# Maintaining Student Engagement in an Evening, Three-hour-long Air Pollution Course: Integrating Active Learning Exercises and Flipped Classes

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## Abstract

Maintaining student engagement for three consecutive hours during an evening lecture-based course that meets once per week can be challenging. With the objective of enhancing student engagement, we integrated active learning interventions and four flipped classes in the evening, three-hour long senior-level air pollution control course at the Colorado School of Mines. The active learning interventions and flipped classes were purposefully placed throughout the course such that students were exposed to approximately one intervention each week. Active learning interventions included small-group exercises, student teaching exercises, and video-followed-by-discussion exercises. The four classes we selected to flip covered the following topics: particulate matter problem-solving techniques, indoor air pollution in developing countries, acid rain sources and effects, and carbon dioxide capture, transport, and sequestration. Students were issued a blind mid-course survey (n = 16 respondents) and an end-of-course survey (n = 9 respondents) to assess how effective the active learning interventions and flipped classes were in maintaining student engagement and teaching lesson objectives. On average, students responded that active learning techniques and flipped classes aided their understanding and helped them stay engaged. Students were also asked to comment on several specific active learning interventions and on each of the four flipped classes. Results concerning specific active learning exercises and flipped classes varied, as students indicated that some interventions were useful, while others were not. Specifically, students felt that the flipped class concerning indoor air pollution in developing countries was effective in keeping them engaged and helping them learn lesson objectives, while activities such as "team teach" exercises, where a team of students, on rotation, briefly introduced selected topics to their peers, were less effective in helping them learn lesson objectives. While examining the effectiveness of these active learning interventions and flipped classes with an increased sample size over several years is likely needed to determine statistical significance, our experience indicates that choosing the appropriate classes to flip and suitable active learning interventions is challenging and selected interventions may not be immediately effective. Nevertheless, a variety of learning techniques is likely beneficial to maintain student engagement in a three-hour evening lecture course covering a highly technical topic such as air pollution control.

## 1. Introduction

According to ABET's criteria for accrediting environmental engineering programs, air pollution, along with water, land, and environmental health, is a major focus area within environmental engineering curricula (ABET 2016). Successfully integrating each of the aforementioned focus areas into a program's curriculum can be difficult. Due to the busy nature of instructor and student schedules, some courses will invariably need to be taught in the evening or in larger blocks of time than a standard 55-minute lecture period. Maintaining student engagement in a longer evening course can be challenging. This study explores the integration of active learning interventions and flipped classes into a 3-hour, evening air pollution course, and gauges the effectiveness of these interventions in maintaining student engagement and teaching lesson objectives.

The use of active learning interventions and the prevalence of flipped classrooms have increased in recent years (Koretsky et al. 2015). While still not universally accepted, some studies suggest that both active learning interventions and flipped class approaches can increase student learning and performance (Freeman et al. 2014; O'Flaherty and Phillips 2015). Active learning interventions can be generally defined as any instructional method that engages students in the learning process (Prince 2004). Several core elements of active learning include student activity, student participation in the learning process, student reflection on ideas presented in the course curriculum, and regular assessment by students concerning their degree of understanding and handling concepts (Michael 2006; Prince 2004). According to Talbert (2015), flipped learning occurs when instruction moves from a group learning space to an individual learning space. The group space then becomes an interactive environment where the instructor guides students as they learn. The classroom component of flipped learning commonly involves active learning interventions (Berrett 2012; Bishop and Verleger 2013; Jamaludin and Osman 2014). Numerous examples of active learning interventions and flipped classes in STEM courses are available, and several studies have outlined approaches in environmental engineering and science courses. A non-exhaustive list of several such studies is provided in Table 1. Despite these examples, few readily available studies in published literature outline active learning interventions in air pollution courses and no readily available study discusses flipped classes in an air pollution course.

**Table 1**. A non-exhaustive listing of active learning interventions and flipped class approaches reported in environmental engineering and science courses. Full citations for each study are found in the references section.

| Type of Intervention | Authors | Year | Title |
|---|---|---|---|
| Active learning | Thatcher | 2007 | Incorporating Active Learning into Environmental Engineering |
| Active learning | Grauer & Grauer | 2010 | Automobile Emissions: A Problem Based Learning Activity Using the Clean Air Act |
| Active learning | Jones & Merritt | 2010 | Promoting active learning for interdisciplinarity, values awareness, and critical thinking in environmental higher education |
| Active learning | Hill & Nelson | 2011 | New technology, new pedagogy? Employing video podcasts in learning and teaching about exotic ecosystems. |
| Active learning | Cupples et al. | 2013 | The Use of Active Learning to Address ABET Course Learning Objectives in a Large Undergraduate Environmental Engineering Class |
| Active Learning | Luster-Teasley et al. | 2016 | Making the Case: Adding Case Studies to an Environmental Engineering Laboratory to Increase Student Engagement, Learning, and Data Analysis |
| Flipped class | Bielefeldt | 2013 | Teaching a Hazardous Waste Management Course using an Inverted Classroom |

## 2. Course Description and Student Demographics

Colorado School of Mines' air pollution course was designed to help students become familiar with air pollution issues, understand the basic chemistry behind major air pollutants, develop a working knowledge of engineered approaches used to mitigate the effects of common air pollutants, and prepare them for future air pollution work in the public or private sectors. The course introduced air pollution fundamentals, such as the ideal gas law, US legislation, the source, nature, and control of particulate matter (PM) and gaseous pollutants, indoor air pollution, and dispersion modeling. The course contained two projects, one of which involved aspects of PM pollution (visibility, emissions, deposition), while the other measured indoor air pollutant concentrations (see Pfluger et al. 2012 for project details). A major course objective was to prepare students for the Fundamentals of Engineering Exam and the Principles and Practice of Engineering Examination for Environmental Engineers, which currently contains 23 air pollution questions (NCEES 2011). During the Spring 2016 semester, in which students were surveyed, 5 masters-level graduate students and 14 undergraduates (junior and senior-level) were enrolled in the course. Of the 19 students, 17 were female and 2 were male. Each master's student enrolled in the air pollution course was a member of either the civil and environmental engineering program or the environmental engineering and science program, and each undergraduate student enrolled was an environmental engineering major. A formal survey of students' previous exposure to active learning interventions or flipped classes was not administered.

## 3. Motivation for Integrating Active Learning Interventions and Flipped Classes

The air pollution course at the Colorado School of Mines was initially taught in the Spring 2015 semester as a 3-hour long, lecture-based, evening course that met once per week. Year-end surveys and anecdotal student comments from first year of teaching the evening course indicated that the 3-hour time period was long and that students had problems maintaining the appropriate level of attention required to learn the material. Students also stated that more group interaction and active learning would be a welcome modification and would help them stay engaged. While some group activities were included in the course, there was no deliberate plan for integrating active learning interventions or flipped classes during the first year the course was taught.

## 4. Active Learning Interventions and Flipped Classes

Active learning interventions and flipped classes were developed such that students experienced at least one intervention per week (i.e. per three-hour class period). Students enrolled in the air pollution course attended 14 three-hour class sessions (over 17 weeks), which were divided by topic area. The following paragraphs briefly introduce the active learning interventions and flipped classes integrated into the 14-session course curriculum. Table 2 provides a list of where each intervention was presented in the curriculum.

Active learning interventions were developed using the following techniques: small-group exercises, interactive problem-solving sessions, hands-on equipment demonstrations, video-followed-by-discussion exercises, student "team teach" presentations, and project group presentations. A total of 16 active learning interventions were integrated into the course curriculum. While Appendix A provides a description of each active learning intervention, defines the time required for each, and provides relevant references, a description of two active learning interventions, the "early atmosphere" small-group exercise and the "team teach" intervention, is provided here. The "early atmosphere" small-group exercise, given in the first lesson of the course, began with providing students several satellite images of Venus and Earth and asking students to think about why Venus' atmosphere developed differently from Earth's atmosphere. Several basic air pollution terms, such as atmosphere, air, weather, and climate were then defined for the students. Students were subsequently broken into groups of 4 or 5 and given 10 minutes to think through how the Earth's present-day atmosphere developed. Students were asked not to look up the answer on the internet, but to think through how major gases ($N_2$, $O_2$, Ar, etc.) came to have appreciable concentrations in our atmosphere and why these gases did not develop on Venus. Each group then discussed their response with the rest of the class. The "team teach" approach was designed such that a group of 4-5 students would introduce a gaseous pollutant to their peers at the beginning of the appropriate class period (see Table 2). Student groups selected a gaseous pollutant ($SO_x$, $NO_x$, VOCs, $O_3$) at the beginning of the course (i.e. Week 2) and the instructor posted relevant materials such as reading assignments, PowerPoint slides, and handouts to BlackBoard in advance. Students were expected to prepare for the "team teach" prior to class and then present the material at the beginning of the class for approximately 5 minutes. Introductory material that students presented for each gaseous pollutant included pollutant sources, human health effects, environmental effects, and applicable regulations (e.g. the National Ambient Air Quality Standards).

A total of 4 flipped classes were integrated into the course curriculum (full descriptions available in Appendix A). Topics for flipped classes were selected by the instructor to cover a range of subjects that were both conceptual and quantitative in nature. The instructor also considered the following factors in selecting topics for flipped classes: availability of literature (i.e. recently published relevant journal articles), perceived student interest in the topics, and placement of the flipped class in comparison to other interventions. Of the four topic areas selected, the PM problem-solving lesson was the most quantitative and the indoor air pollution in developing countries lesson was the most conceptual (i.e. contained no equations or problems). The carbon capture, transport, and sequestration lesson contained several topics that most students had not yet been exposed to in their environmental engineering education, and the acid rain sources and effects lesson contained the most chemical reactions of the four lessons. All lesson materials were posted to our university's online Blackboard site at the beginning of the semester for student review and preparation prior to the flipped classes (see Appendix A).

**Table 2**. Active learning interventions and flipped classes integrated into the course curriculum by week. Active learning interventions are annotated with an "I" (i.e. I1 – I16) and flipped classes are annotated with a "F" (i.e. F1 – F4).

| Week | Air Pollution Subject Areas | Intervention / Flipped Class |
|---|---|---|
| 1 | History, Structure of Atmosphere, and Legislation | I1: Early atmosphere small-group exercise |
| 2 | Introduction to Particulate Matter (PM) & Nature of PM | I2: Nature of PM interactive problem-solving exercise |
| 3 | PM Control – Cyclones and Baghouses | I3/I4: Cyclone and baghouse interactive problem solving exercises |

| | | |
|---|---|---|
| 4 | PM Control – Electrostatic Precipitators (ESPs) and Scrubbers | I5/I6: ESP and scrubber interactive problem-solving exercises |
| 5 | No Class (President's Day) | N/A |
| 6 | PM Review, Exam Preparation, and introduction to Ideal Gas Law | I7: FE & PE exam preparation question & answer period<br>F1: PM problem-solving lesson |
| 7 | Midterm Exam | N/A |
| 8 | Gaseous Pollutant Introduction, Nitrogen Oxides ($NO_x$), Ozone | I8/I9: Team teach: $NO_x$ and Ozone |
| 9 | Spring Break | N/A |
| 10 | Volatile Organic Compounds (VOCs) | I10: Team teach: VOCs |
| 11 | Mobile Pollutant Sources & Sulfur Dioxide Control | I11: Team teach: $SO_x$<br>I12: Mobile source video and exercise<br>F2: Acid rain sources and effects |
| 12 | Indoor Air Pollution (IAP) | I13: Hands-on IAP equipment<br>F3: IAP in developing countries |
| 13 | Project Compensation Time | N/A |
| 14 | Carbon Control & Stratospheric Ozone | I14: Pre- and Post-industrial carbon balance exercise<br>F4: Carbon capture, transport, sequestration |
| 15 | Dispersion Modeling | I15: Indoor air pollution project presentations |
| 16 | Noise Pollution, Current Topics in Air Pollution, and Course Review | I16: Current topic in air pollution presentations |
| 17 | Final Exam | N/A |

## 5. Survey Methods

Students were issued two surveys, one at the course mid-point and one at the course conclusion, to assess the effectiveness of the active learning interventions and flipped classes on a 5-point Likert scale (5 = strongly agree, 4 = agree, 3 = neither agree or disagree, 2 = disagree, 1 = strongly disagree). The mid-course survey was issued so that students could provide responses concerning several active learning interventions and one flipped class while the interventions were still fresh in their mind. Between the two surveys, students were asked to respond and/or comment on several specific active learning interventions and on each of the four flipped classes. Both surveys were kept to 10 questions in length, which allowed for the instructor to assess some interventions, but not each in depth. On each survey, several general questions regarding student perceptions of active learning interventions and flipped classes were posed prior to surveying specific interventions. Further, several open-ended questions concerning flipped classes were posed to students on the end-of-course survey. Each question posed is included in Appendix B. Responses to open-ended questions posed on the end-of-course survey are found in Appendix C. The surveys were not discussed in class to keep student responses unbiased; however, the instructor did state that the purpose of the surveys was to gauge how students learned using the active learning and flipped class techniques, and that their responses would measure the effectiveness of each surveyed intervention. To ensure full student anonymity, the survey was conducted outside of the Blackboard environment using Survey Monkey; the instructor did not administer the survey and only saw anonymized results after the end of the semester. We also incorporated relevant comments from our institution's anonymous student course-end survey in our analysis (Appendix D).

**6. Assessment of Student Responses**

Of the 19 students enrolled in our air pollution course, 16 elected to respond to the mid-course survey and 9 responded to the end-of-course survey. Up front, students were first asked on the mid-course survey if they preferred a lecture-based format for learning air pollution topics, or if they prefer discussion-based formats (i.e. an active learning or flipped format) for air pollution topics. Responding students indicated a preference for a lecture-based format (4.00/5.00 mean Likert score) to a discussion-based format (3.19/5.00 mean Likert score). A student preference for traditional lecture formats is common, especially with students who may be unfamiliar with the flipped class approach (Mason et al. 2013).

In general, students indicated that the active learning interventions aided in their understanding and helped them stay engaged during the 3-hour time period. Between the mid-course and end-of-course survey, there was a slight uptick in student responses indicating that student perceptions of active learning interventions were more favorable after taking the entire course and being exposed to all 16 interventions (see Table 3). Specifically, a paired comparison of individual student responses between surveys indicated that 5 students who answered "agree" on the question "active learning techniques used in class have aided in my understanding of air pollution topics" on the mid-course survey switched their answer to "strongly agree" on the end-of-course survey. A similar uptick between surveys was observed when students were asked whether flipped classes helped students stay engaged and interested during the 3-hour time period (see Table 3); however, a paired comparison indicated little change in individual student responses between the mid-course and end-of-course surveys. At the mid-course survey, students had completed only one flipped class (PM problem solving), which may have influenced student responses. While more assessment data and a larger student population are required to determine statistical significance, student responses to both active learning interventions and flipped classes between the two surveys indicate an increasing trend in perceived effectiveness as they were exposed to more interventions.

Due to the large number of active learning interventions and limited number of survey questions, only 6 of 16 interventions were selected for student survey. Specifically, two less traditional small-group exercises, the early atmosphere small-group exercise and the pre- and post-industrial revolution carbon cycle small-group exercise, and the "team teach" approach for introducing gaseous pollutants were selected for survey. These specific interventions were selected over other interventions because each was newly developed for the semester in which students were surveyed, and the instructor was particularly interested in student perceptions of each. Student responses are summarized in Table 4. Students were asked two questions concerning the "team teach" approach, the first of which is found in Table 4. The second question asked if the intervention helped them stay engaged in interested during the three-hour class period. Student responses to this question were neutral (3.00/5.00 mean Likert score; 6 “agree” responses, 6 “disagree”, and 4 “neither agree or disagree” responses). Students also provided several critical comments concerning the “team teach” intervention on our institution’s course end survey (see Appendix D), indicating that the intervention was not beneficial and failed to help them learn the material.

**Table 3**. Change in student perceptions between the mid-point and end-of-course surveys concerning active learning interventions and flipped classes. Responses were recorded on a 5-point Likert scale. Mean scores from survey data are bolded and the number of student responses in each category are provided.

| **Question** | **Mid-course Survey Response** (n = 16 respondents) | **End-of-Course Survey Response** (n = 9 respondents) |
|---|---|---|
| The active learning techniques used in class have aided in my understanding of air pollution topics. | **4.00 of 5.00**<br>Strongly Agree = 4<br>Agree = 8<br>Neither Agree or Disagree = 4 | **4.33 of 5.00**<br>Strongly Agree = 5<br>Agree = 3<br>Disagree = 1 |
| The “flipped” classes helped me stay engaged and interested during the 3-hour time period allotted for this class.[1] | **3.31 of 5.00**<br>Agree = 8<br>Neither Agree or Disagree = 5<br>Disagree = 3 | **3.78 of 5.00**<br>Agree = 8<br>Disagree = 1 |

[1] A similar question was posed on the mid-course survey for active learning (i.e. active learning helped students stay engaged and interested), but was not asked on the course-end survey. Responses on the mid-course survey indicated that active learning classes kept students more engaged and interested than flipped classes (responses: strongly agree = 5, agree = 7, neither agree or disagree = 3, disagree = 1). This response may have been influenced by the fact that only one flipped class (PM problem solving) had been completed when the mid-course survey was issued.

**Table 4.** Student responses to questions concerning active learning interventions. The intervention number is listed (see also Table 1). Mean scores from survey data are bolded and the number of student responses in each category are provided.

| **Active Learning Intervention** | Intervention helped the student learn the concept |
|---|---|
| I1. Early atmosphere exercise<br>(n = 16 respondents) | **3.63/5.00**<br>Strongly Agree = 3<br>Agree = 8<br>Neither Agree or Disagree = 1<br>Disagree = 4 |
| I8 – I11. Team teach approach for introducing gaseous pollutants ($SO_x$, $NO_x$, VOCs, $O_3$)<br>(n = 16 respondents) | **2.69/5.00**<br>Agree = 4<br>Neither Agree or Disagree = 3<br>Disagree = 9 |
| I14. Pre- and Post-Industrial Revolution Carbon Exercise<br>(n = 9 respondents) | **3.33/5.00**<br>Agree = 5<br>Neither Agree or Disagree = 2<br>Disagree = 2 |

Students were asked to respond to two questions concerning each flipped class. First, students were asked whether the flipped class technique helped them understand the lesson objective. Second, students were asked if they would have preferred a standard lecture format for understanding the lesson objective. Responses for each flipped class are stated in Table 5. Based on mean Likert scores, students indicated that the flipped class was preferable to a lecture format for three of the four lessons: PM problem solving, acid rain sources and effects, indoor air pollution in developing countries. The only flipped class for which students would have preferred a standard lecture format was the carbon capture, transport, and sequestration lesson. This lesson contained several topics to which most students had not yet been exposed, such as transportation of liquid carbon dioxide and supercritical pulverized coal plants, which may have influenced student responses. Student preference for 3 of the 4 flipped classes indicates a shift from their initial responses regarding a preference on the mid-course survey for the traditional lecture format.

Students were also asked several open-ended questions concerning flipped classes on the end-of-course survey. Responses to each are provided in Appendix C. Specifically, students were asked whether or not they sought out and used additional material beyond what the instructor provided to prepare for the flipped classes. Of the nine respondents, only two stated that they had at some point. Students were also asked how long they prepared for the flipped classes. Responses varied, but each of the nine respondents indicated taking less than 1 hour to prepare, and the average preparation time was approximately 30 minutes. Responses to these questions indicate that the majority of students did not take significant time to prepare for the flipped classes, despite instruction that they needed to complete all of the assigned reading to adequately participate in class. Relevant comments concerning flipped classes were also extracted from our institution's standard course-end survey (Appendix D). Comments regarding flipped classes on this survey were mixed, with some students providing positive feedback (e.g. they liked the flipped class format or it helped them learn the material) (n = 7 comments), some providing neutral constructive feedback (e.g. the flipped class should be the last event in class because it was tough to transition back to regular lecture afterwards) (n = 5 comments), and some providing negative feedback (e.g. they disliked the flipped class format because it did not help them remember the material or they felt rushed) (n = 3 comments) (Appendix D). While it is difficult to extrapolate any specific trend from comments on our institution's course-end survey, the variety of comments concerning flipped classes indicates that the approach is impactful and many students gained some benefit from the interventions.

Several trends are observed from the student responses. First, as stated, the students' perception of the effectiveness of both the active learning interventions and the flipped classes increased from the mid-course survey to the end-of-course survey. Second, as indicated by student responses, some interventions were perceived as more effective in helping students learn the lesson objective than others. While most student responses were generally neutral or slightly favorable (i.e. mean Likert score between 3.0 and 4.0), the "team teach" intervention was less well received. Third, based on mean Likert score, students preferred the flipped class approach for three of the four selected topics. The only flipped class for which students preferred the traditional lecture format was one that introduced several new highly technical topics to which they had not been previously exposed.

**Table 5.** Student responses to questions concerning flipped classes. Mean scores from survey data are bolded and the number of student responses in each category are provided. Based on mean Likert score, students preferred the flipped approach for three of the four classes (PM problem solving, acid rain sources and effects, and IAP in developing countries).

| **Flipped Class** | Flipped class technique was helpful in understanding the lesson objective | Student preferred a standard lecture format for understanding the lesson objective |
|---|---|---|
| PM problem solving<br>(n = 16 respondents) | **3.69/5.00**<br>Strongly Agree = 2<br>Agree = 8<br>Neither Agree or Disagree = 5<br>Disagree = 1 | **3.13/5.00**<br>Agree = 6<br>Neither Agree or Disagree = 6<br>Disagree = 4 |
| Acid rain sources and effects<br>(n = 9 respondents) | **3.78/5.00**<br>Agree = 8<br>Disagree = 1 | **3.33/5.00**<br>Strongly Agree = 1<br>Agree =2<br>Neither Agree or Disagree = 5<br>Disagree = 1 |
| IAP in developing countries<br>(n = 9 respondents) | **4.00/5.00**<br>Agree = 9 | **3.11/5.00**<br>Strongly Agree = 1<br>Agree = 2<br>Neither Agree or Disagree = 3<br>Disagree = 3 |
| Carbon capture, transport, sequestration<br>(n = 9 respondents) | **3.22/5.00**<br>Agree = 4<br>Neither Agree or Disagree = 3<br>Disagree = 2 | **3.67/5.00**<br>Strongly Agree = 1<br>Agree = 5<br>Neither Agree or Disagree = 2<br>Disagree = 1 |

## 7. Integration of Student Feedback

Student survey data indicate that the active learning interventions and flipped classes, in general, were a useful addition to the course curriculum and were helpful in achieving some lesson objectives. However, not all interventions were viewed as effective, and in an effort to continuously improve (ABET Criterion 4), several modifications to the course will be made. First, the "team teach" intervention for introducing gaseous pollutants will be modified. Instead of asking small groups of students to prepare before class and teach their peers, students will break into small groups at the beginning of class and the instructor will pose a series of short questions. The questions will cover the material that was previously incorporated into the "team teach" and student groups will present answers to each question to their peers. Second, we will modify the flipped class on carbon capture, transport, and sequestration, which received the lowest Likert score from students concerning effectiveness of learning lesson objectives using the flipped class format. Instead of the reading from the Intergovernmental Panel on Climate Change and the reading assignment from the course text (see Appendix A), students will be provided with two or three current articles discussing carbon capture, transport, and sequestration technologies. In class, where student groups taught each other the main lesson objectives through discussion and course materials (e.g. PowerPoint slides), student groups will instead be given a scenario where they must develop a solution using relevant carbon capture, transport, and sequestration technologies from the reading. Third, to better determine the effectiveness of each intervention, students will be issued informal, anonymous surveys after each intervention to identify necessary changes. Issuing the survey immediately following the lesson will allow students to provide feedback while the intervention is still fresh in their minds, and will give the instructor the ability to make immediate adjustments to future interventions as required.

## 8. Conclusions

This study presents several active learning interventions and flipped classes that can be used in air pollution courses. Maintaining student engagement in courses with longer class periods, such as a 3-hour evening course, is important to student learning. There is no clear-cut approach to achieving this objective; however, results from this study indicate that selected active learning interventions and flipped classes may be a means to enhance student engagement and learning. Survey responses also indicate that students will view some interventions as effective in teaching lesson objectives, while others may be perceived as less effective (e.g. the "team teach" intervention). Some interventions were likely viewed as more effective for several reasons, which include the amount of time required for students to adequately prepare for the intervention outside of the classroom, the difficulty of the subject matter, and the quality of the intervention itself. Further, some students may prefer that engineering topics be taught in a more traditional lecture format, regardless of how well-designed or thoughtful the intervention may be. Our experience also indicates that choosing the appropriate classes to flip and suitable active learning interventions is challenging, but can increase student engagement and learning. Considerations for selecting an appropriate intervention should include the amount of time students are required to prepare outside of class, the amount of time the intervention takes within the class itself, relevancy to the lesson objective. Instructors may also find that flipping classes that cover conceptual material will better facilitate student learning rather than flipping classes with more quantitative material or material that introduces new or complex topics. The instructor should also place interventions such that they occur routinely throughout the course. Having multiple consecutive interventions, or periods with no interventions, may detract from student learning. Further, selected interventions may not be immediately effective and may require modification from year to year. Instructors should continually assess interventions they use in class, and ask students for frequent feedback. For interventions in our air pollution course, more student survey information, coupled with assessment data, collected over several years is likely required to determine which of the presented interventions are most effective and which interventions need to be modified or eliminated. Despite this, student feedback indicated that several interventions, such as the indoor air pollution in developing countries flipped class and the early atmosphere small-group exercise, show promise for improving student learning and keeping students engaged during long class periods.

**Appendix A.** Description of Active Learning Interventions and Flipped Classes

## Active Learning Interventions

### Intervention 1: Early small-group atmosphere exercise

*Description*: students were first presented with large-scale satellite images of Venus and Earth and asked why Venus' atmosphere is so different than Earth's atmosphere. Several terms were defined for the students, to include atmosphere, air, weather, and climate. Students were then broken into groups of 4 or 5 and are given 10 minutes to think through how the Earth's present-day atmosphere developed. Students were asked not to look up the answer on the internet, but to think through how major gases ($N_2$, $O_2$, Ar, etc.) came to have appreciate concentrations in our atmosphere. Each group then discussed their response. Time required for this intervention is approximately 20 minutes.

*External Resources Required*: None.

### Intervention 2: Nature of PM problem-solving exercise

*Description*: students were presented with example problems 3.2 and 3.3 from the Cooper Alley text. After instruction about how to approach the problem, students were broken into groups to finish solving the problem. The instructor answered questions and presented portions of the solution during the process. Time required for this intervention is approximately 20 minutes.

*External Resources Required:* Cooper, C. David & Alley, F.C. 2011. *Air Pollution Control: A Design Approach*, $4^{th}$ Edition, Waveland Press Inc.

### Intervention 3: Cyclone interactive problem-solving exercise

*Description*: students were presented with example problem 4.1 from the Cooper Alley text. After instruction about how to approach the problem, students were broken into groups to finish solving the problem. The instructor answered questions and presented portions of the solution during the process. Time required for this intervention is approximately 20 minutes.

*External Resources Required:* Cooper, C. David & Alley, F.C. 2011. *Air Pollution Control: A Design Approach*, $4^{th}$ Edition, Waveland Press Inc.

### Intervention 4: Baghouse interactive problem-solving exercise

*Description*: students were presented with a three-part example problem designed by the instructor that builds upon basic instruction from the Cooper & Alley text. After instruction about how to approach the problem, students were broken into groups to finish solving the problem. The instructor answered questions and presented portions of the solution during the process. An Excel spreadsheet was used to aid in student understanding of the filter-drag model. Time required for this intervention is approximately 30 minutes.

*External Resources Required:* Cooper, C. David & Alley, F.C. 2011. *Air Pollution Control: A Design Approach*, $4^{th}$ Edition, Waveland Press Inc.

**Intervention 5: Electrostatic Precipitator interactive problem-solving exercise**

*Description*: students were presented with a six-part design problem developed by the instructor. Design parameters were derived from Table 5.1 in the Cooper & Alley text. After instruction about how to approach the problem, students were broken into groups to finish solving the problem. The instructor answered questions and presented portions of the solution during the process. Time required for this intervention is approximately 25 minutes.

*External Resources Required:* Cooper, C. David & Alley, F.C. 2011. *Air Pollution Control: A Design Approach*, $4^{th}$ Edition, Waveland Press Inc.

**Intervention 6: Scrubber interactive problem-solving exercise**

*Description*: students were presented with several scenarios and asked to pick the most appropriate scrubber technology (spray, cyclone, venturi). Two additional scenarios were presented and students were asked to select the most appropriate control device from all previously presented PM control technologies (cyclone, baghouse, ESP, scrubber). The instructor guided students to the correct answer through interactive discussion as needed. Time required for this intervention is approximately 20 minutes.

*External Resources Required:* Cooper, C. David & Alley, F.C. 2011. *Air Pollution Control: A Design Approach*, $4^{th}$ Edition, Waveland Press Inc.

**Intervention 7: FE & PE exam preparation question & answer period**

*Description*: students had varying levels of familiarity with the FE and PE exams coming into the course. The purpose of this intervention was to provide a basic understanding concerning the importance gaining EIT and PE licensure, and to discuss preparation techniques. Students were introduced to the NCEES website and were shown a video from the website concerning the FE. The usefulness of review courses was discussed, as were different approaches to studying for the exams with an emphasis on air pollution topics. Time required for this intervention is approximately 40 minutes.

*External Resources Required:* NCEES website and YouTube video found at http://ncees.org/licensure/.

**Intervention 8: Team Teach – Nitrogen Oxides ($NO_x$)**

*Description*: students signed up for teams of 4 or 5 in the second week of class and selected a gaseous pollutant: $NO_x$, $SO_x$, VOCs, or $O_3$. Students that selected $NO_x$ were provided with a set of 6 slides that discussed the characteristics and sources of $NO_x$, the difference between thermal and fuel $NO_x$, conditions favorable for $NO_x$ creation, $NO_x$ emissions data in the

US, environmental and health effects of $NO_x$, and how $NO_x$ forms acid rain. Students prepared the material before class and presented the slides (and whatever else they found interesting concerning $NO_x$) to their peers. Time required for this intervention is approximately 10 minutes.

*External Resources Required:* Cooper, C. David & Alley, F.C. 2011. *Air Pollution Control: A Design Approach*, $4^{th}$ Edition, Waveland Press Inc.

**Intervention 9: Team Teach – Ozone ($O_3$)**

*Description*: students signed up for teams of 4 or 5 in the second week of class and selected a gaseous pollutant: $NO_x$, $SO_x$, VOCs, or $O_3$. Students that selected $O_3$ were provided with a set of 5 slides that discussed the characteristics and sources of $O_3$, the difference between tropospheric and stratospheric $O_3$, $O_3$ emissions data in the US, $O_3$ concentration trends across the US (i.e. where $O_3$ exceedances occur most frequently), and environmental and health effects of $O_3$. Students prepared the material before class and presented the slides (and whatever else they found interesting concerning $O_3$) to their peers. Time required for this intervention is approximately 10 minutes.

*External Resources Required:* Cooper, C. David & Alley, F.C. 2011. *Air Pollution Control: A Design Approach*, $4^{th}$ Edition, Waveland Press Inc.

**Intervention 10: Team Teach – Volatile Organic Compounds (VOCs)**

*Description*: students signed up for teams of 4 or 5 in the second week of class and selected a gaseous pollutant: $NO_x$, $SO_x$, VOCs, or $O_3$. Students that selected VOCs were provided with a set of 6 slides that discussed the characteristics and sources of VOCs, introduced students to VOC incinerators, discuss the importance of VOC incineration and the "3 T's" of incineration (time, temperature, and turbulence), and the advantages and disadvantages of VOC incineration. Students prepared the material before class and presented the slides (and whatever else they found interesting concerning VOCs) to their peers. Time required for this intervention is approximately 10 minutes.

*External Resources Required:* Cooper, C. David & Alley, F.C. 2011. *Air Pollution Control: A Design Approach*, $4^{th}$ Edition, Waveland Press Inc.

**Intervention 11: Team Teach – Sulfur Dioxide ($SO_x$)**

*Description*: students signed up for teams of 4 or 5 in the second week of class and selected a gaseous pollutant: $NO_x$, $SO_x$, VOCs, or $O_3$. Students that selected VOCs were provided with a set of 5 slides that discussed the characteristics and sources of $SO_x$, the chemistry behind $SO_x$ production, and $SO_x$ emission trends. Students also played a video describing how $SO_x$ forms acid rain from Britannica.com. Students prepared the material before class and presented the slides (and whatever else they found interesting concerning $SO_x$) to their peers. Time required for this intervention is approximately 10 minutes.

*External Resources Required:* Cooper, C. David & Alley, F.C. 2011. *Air Pollution Control: A Design Approach*, 4th Edition, Waveland Press Inc. Video from Britannica can be found at: http://www.youtube.com/watch?v=HE6Y0iEuXMQ.

**Intervention 12: Mobile sources video and discussion**

*Description*: students were shown a video describing the 2-stroke engine versus the 4-stroke engine from monkeysee.com. Students were then broken into groups to discuss three questions: 1) which engine type produces more pollution and why? 2) which engine type is most commonly found in developed and developing countries and why? 3) are mobile sources difficult or easy to regulate? Students were asked to discuss their group's responses with the rest of the class. Time required for this intervention is approximately 20 minutes.

*External Resources Required:* Cooper, C. David & Alley, F.C. 2011. *Air Pollution Control: A Design Approach*, 4th Edition, Waveland Press Inc. Video from monkeysee.com can be found at: https://www.youtube.com/watch?v=GwFB3RcVcHI.

**Intervention 13**: **Hands-on indoor air pollution (IAP) equipment session**

*Description*: students were given a block of time to explore pieces of equipment they were able to use as part of their indoor air pollution project. The instructor was available to answer questions and discuss possible uses of the equipment. The available equipment included Safety Siren Pro Series 3 Radon detectors, EX-1Z ozone monitors by Eco Sensors Inc., Gas Alert MicroClip XT Multi Gas Detectors, and an AM510 Personal Aerosol Meter. Websites for each piece of equipment are listed below. The indoor air pollution project itself is described in Pfluger et al. (2012). Time required for this intervention is approximately 25 minutes.

*External Resources Required*: below-listed or similar indoor air pollution monitor equipment:

1. Safety Siren Pro Series 3 Radon Detector: https://www.safetysirenpro.com/
2. EX-1X Ozone Monitor: http://www.ecosensors.com/products/hand-held-instruments/ez-1x-ecozone-data-sheet/
3. Gas Alert MicroClip XT Multi Gas Detector: http://www.bw-gasmonitors.com/xxyy-mc2.html
4. AM 510 Personal Aerosol Meter: http://www.tsi.com/sidepak-personal-aerosol-monitor-am510/

**Intervention 14: Pre- and Post-industrial carbon balance small-group exercise**

*Description*: students were provided the global carbon mass balance (i.e. sources, sinks, and flows) for the pre-industrial and post-industrial eras. Students broke into groups to discuss the differences between the two scenarios and identify new sources of carbon (i.e. air emissions due to burning of fossil fuels). Significant differences between the two scenarios were then discussed as a class. Time required for this intervention is approximately 25 minutes.

*External Resources Required*: Cooper, C. David & Alley, F.C. 2011. *Air Pollution Control: A Design Approach*, 4th Edition, Waveland Press Inc.

**Intervention 15: Indoor air pollution project presentations**

*Description*: students were asked to present the results of their IAP projects to their peers. They were asked to describe the piece of equipment used, their hypotheses, their methods, and their results. Student groups using the same piece of equipment were asked to discuss differences in their findings. Time required for this intervention is approximately 7 minutes per project group.

*External Resources Required*: N/A

**Intervention 16**: **Current Topics Presentations**

*Description*: after the mid-term exam, students were asked to sign-up into groups and research a current topic in air pollution for presentation to their classmates. Student groups were given flexibility to choose whatever topic they like, as long as it related to air pollution. Students were given 5-minutes to present their findings. Students were not required to use PowerPoint, but often elected to use the presentation medium. Current topic presentations were ungraded. Time required for this intervention is approximately 10 minutes per group.

*External Resources Required*: N/A

## Flipped Classes

**Flipped Class 1: PM problem-solving session**

*Description*: students were given four problems prior to class: baghouse design, PM devices in series, cyclone design, and ESP design. Students were asked to use their books, handouts, and previous homework problems to develop solutions to each problem prior to class. Upon arriving to class, students were broken into teams of 3 or 4 and asked to compare answers. The instructor was available for clarification. After 5-10 minutes of group discussion, the instructor answered questions and explained the portions of the problem solution as required. Time required for this class is 50-55 minutes.

*External Resources Required*: N/A

**Flipped Class 2: Acid rain sources and effects**

*Description*: students read three relevant articles (listed below) concerning the chemistry of acid rain and the effects of acid rain prior to class. Upon arriving to class, students were broken into three teams and assigned one of the three articles to review and summarize for their peers. Each team was required to determine five major points per article, then discuss the similarities and differences of the articles with the rest of the class. Students synthesized knowledge by answering three “big picture” questions at the end of the lesson: 1) what is the major cause of acid rain, and where is the acid rain problem the greatest in the US? 2) fundamentally, how does acid rain affect ecosystems? and 3) are we really solving the acid rain problem, and can the acid rain problem be completely eliminated? How? Time required for this class is 50-55 minutes.

*External Resources Required*: the following articles were provided to students in addition to their course text:

1. Ellerman, A.D., Joskow, P.L., Schamalensee, R., Montero, J-P., Bailey, E.M. 2000. "Part 1: Background" in "Markets for Clean Air: the U.S. Acid Rain Program". Cambridge University Press, United Kingdom.

2. Likens, G.E., Driscoll, C.T., Buso, D.C., 1996. "Long-term Effects of Acid Rain: Response and Recovery of a Forest Ecosystem". *Science*, New Series, Vol. 272, No. 5259, 244-246.

3. Schindler, D.W. 1988. "Effects of Acid Rain on Freshwater Ecosystems". *Science*, Vol. 239, 149-157.

**Flipped Class 3**: **IAP in developing countries**

*Description*: students read three relevant articles (listed below) concerning IAP in developing countries prior to class. At the start of the lesson, 3 short videos were shown to the students that highlight real-world IAP-related issues (listed below). Students were then broken into three teams in class and assigned one of the three articles to review. Each team was required to determine five major points per article, then discuss the similarities and differences of the articles with the rest of the class. Students synthesized knowledge by answering three "big picture" questions to gain a better understanding of the effects of IAP in developing countries: 1) is indoor air pollution in developing countries a solvable problem? If so, what needs to happen? 2) what is the best approach to reducing respiratory illness in developing countries? and 3) is there an inexpensive technology available that could replace indoor cook stoves? Are there technology diffusion issues? Time required for this class is 50-55 minutes.

*External Resources Required:*

The following articles were provided to students in addition to the course text:

1. Bruce, N., Perez-Padilla, R., Albalak, R., 2000. "Indoor air pollution in developing countries: a major environmental and public health challenge". *Bulletin of the World Health Organization*, 78(9), 1078-1092.

2. Ezzati, M. and Kammen, D.M., 2002. "The Health Impacts of Exposure to Indoor Air Pollution from Solids Fuels in Developing Countries: Knowledge, Gaps, and Data Needs". *Environmental Health Perspectives*, 110(11), 1057-1068.

3. Smith, K.R., Samet, J.M., Romieu, I., Bruce, N., 2000. "Indoor air pollution in developing countries and acute lower respiratory infections in children." *Thorax*, 55, 518-532.

The following videos were shown in class:

1. Indoor air pollution in Afghanistan from Al Jazeera English: http://www.youtube.com/watch?v=E6b5Dt58vFc

2. Indoor air pollution caused by biomass burning by TaTEDO: http://www.youtube.com/watch?v=XM4sqFfAtn8

3. Indoor air pollution by Essex Sustainability Institute:

https://www.youtube.com/watch?v=X4vdVkqy604

**Flipped Class 4: Carbon capture, transport, and sequestration**

*Description*: prior to class, students were asked to read Cooper & Alley textbook and one reference from the IPCC (listed below). Students were also provided a set of lecture slides associated with the material. Upon arrival to class, students were broken into 4 groups and randomly assigned a portion of the lesson to present to their peers using the provided references and slides. Students were given 15-minutes to prepare the approximately 5-minute discussion. Topics include: carbon prevention, carbon capture, carbon transport, and carbon sequestration. Each 5-minute discussion was followed by Q&A and the instructor fills gaps as required. Time required for this class is 50-55 minutes.

*External Resources Required:*

1. Cooper, C. David & Alley, F.C. 2011. *Air Pollution Control: A Design Approach*, 4th Edition, Waveland Press Inc.
2. Intergovernmental Panel on Climate Change, 2005. "Carbon Dioxide Capture and Storage". Prepared by Working Group II of the Intergovernmental Panel on Climate Change. Cambridge University Press.

**Appendix B**. Survey Questions.

| **Mid-course Survey Questions** |
| --- |
| 1. I prefer a lecture format for learning air pollution topics. |
| 2. I prefer discussion-based classroom formats for learning air pollution topics. |
| 3. The active learning techniques (discussion-based or problem-solving approaches) used in class to date have aided in my understanding of air pollution topics. |
| 4. The active learning techniques (discussion-based or problem-solving approaches) used in class to date have helped me to stay engaged and interested during the 3-hour time block allotted for this class. |
| 5. The exercise and small group discussion during Week 1 concerning the development of earth's atmosphere helped me understand the different atmospheres the earth has developed over time, why it changed, and how our atmosphere is different from atmospheres on other planets (e.g. Venus) today. |
| 6. The "flipped" classes helped me stay engaged and interested during the 3-hour time block allotted for this class. |
| 7. The "flipped class" technique for Lesson 6.1 (Particulate Matter Problem Solving) was a useful review and helped my understanding of particulate matter problems shown in class. |
| 8. I prefer that the instructor present review problems in a different, more directed format in Lesson 6.1 (Particulate Matter Problem Solving) (e.g., the instructor solves the problems on the board or on PowerPoint slides). |
| 9. The "team teach" concept for introducing gaseous pollutants (i.e., SOx, NOx, VOCs, Ozone, etc.) helped me understand the pollutant's negative health and environmental effects. |
| 10. The "team teach" concept for introducing gaseous pollutants (i.e., SOx, NOx, VOCs, Ozone, etc.) helped me stay engaged and interested during the 3-hour time block allotted for this class. |

| End of Course Survey Questions |
| --- |
| 1. The active learning techniques (discussion or problem-solving approaches) used in class have aided in my understanding of air pollution topics. |
| 2. The "flipped" classes helped me stay engaged and interested during the 3-hour time block allotted for this class. |
| 3. The "flipped class" technique for Lesson 11.4 (Acid Rain) helped me understand the problems associated with acid rain and how acid rain affects different ecosystems (i.e. forest, aquatic, etc). |
| 4. I prefer a standard lecture format for learning the problems associated with acid rain and how acid rain affects different ecosystems (i.e. forest, aquatic, etc.). |
| 5. The "flipped class" technique for Lesson 12.3 (Indoor Air Pollution in Developing Countries) helped me understand the challenges that developing countries face in mitigating indoor air pollution. |
| 6. I prefer a standard lecture format for learning the problems associated with indoor air pollution in developing countries and how to mitigate its effects. |
| 7. The small group exercise concerning the pre- & post-industrial carbon cycles during Week 14 aided in my understanding of how anthropogenic fossil fuel use modifies the flow of carbon from one environmental sphere (i.e., atmosphere, hydrosphere, lithosphere, biosphere) to another? |
| 8. The "flipped class" technique for Lesson 14.2 (Carbon Dioxide Control) helped me understand methods for carbon prevention, carbon capture, carbon transport, and carbon sequestration. |
| 9. I prefer a standard lecture format for learning the methods for carbon prevention, carbon capture, carbon transport, and carbon sequestration. |
| 10. Please comment on the following: (1) In general, did the "flipped class" lessons facilitate your ability to learn the material? Would a traditional lecture format be more effective? (2) Did you research additional material outside what was provided by the instructor (Yes or No)? (3) How long, on average, did you spend preparing for flipped classroom lessons? |

**Appendix C.** Responses to open ended questions posed on the end-of-course survey (Question 10).

- Comments on open-ended question 1: did the "flipped class" lessons facilitate your ability to learn? Would a traditional lecture format be more effective?
    - I think the flipped class was useful.
    - They are an interesting change up to the standard format... however, it sometimes does help with the 3-hour long class periods. Makes them a bit more bearable.
    - Generally, the flipped classes were a nice break and pretty effective
    - I think they helped me stay engaged during the time block, but I do not necessarily think they enhanced my understanding.
    - It didn't really keep me engaged as all the notes were there. Having "fill in the blank" keeps me more engaged. Activities also do that.
    - As much as I enjoyed the flipped classes, they didn't really help with the way I learn; I tend to remember the material better in a traditional lecture setting.
    - Yes, it was nice to switch it up
    - Yes flipped class helped, traditional lecture is fine though
    - Yes for concepts, no for actual mechanisms

- Comments on open-ended question 2: Did you research additional material outside what was provided by the instructor (Yes or No)?
  - No
  - No
  - No
  - I did not.
  - No
  - Yes, occasionally
  - Occasionally but not usually
  - Yes
  - No
- Comments on open-ended question 3: How long, on average, did you spend preparing for flipped classroom lessons?
  - 30 minutes about
  - Little to none.
  - 15-20 minutes
  - I usually forgot about them and did not prepare before class.
  - 30 minutes
  - About 30 minutes-1 hour.
  - 30 minutes
  - 25 mins for PP, maybe 10 mins to present
  - 0 to 60 min. the first one required at least one hour. The others varied based on article length. Some I didn't prepare for at all.

**Appendix D.** Relevant comments from our institution's standard course-end student survey. 14 students responded to this survey.

- I thought the content of the class itself is very interesting. It was also interesting when he would incorporate outside examples, articles, or videos, to help us understand the content of the class. I really liked the flipped class where we had to work problems, but all of the flipped classes were beneficial.
- I liked the flipped class discussions. I think they helped with understanding of topics.
- I was not a huge fan of the flipped classes. It was very rushed every time and maybe if we were to work out problems instead of read articles they could have been better.
- I don't think the team teaches benefit me at all. Also, all class discussions or flipped class with readings should go at the end of class. It's hard to stay focused for another lecture after a discussion.
- I would not have the flipped class homework stuff and I would move all class discussions to the last portion of the night. This is because it is difficult to transition back to a lecture scenario after discussion. Presentations didn't seem to have this same effect.
- While I liked doing the flipped classes, I found that I didn't really remember that material as well.

- I'm not sure how effective the team teaches are; although they do provide opportunities for students to practice their public speaking.
- The team teaches don't really do anything for me. I don't feel like I'm learning the material as well when my peers are explaining/ or I am explaining it to my peers. It also just takes some extra time to prepare for that I don't always have.

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