Using Lightboard Video Lectures to Improve Student Learning in a Flipped Classroom Environment

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Abstract

This paper examines how the online content of a flipped (inverted) course within the Civil Engineering program was improved through the use of online videos created using a Lightboard. Unlike traditional whiteboards which require the lecturer to have his/her back to the camera during recording, the Lightboard is an innovative technology which allows the lecturer to face the camera while recording the lesson. Since the clear glass board of the Lightboard is lit up internally with LEDs, the writing on the board appears as a lighted marker.

Quantitative data for the study was analyzed by comparing student performance on in-class learning activities in which the pre-class component (flipped classrooms require students to review lesson material prior to class) included Lightboard videos with identical assignments in which Lightboard videos were not included. Additional quantitative and qualitative data was collected through an end-of-semester questionnaire containing short answer and Likert-scale questions addressing the impact of the Lightboard videos on student learning, critical thinking, and problem-solving skills.

Keywords

Lightboard, inverted classroom, critical thinking, civil engineering

Introduction

Since the course in this study utilizes a flipped (inverted) classroom, this section starts by providing a brief overview of flipped classrooms; both in terms of its overall purpose and primary features. The author also provides some background information regarding the origins of flipped classrooms in order to shed some light into its pedagogical evolution. Having provided this orientation, the remainder of the introduction provides a brief overview of the evolution of online education and an examination of how videos have been used within online programs and disciplines to improve student learning and critical thinking.

Flipped Classrooms

Flipped classrooms encourage student participation and engagement by providing a variety on hands-on learning activities during class. Freeing up class time for learning activities is achieved by having students review lesson material (PowerPoints, videos) online prior to attending class. Having reviewed the lesson materials beforehand, students arrive in class knowing the necessary background to participate in the learning activity.

Flipped learning arguably was pioneered by two high school science teachers, Jon Bergmann and Aaron Sams, in the spring of 2007. Both Bergmann and Sams were chemistry teachers at Woodland Park High School in Woodland, Park Colorado. The first flipped classroom sessions used software to voice record over PowerPoint lectures. At the time students who attended Woodland Park High School would often miss class to attend school sponsored extra-curricular events. The first recorded lectures were used as a way to teach students who could not attend all class sessions due to scheduling conflicts. After both teachers began using the model they noticed how flipping improved student interaction both among peers and with the teacher[1, 2].

Flipped learning is a type of learner-centric model. The learner-centric model in America is mostly attributed to early progressive educator John Dewey. John Dewey suggested that the process of learning was more important than goals or predetermined learning outcomes. Further he suggested that if learning is to be successful it requires the learner to take an active role in that process [3]. John Dewey believed that "reflection involves not simply a sequence of ideas, but a consequence—a consecutive ordering in such a way determines the next as its proper outcome, while each in turn leans back on its predecessors." [4]

Evolution of Online Education

Distance education, defined as a method of delivering education and instruction to students who are physically separated from the student, is certainly not a new concept. Today's myriad of online education offerings, ranging from blended courses which utilize online media to supplement face-to face courses to programs offering fully online degrees, have their origins from simpler technologies.

The earliest form of distance education occurred through parcel post. In 1728, Caleb Phillips offered what is thought to be the first distance learning course in shorthand to "any person in the Country desirous to Learn this Art, may be having several Lessons sent Weekly to them, be as perfectly as those that live in Boston" [10]. With the development of the radio in the 1890s, numerous institutions like the University of Wisconsin and Penn State developed radio-based distance education programs. By the late 1920s, the number of educational institutions with some form of radio-based distance education grew to 176 [8]. Even though commercial television became public in 1927, the use of television for broadcasting educational content did not surface until between 1932 and 1937 at the University of Iowa (although this was really only an experiment) [8]. While educational programmed gained popularity in the 1960s and 1970s with cable television and Public Broadcasting Service offerings, television's use in distance education (connecting students to instructors asynchronously) did not.

The use of computers to train employees gained popularity in corporate America in the late 1980s [11]. Shortly following the unveiling of the World Wide Web, the University of Phoenix became one of the first programs to offer formal online education programs. This prompted other for-profit and not-for-profit institutions to follow suit including New York University Online in 1998 and California Virtual University (consortium of 100 universities and colleges) also in 1998.

Impact of Videos on Student Learning

Starting with research pertaining to online learning in K-12 classrooms, in 2010 the U.S. Department of Education published a comprehensive evaluation of evidence-based practices in online education which encompassed a meta-analysis and review of more than a thousand empirical studies of online learning conducted from 1996 through 2008 [9]. As part of the study, researchers identified 50 independent effects, which were first divided into two categories (effects pertaining to purely online learning, effects relating to blended courses) prior to subjecting them to the meta-analysis. Among the many findings relating to online education, the study concluded that combining online content with face-to-face elements (i.e. blended courses) impacted student learning more in traditional face-to-face courses than it did in purely online classes. While adding an online element to a face-to-face course impacts learning, the study warns that the positive effects associated with blended courses cannot be directly attributed to the exposure to elements such as video. So, while the addition of the video enhanced the course content and improved the overall experience, the study could not find any direct quantifiable evidence that videos improved student learning.

Studies examining undergraduate and graduate online education programs at various colleges and universities support similar findings. In a study by Kao [7] at State University of New York (SUNY) at Stony Brook, the investigator incorporated video podcasts (done through iTunes) into several undergraduate and graduate level mechanical engineering courses with class sizes ranging from 20 to 60 students. Based on an analysis of 16 end-of-semester surveys, 90% of the students indicated that blending the courses with the podcasts was beneficial. The surveys also indicated that students felt comfortable and empowered to learn with the technology. While blending the courses clearly improved the content and student enjoyment of the course, the study did not address if the inclusion of video influenced student learning. This lack of quantifiable data relating student learning to the inclusion of video content is prevalent throughout engineering education literature. For example, in a study by Halyo and Le [5] at Hampton University, the authors incorporated two video lectures into their Introduction to Engineering (freshman level) and Introduction to Control Systems (senior level) courses. For both videos, students were asked to view each video prior to attending class. The study concluded that, by having the students review the videos before class, more class time was available for instructor interaction and open-ended problem solving. Likewise, student surveys indicated that they preferred watching the videos to reading their textbooks. However, the study did not include any quantifiable measure of how the videos impacted student learning. Looking at projects outside the United States, at the American University of Beirut, Itani [6] examined the use of videos as a learning tool in an engineering ethics course over a period of three semesters. The videos consisted of nine movies: 2 were Hollywood productions, 2 movies were produced by the National Institute for Engineering Ethics (NIEE), and 5 were documentaries. The investigator used questionnaires to discern how well students understood the videos, the extent to which the videos helped students relate to key concepts in the course, and comments regarding their opinions about the videos as a learning tool. The study concluded that the students viewed the videos an effective learning tool in engineering ethics courses and that the use of videos based on a true-story is more effective in achieving the course outcomes than showing hypothetical ethics videos. Similar to the aforementioned studies, the results from this investigation were also based solely on self-reporting and did not contain quantifiable measures for assessing how the videos impacted student learning.

Methodology

This section provides background information regarding the engineering course used in this study, details relating to how Lightboard videos were created and used within the course, and the methodology used for collecting the qualitative and quantitative data.

Course Information

Fluid Mechanics is a required course in the Civil Engineering curriculum usually taken during the second semester of the sophomore year. Enrollment is limited to 24 students due to the space limitations of the laboratory (the course has both lecture and lab components) and there are normally two sections of the course per semester.

As part of the required pre-class preparation associated with the flipped (inverted) classroom methodology, students arrive for class with a “ticket” which addresses several key concepts from the online lesson. The online lesson contains a combination of PowerPoint, Internet-based videos (YouTube, etc.), and Lightboard video content. The “ticket”, which is also posted online, contains a both short answer (addressing basic knowledge and comprehension levels) and computational-based questions which require students to rework examples from the online lesson (with different variables) or a similar problem specific to the online lesson. In lieu of the importance of pre-class preparation in the inverted classroom approach, students entering the classroom without their completed “ticket” are considered absent for the class (counting against their attendance grade) but are allowed to participate in the problem solving portion of the class. As the tickets are collected, each is evaluated for completeness and originality (i.e. making sure that no two tickets are direct copies of each other). Students identified as having copied tickets are not given credit for attending that day’s class.

Having collected the tickets, each class starts with a 10~15 minute lesson overview in which the instructor highlights the concepts covered in the online lesson. In doing so, he addresses the concepts addressed within the ‘ticket” while also emphasizing how the lesson’s content relates to previous and/or upcoming lessons, the course, and the profession. The remainder of the class time is devoted to a variety of hands-on learning activities including: problem solving sessions, computer-based activities with commonly-used software (MS Excel, Flow Master, etc.), and laboratory activities (formal and informal). The majority of these activities are performed in groups of three which provides a collaborative environment for students to share ideas and pose questions to other students that require critical thinking.

Lightboard Video Development

The Lightboard videos used for this project where developed through a collaborative effort between the University's Center for Online Learning (COL), Information Technology Services (ITS), Multimedia Development Center (MDC) and the department OF Civil Engineering and Construction Management. Whereas the videos were recorded at the MDC by MDC staff, COL staff assisted with the pre-recording training and final video editing and publishing.

The Lightboard unit itself was constructed by Jessica and Jeff Orvis, faculty members of the Georgia Southern's Chemistry Department.

Performance-Based Data Collection

The inclusion of the Lightboard videos within the course's online content followed a schedule that intentionally alternated between two consecutive semesters (see Table 1). Whereas Lightboard videos were provided to students for lectures 2, 4, 6, 8, 10, 12, and 14 during the Spring 2017 semester, students in the following Fall 2017 semester were provided Lightboard videos for lectures 3, 5, 7, 9, 11, and 13.

Alternating the videos in this manner provided the course instructor with a direct comparison of student performance, on identical in-class assignments, with and without having viewed the Lightboard videos. The results from this comparison is provided in Tables 3 and 4 of the Results section along with additional analysis.

Questionnaire-Based Data Collection

Students from both semesters' classes were asked to complete an end-of-semester questionnaire which was completed anonymously. The questionnaire contained two types of questions aimed at addressing different topics:

- Short answer questions regarding student perspectives of inverted classrooms.
- Likert-scale questions that address the impact of the Lightboard videos on student learning and problem-solving skills. These questions were separated into three broad categories: understanding, engagement and satisfaction.

Table 1. Schedule of Lightboard Video Use between Two Consecutive Semesters

Lecture No.	Topics	Spring 2017	Fall 2017	Assessment Measure
2	Pressure, Barometers, Manometers, Other Pressure Measurement Devices	✓		HW Set #1
3	Hydrostatic forces on plane surfaces		✓	HW Set #2
4	Hydrostatic forces on curved surfaces, Buoyancy and Stability	✓		HW Set #3
5	Conservation of Mass, Continuity Equation, Euler and Bernoulli Equations		✓	HW Set #4
6	Reynolds Number, Laminar Flow in Pipes, Turbulent Flow in Pipes, Minor Losses	✓		HW Set #5
7	Energy and Hydraulic Grade lines, Pitot Tubes, Series and Parallel Flows		✓	HW Set #6
8	Dimensional Analysis, Similitude, Orifice & Venturi Meters	✓		HW Set #7
9	Linear Momentum I		✓	HW Set #8
10	Linear Momentum II, Drag, Lift	✓		HW Set #9
11	Turbomachinery - Pumps, Pump Performance and System Curves, NPSH		✓	HW Set #10
12	Pump and Turbine Scaling Laws	✓		HW Set #11
13	Principles of Open Channel Flow, Manning's Equation		✓	HW Set #12
14	Uniform Flow, Specific Energy, Critical and Normal Depths	✓		HW Set #13

The qualitative (short answer) questions from the end-of-semester questionnaire were evaluated by reading through the students' answers and summarizing their responses. Conversely, the quantitative data from the Likert-scale questions was analyzed at the class-level using spreadsheets that evaluate statistical measures such as the mean, standard deviation, etc.

Both portions of the questionnaire are shown in Figures 1a and 1b below. Note that information relating to student gender and GPA was also collected in an effort to determine if there is any correlation between these variables and the impact of Lightboard videos on student homework performance. This type of analysis will be performed at a later date, once multiple semesters of data have been collected and the sample size is statistically significant.

CENG 2131 - Spring 2017
End-of-Semester Questionnaire
Flipped Classroom & Lightboard Videos

The following questions relate to the instructor's use of the" flipped classroom" approach and Lightboard videos for this course and will only be used in understanding your perceptions and opinions of the teaching method. The instructor appreciates your honesty in answering the questions and assures you that your answers will not have any impact on your course grade. Please ***not*** *write your name anywhere on this sheet.*

General Information

1. Please indicate your gender:
   a. Male
   b. Female

2. Please indicate your overall grade point average within the following ranges:
   a. < 2.0
   b. 2.1 – 2.5
   c. 2.6 – 3.0
   d. 3.1 – 3.5
   e. > 3.5

Part 1: Questions pertaining to the Flipped Classroom

3. What did you like most about the "flipped classroom" approach used for this course?

4. Was there anything about the "flipped classroom" that you did not like?

5. If you could offer one suggestion to improve the flipped learning experience, what would it be?

6. It what ways has the "flipped classroom" learning environment helped you learn this semester?

7. In what ways did the "flipped classroom" learning environment not help you to learn this semester?

Figure 1a. First Page of the End-of-Semester Questionnaire

Part 2: Questions pertaining to the Lightboard Videos

Please use the table below in rating different aspects of the course's Lightboard Videos. Use the following scale for your evaluation:

1 = strongly disagree
2 = disagree
3 = neither agree or disagree
4 = agree
5 = strongly agree

	(1)	(2)	(3)	(4)	(5)
Understanding					
1. The videos were easy to watch and understand.	☐	☐	☐	☐	☐
2. The videos helped me visualize the problem solving process.	☐	☐	☐	☐	☐
3. The videos helped identify major points in solving each problem.	☐	☐	☐	☐	☐
4. Having handwritten notations (equations, etc.) helped with my understanding.	☐	☐	☐	☐	☐
5. Overall, the Lightboard videos improved my understanding.	☐	☐	☐	☐	☐
Engagement					
6. The interactive nature of the videos made it easier to pay attention and follow.	☐	☐	☐	☐	☐
7. The length of the videos was appropriate.	☐	☐	☐	☐	☐
8. Watching the videos was an effective use of my time.	☐	☐	☐	☐	☐
9. The Lightboard technology is an appropriate way to engage students through an online environment.	☐	☐	☐	☐	☐
10. Overall, the Lightboard videos were engaging.	☐	☐	☐	☐	☐
Satisfaction					
11. I found the videos interesting and stimulating.	☐	☐	☐	☐	☐
12. The video's technology is attractive (style wise).	☐	☐	☐	☐	☐
13. The videos are an effective tool for learning about fluid mechanics.	☐	☐	☐	☐	☐
14. I would recommend Lightboard videos to my peers.	☐	☐	☐	☐	☐
15. I would recommend developing and using more Lightboard videos for *this* class.	☐	☐	☐	☐	☐
16. I would recommend developing and using more Lightboard videos for *other* engineering courses.	☐	☐	☐	☐	☐
17. Overall, I enjoyed and recommend the Lightboard videos.	☐	☐	☐	☐	☐

Figure 1b. Second Page of the End-of-Semester Questionnaire

Results:

This section presents the qualitative results as measured through a questionnaire which addresses the students' perspectives of the inverted classrooms. Quantitative results are also presented both in two forms: i) assessment of student responses to Likert-scale questions pertaining to their perceptions of the Lightboard videos in the end-of-semester questionnaire and ii) a statistical evaluation of student performance on identical assignments with and without having viewed the Lightboard videos prior to class.

Qualitative Data Analysis

At the conclusion of each course, students completed a questionnaire containing five short answer questions addressing their views on the use of the inverted classroom model for their course. The following provides a representative sample of the comments received from the questionnaire:

What did you like most about the "flipped classroom" approach used for this course?

- I liked that we did our homework in class because that is what most students struggle with and seldom seek help with.
- I liked have exposure to the material multiple times: at home, at the beginning of each class, and during the problem solving sessions.
- It forced students to work together as a group (something we'll have to do when we graduate).
- Having daily tickets and in-class assignments helped me keep up in the class and not fall behind.
- It allowed me to study and learn at my own pace.

Was there anything about the "flipped classroom" that you did not like?

- It required me to retrain myself (during the first few weeks) because it was so different.
- If somebody within the group was not pulling their weight, it put extra work on the other group members.
- I didn't like having to learn the material from scratch by myself.
- I'd like to see more intervention by the instructor during the in-class problem solving sessions. He made the group work through our own difficulties which is frustrating.
- I felt that the online lessons had less examples.

If you could offer one suggestion to improve the inverted learning experience, what would it be?

- I'd like to see some more cool videos.

- Sometimes the color of Dr. Rogers' shirt color interfered with the writing on the Lightboard. He needs to choose his shirt color wisely.
- I'd like to see more in-class examples so that I can hear the teacher's explanations.
- Assign additional (independent) homework problems for students to do outside of class.
- Highlight key points in the videos and lessons.

In what ways has the "flipped classroom" learning environment helped you learn this semester?

- It's really beneficial having the teacher available in class to answer my homework-related questions.
- I found it helpful to review the material at home then come to class with specific questions.
- It helped me with attendance since it was important for me to come to class
- I learned a lot by working with others.
- It takes the focus away from doing homework for just the grade.

In what ways did the "flipped classroom" learning environment not help you to learn this semester?

- Since the in-class activities focused on problem-solving, I felt like I didn't learn enough about the theory.
- The tickets focused on mostly concepts, while the homework focused on calculations. It wasn't always clear which part (concepts, application) was more essential in the class.
- Having in-class homework kept me from studying more outside the classroom.
- Sometimes (not often) I piggybacked off other students and didn't contribute to the problem solving sessions.
- I learn better in a lecture-based classroom environment

<u>Qualitative Data Analysis</u>

Table 2 summarizes the student responses taken from two sections of the course from the Spring 2017 and Fall 2017 semesters (total enrollments of 37 and 34 respectively) to Likert-scale questions from the end-of-semester questionnaire. For the Spring 2017 semester, the average response was a 4.10 with a low of 3.68 and a high of 4.50 respectively. The two of the lowest scoring questions (3.68, 3.73) were for question 6 (interactive nature of the videos made it easier to pay attention and follow) and question 8 (watching the videos was an effective use of my time). Both questions are within the engagement category, indicating that there is room for improvement in developing more engaging videos. The highest scores for the Spring semester (4.50, 4.36) were for question 1 (the videos were easy to watch and understand) and questions 2 and 6 (the videos helped me visualize the problem solving process, the Lightboard videos improved my understanding). Having these questions score high was encouraging considering the purpose of developing the Lightboard videos was to make the lesson enjoyable while also improving student understanding.

Table 2. Comparison of Student Rating Data for Questions Relating to Lightboard Videos from End-of-Semester Questionnaires

Questions Relating to Lightboard Videos	**Average Student Rating (Scale: 1-5)**	
	Spring 2017	**Fall 2017**
Understanding		
1. The videos were easy to watch and understand.	4.50	4.41
2. The videos helped me visualize the problem solving process.	4.36	4.24
3. The videos helped identify major points in solving each problem.	4.00	4.13
4. Having handwritten notations (equations, etc.) helped with my understanding.	4.32	4.41
5. Overall, the Lightboard videos improved my understanding.	4.36	4.42
Engagement		
6. The interactive nature of the videos made it easier to pay attention and follow.	3.68	3.54
6. The length of the videos was appropriate.	4.14	4.19
7. Watching the videos was an effective use of my time.	3.73	3.92
8. The Lightboard technology is an appropriate way to engage students through an online environment.	4.09	4.27
9. Overall, the Lightboard videos were engaging.	4.00	4.16
Satisfaction		
10. I found the videos interesting and stimulating.	3.77	3.86
11. The video's technology is attractive (style wise).	4.14	4.08
12. The videos are an effective tool for learning about fluid mechanics.	4.14	4.24
13. I would recommend Lightboard videos to my peers.	4.23	4.34
14. I would recommend developing and using more Lightboard videos for ***this*** class.	4.09	4.23
15. I would recommend developing and using more Lightboard videos for ***other*** engineering courses.	4.05	4.34
16. Overall, I enjoyed and recommend the Lightboard videos.	4.18	4.24

Results from the Fall 2017 semester were very similar; the average response was 4.17 with a low of 3.54 and a high of 4.42. Like the Spring 2017 semester, two of the lower scoring questions (question 6 relating to the interactive nature of the videos, question 8 which addresses if watching the videos is an effective use of time) are within the engagement category. This common trend indicates that more attention needs to be placed on making the videos more engaging.

Table 3 compares student performance on in-class assignments in which students viewed Lightboard videos as part of their pre-class preparations during the Spring 2017 semester but did not have access to the videos for the same lecture for the Fall 2017 semester. As shown in the table, the average assignment scores during the Spring 2017 semester ranged from 76.57% to 85.87% with an average of 83.43%. Fall 2017 performance varied from 69.82% to 86.32% with a slightly lower average of 81.98%. While having access to the videos increased student performance by only a modest 1.45%, it's important to note that student performance did improve in 5 of the 7 measures.

Table 3. Comparison of Student Performance for Assignments in which Lightboard Videos were used in Pre-Class Lectures in Spring 2017 but not in Fall 2017

Lecture No.	Topics	Average Student Performance	
		Spring 2017 (with Video)	Fall 2017 (without Video)
2	Pressure, Barometers, Manometers, Other Pressure Measurement Devices	85.87%	85.02%
4	Hydrostatic forces on curved surfaces, Buoyancy and Stability	76.57%	69.82%
6	Reynolds Number, Laminar Flow in Pipes, Turbulent Flow in Pipes, Minor Losses	85.22%	84.32%
8	Dimensional Analysis, Similitude, Orifice & Venturi Meters	84.33%	81.89%
10	Linear Momentum II, Drag, Lift	85.67%	86.32%
12	Pump and Turbine Scaling Laws	84.58%	84.03%
14	Uniform Flow, Specific Energy, Critical and Normal Depths	81.78%	82.46%

Table 4 is similar to that of Table 3, but compares student performance on in-class assignments in which the students did not have access to Lightboard videos in the Spring 2017 semester, but did review the videos for the same lecture in the Fall 2017 semester. Observe that the scores for the assignments in Spring 2017 in which Lightboard videos were not used, ranging from 81.71% to 86.05% with an average of 83.95%, were lower than the scores on assignments in the Fall 2017 semester. The range of scores for the Fall 2017 semester was 82.89% ~ 87.50 with a mean of 85.17%. In addition to having a slightly higher average performance (1.22%), the table illustrates that providing students access to the videos before class improved student performance in 5 of the 6 measures. The trends shown in Tables 3 and 4, both in terms of the overall (average) student scores and in terms of performance on specific measures (students with access to the videos scored higher in 10 of the 13 measures) clearly illustrate that the videos contribute to student learning.

Table 4. Comparison of Student Performance for Assignments in which Lightboard Videos were used in Pre-Class Lectures in Fall 2017 but not in Spring 2017

Lecture No.	Topics	Average Student Performance	
		Spring 2017 (without Video)	Fall 2017 (with Video)
3	Hydrostatic forces on plane surfaces	81.71%	82.89%
5	Conservation of Mass, Continuity Equation, Euler and Bernoulli Equations	85.32%	87.50%
7	Energy and Hydraulic Grade lines, Pitot Tubes, Series and Parallel Flows	84.56%	84.14%
9	Linear Momentum I	81.94%	83.42%
11	Turbomachinery - Pumps, Pump Performance and System Curves, NPSH	84.13%	86.26%
13	Principles of Open Channel Flow, Manning's Equation	86.05%	86.82%

Discussion:

By comparing student performance on in-class learning activities in which the pre-class component included Lightboard videos with identical assignments in which Lightboard videos were not included for two consecutive semesters, the study sheds some insight on how the use Lightboard videos impact student learning. While this study is a step in the right direction, clearly more data needs to be collected (over several semesters and with different courses) in order to establish definitive results and trends that can be used to improve online and/or blended courses.

The quantitative (Likert-scale questions) and qualitative (short answer questions) data collected through an end-of-semester questionnaires provided valuable insight regarding student perspectives of flipped classrooms, ways in which blended courses can stimulate critical thinking, and the strengths and weaknesses of the Lightboard videos themselves.

Observations relating to the inverted classroom:

- Students benefit from having exposure to the lesson material multiple times: online before class, during the instructor's lesson review at the beginning of class, and during the in-class problem solving sessions.
- The online environment allows students to review lesson material at their own pace. Whereas advanced students liked the freedom to move quickly through material, students struggling with certain topics are able to move at a slower pace (replay videos, take notes on slides, etc.).
- Students prefer the collaborative in-class problem solving environment to the traditional method of using homework assignments as a student's first exposure to problem solving.
- Having daily tickets and in-class assignments keeps students from falling behind.
- The inverted classroom allows instructors to use class time for more challenging and engaging activities that stimulate critical thinking. By covering fundamental concepts prior to class, instructors can use class time to explore practical applications and push students to "think outside the box".

Observations relating to the Lightboard videos:

- Responses from the Likert-scale questions suggest that the videos have good content, are effective in helping students visualize the problem solving process, and help students grasp fundamental concepts.
- Lower student ratings on engagement-related questions (the interactive nature of the videos made it easier to pay attention and follow, watching the videos was an effective use of my time, etc.) clearly indicate that the instructor needs to make the videos more entertaining and appealing to the students.
- Student feedback from end-of-semester questionnaires and direct conversations with the instructor clearly indicate that students enjoy the videos, believe that the videos enhance the course content, and feel that the videos strengthen their understanding of the subject matter.
- Despite an overall trend in which student performance on in-class assignments generally improved in lessons in which students viewed the Lightboard videos as part of their pre-class preparations, the variability of the assignment-level data (Tables 3 and 4) and modest overall increases (1.45% and 1.22% respectively) indicate that correlation between student learning and the use of videos is weak at best. This finding was confirmed in other studies cited in the literature review.

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