# Teaching a Hazardous Waste Management Course using an Inverted Classroom

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## Abstract

In engineering, the use of class time for active learning by students rather than traditional lectures is gaining popularity. There is a growing body of compelling evidence that active learning enhances student learning. However, there are a number of different models to integrate active learning into the classroom. This research explored the re-design of a senior and graduate level hazardous waste management course to use an inverted classroom model during the first half of the semester. The standard 75-minute lecture was segmented into videos that the students were tasked with watching before class. During class the primary focus was for the students to work in small self-selected groups of two to three to solve a series of example problems. The graded activities for students remained the same as in previous semesters: homework assignments that were primarily quantitative; a team project related to remediation that required two written reports and two oral presentations based on a site risk assessment and a remedial design feasibility evaluation; and a midterm and final exam. Assessment methods used to determine the effectiveness of the revised course model included: student logs showing video resource use from the Blackboard software; student feedback on an informal in-class survey and the final course evaluations; a comparison of student knowledge from the traditional class model and inverted model based on performance on the final exam. The primary limitation to success of the inverted course model was inconsistent buy-in from the students to watch the videos before class. About 40-60% of the class watched the appropriate online lecture prior to the relevant class time, but by the midterm exam about 90% of the students had viewed the majority of the online lectures. Student performance was better with the inverted classroom on two of four related homework assignments. The average student performance on the midterm exam was similar, although the "bottom" of the curve was improved during the inverted class (increased from ~44-53% traditional to 68% inverted). Improvements in student learning were primarily evident on the more difficult quantitative concepts. Plans for future use of the inverted course model and recommendations for others are provided.


## Background

A number of studies in engineering, physics, and other disciplines have shown that active learning by students during class rather than traditional lectures enhances student learning.[1] But how can instructors de-design a class to allow more active learning? A flipped or inverted classroom moves lectures out of class time to videos, thereby allowing time for active in-class activities such as small group problem solving.[2-7] A recent search of the American Society for Engineering Education (ASEE) conference proceedings website identified 238 papers that included the search term "inverted classroom". These lecture videos allow students to watch at their own pace, pause, and re-watch them at any time. The disadvantage is that students cannot ask questions of the professor during the lecture itself. However, the inverted classroom provides ample time for these questions during class time.

Sometimes, these video lectures are called "screencasts". However, screencasts can serve other functions, including showing example problems, walking through problem-solving strategies, and demonstrations.[8] Parker[9] used screencasts to demonstrate solving example problems in a fundamentals of environmental engineering course. The chemical engineering department at the University of Colorado Boulder has widely adopted screencasts in many of their courses, creating over 525 screencasts for eight chemical engineering courses.[10,11] Screencasts have also been used to provide students feedback on graded assignments, such as on the quality of writing in a capstone design course.[12]

Sugar et al.[13] used a cooperative inquiry approach to analyze the content of screencasts used to teach specific computing procedures. Twelve screencasts used by three professors in highly rated courses (rating 6.5 out of 7) were analyzed. The screencasts ranged in length from 43 seconds to 12 minutes [median length 5:10]. There were also 25 professional screencasts examined, which ranged in length from 34 seconds to 14:26 [median length of 2:18]. Common structural elements included bumpers (a statement of identity at the beginning and/or end of the broadcast), static screencast, and both explicit and implicit narration.

In this paper, the use of an inverted classroom in a senior and graduate level course in hazardous and industrial waste management was explored. Hazardous and industrial waste is a challenging course typically covering a broad range of topics, including regulations, fate and transport of contaminants, toxicology, risk assessment, and a wide array of waste treatment and remediation technologies. One of the standard textbooks that is commonly used is about 1200 pages long![14] The breadth and depth of the topics in the course presents an on-going challenge for teaching, making the course a potential target for an inverted classroom teaching methodology.

More specifically, when I was teaching Hazardous and Industrial Waste Management in fall 2010, a student indicated that video lectures would have been nice. The student had a diagnosed learning disability that the University determined should allow him 50% extra time to take exams. This student noted that even being provided the PowerPoint slides in advance of the lecture, he couldn't keep up. Video lectures, he stated, would give him time to pause and think. His request combined with the growing body of evidence on the effectiveness of inverted classrooms led to the revision of the course in fall 2011. Over the summer, the normal lectures from 2010 were "captured" by audio-recording in PowerPoint. The expectation that students would watch the videos before class supplanted the expectation in previous semesters that students would read related textbook material before class. This paper will describe the course and how it was modified for the inverted classroom model. Next, student learning in the traditional course and inverted classroom style will be compared. Finally, students' feelings about the inverted course will be described.

## Research Objectives

The first objective of this study was to determine if the students would learn hazardous waste management better using an inverted classroom teaching style. The second objective was to determine if students would like or prefer the inverted classroom to the traditional lecture format of the course.

**Course Overview**

At the University of Colorado Boulder, the hazardous waste management course content and teaching methods were quite similar from 2007 to 2010. The learning objectives for the course remained consistent over this time, with many based on outcomes articulated in the Environmental Engineering Body of Knowledge.[15] Students were expected to:

- identify, describe and explain current regulations which are pertinent to industrial and hazardous wastes
- apply the fundamental principles governing transfer of chemicals between phases to well-defined situations (e.g. where equilibrium assumptions apply)
- apply conservation and transport principles to determine the fate of substances in air, water and soil
- understand how quantitative risk assessments are conducted, and the limitations of the results
  - identify potential hazards, exposure pathways and risks to the environment and the public health, welfare and safety associated with exposure to chemical hazards associated with contaminated sites and industrial wastes
  - determine the potential chemical exposure and risk to the environment and the public health, safety and welfare
  - analyze the potential exposure and risk to the environment and exposed populations for multiple chemical exposure routes and hazards
- apply creativity and knowledge to design a system for site remediation that meets realistic constraints such as economics, environmental, social, regulatory, health & safety, constructability, and sustainability
  - analyze real world situations to determine design needs, design requirements, and compare treatment strategies for site remediation
- know where to find information on chemical toxicity and site remediation methods
- understand the larger framework of site remediation, including ethical considerations, public involvement, cost/benefit analyses
- work effectively in teams and communicate technical information via both written and oral formats

Over the 15-weeks of the semester, the class met twice each week for 75-minutes per class. Class time was used primarily for lectures with a few problems solved by the instructor in-class. These lectures were supported by PowerPoint slides, which were made available to the students. Students were encouraged to read or skim the textbook material related to the lecture before class. These pre-class reading assignments were incentivized using various methods such as in-class reading quizzes or the ability to turn in reading notes for extra credit. Despite various incentives, student participation in pre-class reading was highly uneven. It was hoped that pre-class videos would be more received more favorably.

A variety of assessment methods were used to evaluate student learning in the course. There were six to seven homework assignments. These were primarily quantitative problems and worth 30% of the course grade. The homework assignments varied in length, but many were quite substantial, intended to take about 10 hours of time to work through all of the problems. These assignments were a key learning activity in the course, and designed so that students would struggle and learn. Students often worked together with self-selected informal study groups on these assignments. The course also included two large team-based projects: (1) a risk assessment; (2) a feasibility study of remediation methods. Each team was assigned to a different contaminated site that had been proposed to the National Priorities List (NPL). These projects included both a written report (each generally ~50 pages long) and an in-class oral presentation, and combined were worth 32% of the course grade. Finally, there was an in-class midterm exam and a 2.5 hour comprehensive final exam, worth 15% and 23% of the course grade, respectively. The exams were the primary method used to assess individual student learning in the course.

In fall 2011, the use of in-class time during the first half of the semester was changed (Table 2). However, the learning objectives and student assessment methods to award grades remained consistent with previous semesters. When lectures were removed from the class, the bulk of the in-class time was spent solving problems. Students were asked to form informal pairs and solve a problem. Often, each pair in the class was assigned a different chemical. Students were given time to solve the problem, the professor circulated around the class to give pointers, and after most teams were done, each pair reported their answers. Then the class could discuss the solution approach, the instructor could illustrate common "mishaps", etc.

The course is an elective and as such the students who enroll often differ widely in their preparation and motivation. The environmental engineering (EVEN) undergraduates generally have good background preparation for the course (such as material and energy balances, Fundamentals of Environmental Engineering, and perhaps including environmental organic chemistry, groundwater, environmental microbiology, etc.). Many of the EVEN students have also selected remediation as their focus track and are therefore very motivated. Civil engineering undergraduate students often have only had a Fundamentals of Environmental Engineering course before hazardous waste, a weaker chemistry background compared to the environmental engineers, and just a more general environmental interest. Only a few graduate students typically enroll in the course, since many graduate students have already taken a similar undergraduate course. The graduate students are generally taking fewer courses and are more serious and motivated. Therefore, based on purely demographic factors the highest average performance in the course would be predicted for the fall 2010 cohort (highest percentage of graduate students) and lowest for Fall 2009 (low percentage graduate students and highest percentage civil engineering undergraduates); this was found to be roughly true (see Table 1).

Table 1. Summary of Enrolled Students and Average Grade

| Semester: | Fall 2011 | Fall 2010 | Fall 2009 | Fall 2008 | Sp 2007 |
|---|---|---|---|---|---|
| | Number of Students Enrolled | | | | |
| Undergraduate Environm. Eng. | 9 | 14 | 6 | 9 | 6 |
| Undergraduate Civil Eng | $4^{+2*}$ | 2 | 6 | 2 | 4 |
| Undergraduate Chemical Eng | 0 | 2 | 0 | 0 | 0 |
| Graduate students | 5 | 4 | 3 | 6 | 4 |
| Average grade (4=A, 3=B) | 3.36 | 3.19 | 2.96 | 3.58 | 3.41 |

* Late dropped just prior to midterm exam

Table 2. Summary of Inverted Portion of the Hazardous Waste Management Course

| Class day | Topic | Pre class video topic; file size; minutes | In-class activities | Related to assignment |
|---|---|---|---|---|
| 2 | HazW history | History 6.3MB 25 min | Discussion | HW1 |
| 2 | regulations | RCRA 2.9 MB 10 min<br>international policies 2.6MB 6.5 min<br>CERCLA 3.4 MB 13 min | Discussion (used 1 day in-class for this topic compared to traditional 2-3 days) | HW1 |
| 3 | Toxic chemicals<br>Water solubility<br>NAPLs | Hazday3 2.6 MB 10 min<br>Hazday3-solubility 2.7 MB 10 min<br>HAZnapl 6.3MB 20 min<br>CartoonLNAPL 1 MB 3 min<br>CartoonDNAPL 1.9MB 6 min | Lots of problems converting concentration in water units, concentration dissolved in water when a given amount of chemical added (may be left over NAPL), and mixed NAPL / Raoult's Law | HW2 |
| 4 | Soil sorption | HAZsoil 5.6MB 22 min | Soil concentration units (ppm, mg/kg); soil:water equilibrium partitioning of metals and organics; total mass of contaminant in soil at equilibrium based on the concentration measured in 1 phase | HW2 |
| 5 | Volatilization (all phases) | HAZairEQ-sound-lo 3.7MB 14 min<br>HAZequilPhases 2.7MB 10 min | Air concentration unit conversions (ppm, mg/L); air saturation; air:water equilibrium; concentration and/or mass in all 4 phases (air, water, soil, NAPL) | HW2 |
| 6 | Fate & Transport: air | Air fate and transport (no audio)<br>Deep soil contamination 2.5MB 9 min<br>3D plume modeling 1.9 MB 8 min<br>Soil vapor intrusion 2.2 MB 7 min | Estimate time until 90 – 99.9% of chemical had volatilized away from a surface spill; estimate chemical concentrations in air above groundwater plume, in downwind air, and in indoor air | HW3 |
| 7 | Fate & Transport ground water | Darcy's law; retardation 4.3MB 16 min<br>Plume modeling 6.7 MB 23 min | Calculate average contaminant travel time between two ground water wells; discuss uncertainties | HW3 |
| 8 | Toxicity | Toxic Effect Chemicals 3.3 MB 12 min<br>Carcinogens 4.8 MB 18 min<br>Endocrine Disruptors 1.7 MB 6 min | Estimate probability of cancer for different chemicals; Discuss uncertainty factors | HW4 |
| 9 | Toxicity | Toxicology 4.8 MB 18 min | Given a graph of response vs. dose calculate the ADI, LOAEL, NOAEL; given a table of dose vs. # of dead rabbits, estimate the safe dose of the chemical for humans | HW4 |
| 10 | Risk Assessment | Hazard ID 3.5 MB 14 min<br>Exposure Assessment 2.8 MB 10 min<br>Risk Quantification 2.5 MB 9 min | Discuss exposure routes from a scenario; calculate chemical intake for different scenarios; calculate hazard index and risk of cancer; discuss uncertainties | Project; midterm |

## Results: Student Learning

First, it is important to note that there was inconsistent buy-in from the students to watch the videos before class. Typically, 50 to 80% of the class had logged into the Blackboard software and accessed one of more of the relevant videos before class. Students seemed to generally download the file to their personal computer, so it is unclear what amount of the video was actually watched. This non-uniform participation by students resulted in difficulties during class: about half of the students were comfortable trying to work out the problems and half were completely lost. In addition, some students working from Mac-based computers reported technical problems, so they could not use their personal computers to listen to the lectures; these students seemed to have older versions of the PowerPoint software.

In an attempt to determine any differences in average student learning, performance on the first four homework assignments were compared (Table 3). On each homework assignment the graduate students were given additional problems, so the two levels of students must be compared separately. However, the number of students was small, increasing the difficulty in detecting significant differences. Two-tailed, unpaired, unequal variance t-tests were performed. No statistically significant differences were found, with the exception of best performance on the first homework covering regulations by the 2010 undergraduate cohort (which was taught in the normal manner).

Table 3. Homework Performance Comparison (Fall 2011 inverted; Fall 2009 and 2010 standard)

<table>
<tr><td></td><td></td><td>Fall 2011</td><td>Fall 2010</td><td>Fall 2009</td><td colspan="2">t-test p values</td></tr>
<tr><td>Undergraduates</td><td></td><td>N=13</td><td>N=18</td><td>N=12</td><td>2011 v 2010</td><td>2011 v 2009</td></tr>
<tr><td>HW1: regulations (qualitative)</td><td>Avg<br>Median<br>Range</td><td>90%<br>90%<br>83-97%</td><td>94%<br>96%<br>86-99%</td><td>87%<br>91%<br>43-97%</td><td>0.006</td><td>0.41</td></tr>
<tr><td>HW2: equilibrium partitioning</td><td>Avg<br>Median<br>Range</td><td>84%<br>85%<br>51-98%</td><td>75%<br>79%<br>48-96%</td><td rowspan="2">82%<br>87%<br>52-95%</td><td>0.14</td><td>0.89*</td></tr>
<tr><td>HW3: fate & transport</td><td>Avg<br>Median<br>Range</td><td>80%<br>88%<br>34-96%</td><td>87%<br>88%<br>53-99%</td><td>0.23</td><td>N/A</td></tr>
<tr><td>HW4: toxicology & risk assessment</td><td>Avg<br>Median<br>Range</td><td>84%<br>85%<br>75-97%</td><td>80%<br>78%<br>71-88%</td><td>79%<br>84%<br>41-93%</td><td>0.08</td><td>0.42</td></tr>
<tr><td>Graduates</td><td></td><td>N=5</td><td>N=4</td><td>N=3</td><td></td><td></td></tr>
<tr><td>HW1</td><td>Avg<br>Median<br>Range</td><td>95%<br>95%<br>92-97%</td><td>92%<br>93%<br>86-95%</td><td>90%<br>88%<br>87-94%</td><td>0.23</td><td>0.16</td></tr>
<tr><td>HW2</td><td>Avg<br>Median<br>Range</td><td>89%<br>91%<br>78-94%</td><td>85%<br>86%<br>82-88%</td><td rowspan="2">95%<br>93%<br>92-98%</td><td>0.33</td><td>0.17*</td></tr>
<tr><td>HW3</td><td>Avg<br>Median<br>Range</td><td>88%<br>92%<br>75-95%</td><td>87%<br>85%<br>NS-92%</td><td>0.78</td><td></td></tr>
<tr><td>HW4</td><td>Avg<br>Median<br>Range</td><td>82%<br>86%<br>50-96%</td><td>81%<br>80%<br>78-85%</td><td>95%<br>95%<br>93-96%</td><td>0.88</td><td>0.21</td></tr>
</table>

* comparisons to 2009 and earlier are complicated by different topic distribution between homeworks 2, 3, and 4. Only 3 pre-midterm homeworks in 2009.

The lack of difference in the homework scores is not entirely surprising. Students often work together and always had ample opportunity to receive help during office hours. In addition, the number of students is small to determine statistically significant differences.

The performance on the exams may be a more accurate reflection of students' learning (see Table 4). The midterm exam covered content from the inverted part of the 2011 class. Each year the exact questions on the midterm change, but are in general very similar (data from earlier versions of the course from 1997 to 2005 is not shown). The average and median student performance in 2011 was not any better than 2007 to 2010 with the standard course format. However, the spread in student performance diminished, with the bottom of the curve improved by ~10 to 20%.

Table 4. Exam Performance (2011 inverted class; other years standard course model)

| | | Fall 2011 | Fall 2010 | Fall 2009 | Fall 2008 | Sp 2007 |
|---|---|---|---|---|---|---|
| Undergraduates | | N=13 | N=18 | N=12 | N=11 | N=10 |
| Midterm | Avg | 79% | 77% | 78% | 80% | 74% |
| | Median | 78% | 79% | 82% | 80% | 76% |
| | Range | 29%(66-95) | 42%(51-93) | 52%(45-97) | 43%(53-96) | 41%(44-85) |
| Final: | Avg | 83% | 69% | 74% | 74% | |
| Equilibrium | Median | 95% | 74% | 84% | 92% | 77% |
| partitioning | Range | 20-100% | 31-98% | 20-100% | 25-92% | 83% |
| Final: ppmv | Avg | 99% | 88% | 94% | | 50-92% |
| | Median | 100% | 100% | 100% | NA | |
| | Range | 83-100% | 0-100% | 88-100% | | |
| Final: | Avg | 83% | 72% | 91% | | |
| NAPL fate | Median | 93% | 75% | 100% | NA | NA |
| | Range | 25-100% | 25-100% | 50-100% | | |
| Final: risk | Avg | 94% | 93% | 80% | | |
| quantification | Median | 100% | 94% | 88% | NA | NA |
| | Range | 67-100% | 69-100% | 0-100% | | |
| Graduates | | N=5 | N=4 | N=3 | N=6 | N=4 |
| Midterm | Avg | 85% | 78% | 88% | 81% | 70% |
| | Median | 85% | 79% | 90% | 80% | 71% |
| | Range | 10%(77-87) | 27%(64-91) | 10%(82-92) | 16%(74-90) | 23%(57-80) |

NA = question on this topic was not asked in that year

Only some of the topics on the final exam corresponded to the inverted topics. Therefore, performance on particular types of questions was analyzed. A complex equilibrium partitioning problem was provided, requiring students determine the total mass of an organic chemical in a barrel containing soil, air, water, and sometimes non-aqueous phase liquid (NAPL). The exam problem provided the concentration in one media (i.e. air) and the students must compute the other concentrations based on chemical properties and total mass. The average undergraduate students' understanding of this topic appeared significantly improved in 2011 (by ~10%). The ability to convert between air concentrations in mg/L and ppm-v also appeared to be improved. These topics both lend themselves well to online lectures with example problems, and can benefit from additional practice solving these problems in-class. Conversely, no significant improvement in describing the fate of NAPL or risk quantification seemed to result from the inverted teaching model. Caution should be used when interpreting these results due to the small numbers of students in the course, but imply potentially improved performance on more complex topics. [Due to the small number of graduate students in the course, the performance of the graduate students has not been shown.]

**Results: Student Reception to the Inverted Classroom**

As discussed earlier, student participation in watching the videos before class was uneven. The course software indicated which students had accessed which files and amount of time spent, but students may have downloaded the files to their personal computer and watched them off-line. Or they may not have watched the files that they downloaded before class.

The expectation that students would watch the videos in advance was similar to expectations for reading in earlier semesters. The buy-in from students to the pre-class reading was also variable. In 2005 and 2007 students could receive 2 points of extra credit (added to their homework scores) for turning in reading notes at the beginning of class to document their pre-class reading activity. The student participation in this activity was highly uneven, with some students participating sometimes and on average more participation among graduate students (Table 5). In general, more students accessed the online videos prior to class than submitted textbook reading notes for extra credit. This may indicate that videos are a more palatable format for student learning than reading the textbook. In 2011 the students knew that they would not receive a lecture on the topic, and so they would certainly have a harder time participating in-class, compared to previous semesters where the lectures did not demand active engagement. The use of particular videos before class was uneven. Students were not told the length of the videos in advance. So they may have allocated time to watch the videos, but if the first video was too long they may not have watched the later "segments".

Table 5. Student Participation in Pre-class Activities

| Year | Student Level | % students never turned in reading notes | Of students turning in some reading notes, % of lectures pre-reading completed; average (range) |
|---|---|---|---|
| 2005 | Undergraduate students | 25 | 27 (10-62) |
| 2007 | Undergraduate students | 70 | 22 (17-28) |
| 2005 | Graduate students | 33 | 71 (67-76) |
| 2007 | Graduate students | 20 | 35 (22-50) |
| | | % students never accessing video before lecture | Of students accessing some lectures, % of videos accessed before class; average (range) |
| 2011 | Undergraduate students | 11 | 65 (25 – 75) |
| 2011 | Graduate students | 0 | 69 (50 – 80) |

An in-class anonymous, informal evaluation was administered to the students the class before the first homework was due. Twenty-one students filled out a brief in-class survey (which included an auditor). Student satisfaction with the inverted classroom model was variable. Eighty-one percent of the students indicated that the online lectures were "ok", 14% said they were "too long", and only 33% indicated they were helpful with the homework. Given additional informal feedback, student resistance to using the lectures, and the extra instructor requirements, about halfway through the course it was reverted to the standard model.

At the end of the semester, all courses at the University of Colorado Boulder are required to administer anonymous evaluations, so-called FCQs. By the end of the semester, the average student FCQ ratings for the course and instructor were within the typical range (Table 6). Lower FCQs corresponded to the semester with the most civil engineering students; this is generally due to their lower preparation and interest associated with the course. The students' rating of the amount learned was also in the typical range. The average amount of time spent was reported as 10-12 hours/week with a median of 7-9 hours/week. Again, this was in the typical range, but without any students in the 4-5 hour range. This largely contradicts feedback from some students that that they believed they were spending more time on the class to watch the lectures in advance. However, this evaluation was given at the end of the semester so the more recent standard-lecture part of the course may have been more prominent in their minds. Overall, I found that there was less variation in student responses in the 2011 data compared to earlier semesters (i.e. course overall, instructor overall, hours per week).

Table 6. End-of-Semester Course Evaluation by Students (scale: lowest = 1 to highest = 6)

| | | Fall 2011 | Fall 2010 | Fall 2009 | Fall 2008 | Fall 2007 |
|---|---|---|---|---|---|---|
| Enrollment (initial) | | 20 | 22 | 15 | 17 | 15 |
| # evaluations | | 14 | 18 | 13 | 17 | 14 |
| Course overall | Avg | 5.2 | 5.3 | 4.5 | 5.5 | 5.0 |
| | Median | 5.0 | 6.0 | 5.0 | 6.0 | 5.0 |
| | Range | 5-6 | 4-6 | 3-6 | 4-6 | 2-6 |
| Instructor overall | Avg | 5.5 | 5.3 | 5.2 | 5.6 | 5.5 |
| | Median | 5.5 | 6.0 | 5.0 | 6.0 | 6.0 |
| | Range | 5-6 | 3-6 | 4-6 | 5-6 | 2-6 |
| Hrs/week spent on course (incl class) | Avg | 10-12 | 10-12 | 7-9 | 7-9 | 10-12 |
| | Median | 7-9 | 10-12 | 7-9 | 7-9 | 10-12 |
| | Range | 7-9 to 13-15 | 4-6 to 16+ | 4-6 to 13-15 | 4-6 to 13-15 | 4-6 to 16+ |
| How much you learned in course | Avg | 5.4 | 5.6 | 4.8 | 5.4 | 5.2 |
| | Median | 5.0 | 6.0 | 5.0 | 6.0 | 5.5 |
| | Range | 5-6 | 5-6 | 3-6 | 4-6 | 4-6 |
| The course improved my ability to solve engineering problems | Avg | 5.2 | 5.3 | 4.8 | NA | NA |
| | Median | 5.0 | 5.0 | 5.0 | NA | NA |
| | Range | 4-6 | 4-6 | 3-6 | NA | NA |

NA = question not asked

Students were encouraged to discuss the inverted course style on the final evaluations. Of the 14 evaluations that were submitted, 13 discussed the inverted classroom and/or audio lectures.

These student quotes related to the audio slides were coded into categories with results shown in Table 7. About half were favorable, and a little under half were not. The perception that using this course format increased students' time devoted to the class was indicated by 29% of the students. Three students also made comments that students probably would not take the time to watch the videos before class near the end of the semester, when schedules were presumably busier. One student noted: ""Online lectures were really good for learning material before class, but without quiz I feel students won't keep up with lectures."

Table 7. Summary of Hand-Written Comments on the End-of-Semester Course Evaluations

| Type of Comments | % of 14 FCQs submitted | Example quote(s) |
|---|---|---|
| Generally favorable | 50% | "I appreciated having notes with audio – especially for studying for exams, but also for listening to before class…" "I liked to just do problems in class" |
| Extra time / too much time | 29% | "was not a fan of online presentations as they doubled the amount of time spent on this course outside of class" |
| Technical difficulties (volume, software, equation editor) | 36% | "The only problem with the ppoints was that the newest [software] version was required and sometimes the sound was a little too quiet." "Equation editor would be helpful." |
| Generally unfavorable | 43% | "Personally, I enjoyed lectures more than the online lectures. The ability to ask questions and be there in person while the information is presented seems valuable." "Posted lectures with comment great for review and homework, but trying to listen to them before class was overwhelming. Good tool but I prefer in-class lectures." |

**Instructor Perspective**

From an instructor perspective, making the lectures in advance took time and the resulting files were very large. Creating additional problems for in-class work also took additional time. However, I found it more enjoyable to spend class time interactively working problems. Peer-to-peer instruction was observed. Students questions while they were working through a problem could be answered immediately, and errors in their approach were also identified. I observed that the students experienced far less difficulty on the homework assignments. There was a lot less traffic during my office hours. So I felt that the time devoted in-class to problem solving reduced the time students spent working through the challenging homework sets. It also gives students flexibility in the resources they utilize for the course.

**Recommendations**

I will try the inverted course model again in the future, with some modifications. The online lectures will be edited to make each one shorter and more focused. I will target a maximum length of 10 minutes, and try to have most around 6 minutes. This may help reduce the perception that watching the lectures before class adds to the total time students invest in the course. In addition, since students come to the course having taken widely different related courses, students may be able to skip some topics with which they are already very familiar. For example, some students have already taken an entire course devoted to groundwater, and may be able to skip those lectures within the fate and transport section of the course. I have since learned that compression methods for file sizes have improved and that the audio PowerPoint files can also be converted into various media files so that students don't need to use PowerPoint to listen and watch the lectures. I will also try to find the time to redo the slides using equation editor and improve the sound quality.

To encourage student participation in learning on their own before class, online quizzes covering the lecture will be given before class and/or there will be the possibility of a quiz at the start of class. This is similar to the recommendation of Talbert[6] to give a five-minute clicker quiz at the beginning of class to "keep students honest" about completing the pre-class assignments. In-class there will also be some quick mini-lectures of ~5 to 10 minutes interspersed with the longer time for students to solve problems. Lage[5] used the model that the start of each class was opened for questions from students. Based on the questions, there might be a mini-lecture of approximately 10 minutes. But if no questions were asked, a lecture was not given. This methodology was used to encourage students to be critical consumers of the pre-class materials and come prepared with questions. Some of the class time may also be spent directly discussing particularly complex homework questions to facilitate students more efficiently and effectively completing the assignments.

## Summary

Student reception of the inverted class model was mixed. There was some evidence of improved student learning of challenging topics on the final exam. This was likely attributable to increased solving of practice problems in-class and students' ability to review example problems embedded in the lectures using the online videos. Instructors considering making videos of lectures should try to make concise lecture segments and work with instructional support to ensure adequate quality and platform compatibility.

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