MM)
Class discussion (CD)
Student presentation (SP)
Humor (HUM)
Lecturing (L)
Articulation (ART)
Lecturing with demonstration (LDEM)
Illustration (IL)
Instructor rhetorical question (IRQ)
Recitation/Memorization of facts (RMF)
Emphasis (EMP)
Administrative task (AT)
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Lecture with pre-made visuals (LPV)
Lecture with handwritten visuals (LHV)
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