ASEE's 123rd Annual • Conference & Exposition • New Orleans, LA • June 26-29, 2016

Paper ID #15188

Teaching First-Year Engineering Design Using a Flipped Classroom Model

Dr. Ann Saterbak, Rice University

Ann Saterbak is Professor in the Practice in the Bioengineering Department and Associate Dean for Undergraduate Education in the School of Engineering at Rice University. Saterbak was responsible for developing the laboratory program in Bioengineering. Saterbak introduced problem-based learning in the School of Engineering and more recently launched a successful first-year engineering design course taught in the Oshman Engineering Design Kitchen. Saterbak is the lead author of the textbook, Bioengineering Fundamentals. Saterbak's outstanding teaching was recognized through university-wide and departmental teaching awards. In 2013, Saterbak received the ASEE Biomedical Engineering Division Theo C. Pilkington Outstanding Educator Award. For her contribution to education within biomedical engineering, she was elected Fellow in the Biomedical Engineering Society and the American Society of Engineering Education.

Dr. Matthew Wettergreen, Rice University

Matthew Wettergreen is a lecturer at the Oshman Engineering Design Kitchen. He teaches engineering design courses, including first-year engineering design and their follow on engineering design courses. Additionally he provides education via hands-on workshops and formal courses that teach students how to manufacture prototypes via low fidelity prototyping, iterative design, and the use of advanced manufacturing tools to produce high quality functioning devices. Matthew received his Ph.D. from Rice University in Bioengineering.

Zoe Roberts, Rice University

Zoe Roberts is in her third year of studying mechanical engineering at Rice University. She plans to graduate in May of 2017 and work in the field to gain first-hand experience before heading to graduate school. Zoe is interested in education, product design, and sustainability. Zoe became involved with the Flipped Classroom teaching model last summer and is currently helping to implement it at Rice University.

Teaching First-Year Engineering Design Using a Flipped Classroom Model

Abstract

A team of faculty at Rice University and other institutions has created instructional resources to support a flipped classroom model for first-year engineering design. Gone is the traditional 'class' in which faculty lecture on the design process and other professional skills. These 'lectures' are now delivered on video, essentially shifting low cognitive load work to videos that students watch outside of class. In class, students complete active learning exercises focused on the engineering design process. Afterwards, student teams also apply the engineering design process to their specific projects.

The authors have created the following educational materials to flip the first-year multidisciplinary engineering design classroom:

- Sixty web-based videos featuring student teams and faculty at Rice University as well as three other institutions that focus on steps of the engineering design process and professional skills. Topics include defining the problem, researching the design problem, framing design criteria, brainstorming solutions, selecting solutions with Pugh matrices, project planning using Gantt charts, prototyping, and testing.
- Twenty-one online quizzes (with 10-25 questions each) that cover information discussed in the videos. Quizzes are multiple choice and true/false and test students' knowledge and application of the technical content in the videos.
- Thirty in-class exercises that support active learning in the classroom. The in-class exercises typically require students to apply a specific step in the design process to a new problem, critique a completed design step, or synthesize knowledge.

During the 2015-2016 academic year, all engineering design and professional skills lectures were flipped. The focus of this poster is to qualitatively and quantitatively evaluate students' use of the videos, quizzes, and in-class exercises during the fall 2015 semester. Using analytics from YouTube and our course management software, we evaluated the percent of students who watched the videos, the number of students who started the videos, the average watch time, the percent of students who completed the quiz, and their grades. From this we learned that >80% of the students started the instructor videos, and that the number of student starts and average video watch time declined during a given playlist. Also, students performed well on quizzes, with an average score of 90%.

These materials are available for others to use. The team is seeking feedback on developing materials that will be helpful for the academic community teaching engineering design.

Emergence of Flipped Classroom Model

The flipped classroom is a style of teaching that is gaining steam within many schools and universities. The premise behind a flipped class is that students complete the lower-level thinking associated with listening to a lecture out of class and complete activities that target higher levels of thinking while they are in class with the instructor present. Typically, the "lecture" material is transferred to rich media that can be watched outside of the classroom. Some STEM educators who have adopted the flipped class model at universities have seen increases in student test scores when compared to students studying in traditional lecture-based classes.[1,2] There is increasing evidence that the flipped classroom is an applicable model to technical disciplines such computer science, mechanical engineering, and upper-level math.[3,4,5]

Student feedback has shown that the ideal video length is less than 15 minutes; students voice concerns about videos that are longer than 20 minutes.[6] Qualitative student feedback from various studies has shown that students find videos to be beneficial to watch but details on watch times are scarce.[5,7,8] One study of an information technology course at Indiana University Purdue University at Indianapolis found that in a flipped class of 27 people, over half of the students reported watching less than 90% of assigned recorded videos.[9] The study also found that a majority of the students reported rarely rewatching videos.[9] As flipped classrooms become more common, it is important to know the extent to which students use faculty-produced videos. This paper explores how students utilize videos and analyzes their watching behavior.

First-Year Design Course

Introduction to Engineering Design (ENGI 120) is a one-semester multidisciplinary design course for freshman students at Rice University. In ENGI 120, students learn the engineering design process and use it to solve meaningful problems drawn from Rice University campus, local hospitals, local non-profits, and international communities.

In brief, the first half of the semester is devoted to defining the design problem, developing the design context review, establishing design criteria, brainstorming solutions, using a Pugh matrix to evaluate and select a solution, and then describing the selected solution. During the second half of the semester, student teams focus on physical prototype development and testing. Teams are expected to build prototypes of increasing fidelity, culminating with a functional prototype that meets some of the established design criteria. The course outcomes, structure, and deliverables have been described in detail elsewhere.[10]

Methods for Video and Quiz Analytics

Before coming to class, students were required to watch videos on the assigned videos and complete the associated quiz. The videos for ENGI 120 were integrated into a university course management system and were also hosted on YouTube as playlists. Quizzes were administered on the university course management system.

From our university course software, we pulled the following analytics:

- Number of people who took a quiz for each module
- Total possible points of each quiz
- Score on each quiz for each student

The metrics that YouTube reports for each video included the following:

- Length of video
- Watch time
- Views
- Unique cookies
- Geographical location
- Traffic sources
- Playback location (playlist or embedded page)

"Views" is an ill-defined metric that is analogous to, but not equivalent to, the number of people who watched the video. While YouTube defines views as "the number of times a video was viewed," YouTube does not report how views are calculated.[11] If one person watches a full video or even a portion of a video twice, that can count as two views. To know how many unique people watched the video, YouTube offers a metric called "unique cookies" that reports unique viewers by planted cookies. This metric only assesses desktops and does not include mobile devices, tablets, or TV views of a video. In surveying the video analytics, it was clear that "unique cookies" was a much better approximation to the number of unique students who started the videos (i.e., unique views) than the number of "views" reported by YouTube.

To establish the number of student starts, we used the minimum of the reported number of unique views (i.e., unique cookies) or the number of students in the class (82 in fall 2015). For some modules, not all students watched the videos, as observed by the number of submitted quizzes being less than 82, which is why we used the analytics of unique views. To calculate the average watch time per student, we divided total watch time (defined as the estimated total minutes of viewing time of the video[12]) by the number of students who started the video.

Overview of Flipped Classroom Materials

The team produced flipped classroom materials for 20 modules on the engineering design process and professional skills. For each topic, there are three components of the developed instructional materials:

- Web-based videos featuring student teams and faculty
- Online quizzes that cover information discussed in the videos
- In-class exercises (ICEs) that support active learning in the classroom

Videos

To date, the authors from Rice University and their colleagues have produced 60 web-based videos, which are grouped into 20 modules (Table 1). Most of these playlists can be found online at http://goo.gl/5HBkJ5.

Table 1. Details of video modules. Playlist links are live.

Playlist Title	# of Instructor Videos	# of Design Team Videos	Playlist Link
Engineering design process overview	1	0	https://www.youtube.com/playlist?list=PLFiViU_gwuxkjAqcY-sriotrEfYbLOlzH
Clarifying team assignments	1	1	https://www.youtube.com/playlist?list=PLFiViU_gwuxkTUjDxMvmxJAHvDv4Q3Wy7
Understanding the problem and context	5	0	https://www.youtube.com/playlist?list=PLFiViU_gwuxkiP-aCbjY9jwG-_IjOa6RR
Design criteria	4	3	http://www.youtube.com/playlist?list=PLFiViU_gwuxmx-q9jgr1fpkOBPm4YYMls
User-defined scales	1	2	http://www.youtube.com/playlist?list=PLFiViU_gwuxn0XlompVzPvSgaDTYreHlx
Pairwise comparison charts	3	3	http://www.youtube.com/playlist?list=PLFiViU_gwuxlzKhwcohMGN0o7eFIeUrtp

Brainstorming	3	2	http://www.youtube.com/playlist?list= PLFiViU_gwuxkW5tcLdur2xsec-Fb11iz2
Decomposition	1	3	http://www.youtube.com/playlist?list= PLFiViU_gwuxngirzaJqF6trrtxHL4MH3H
Morphological charts	1	3	http://www.youtube.com/playlist?list= PLFiViU_gwuxmIp-P1HEQvIyVdtE3BaN_y
Pugh screening matrix	5	3	http://www.youtube.com/playlist?list= PLFiViU_gwuxnlc2RkX2laBc5QaKnzjuae
Pugh scoring matrix	2	3	http://www.youtube.com/playlist?list= PLFiViU_gwuxkisOyufuyQs-Z7GHhXdFgh
Prototyping - Overview	2	0	https://www.youtube.com/playlist?list=PLFiViU_gwuxkWiJSdiQvQM_KaSU53jBFA
Prototyping - Tools	1	0	https://www.youtube.com/playlist?list=PLFiViU_gwuxl56p1MQGYBmMEN_SzMPwci
Low fidelity prototypes	2	2	https://www.youtube.com/playlist?list=PLFiViU_gwuxkWHQHJFFfqZh2e6zSzE-A9
Medium fidelity prototypes	2	1	
Testing	4	0	https://www.youtube.com/playlist?list=PLFiViU_gwuxnPvcQuvcS_GH1iMn9SbUX2
Teamwork	3	0	https://www.youtube.com/playlist?list=PLFiViU_gwuxnulj3Gr8dXlV8WnrV-lgId
Intellectual property	1	0	
Project planning	2	0	https://www.youtube.com/watch?v= C3aM4suNHGc&list=PLFiViU_gwuxlbq2L6GHRWC9NLmV8gLrMs
Presenting a design proposal	1	0	https://www.youtube.com/watch?v= MisdE7l8q2w&list=PLFiViU_gwuxmAMSJjLRAELSFiY6R9_UBY&index=27

In keeping with best practices, the videos are 1-11 minutes in length, except for the video on presenting a design proposal, which is about 30 minutes in length (Table A1 in Appendix). The instructor videos are a mixture of one of the instructors talking, the instructors dialoguing with each other, slide-show presentations (e.g., PowerPoint), and an instructor talking with text added to the side. Instructor videos focus on describing methods, defining relevant terms, and explaining strategies.

In addition, three former ENGI 120 student design teams at Rice University produced videos to support 11 modules. These videos present a reenactment of the student team tackling their previous design problem at the relevant step of the engineering design process. These videos explicitly show common pitfalls and best practices. More detailed descriptions of the instructor and student videos can be found elsewhere.[13]

Quizzes
Online quizzes monitor students' knowledge and application of the content presented in the videos. The quizzes test students' basic understanding of key terms and processes presented in the instructor videos. They are comprised mostly of multiple choice and true/false questions. For each module, 10-25 questions have been developed. Quizzes can be found at https://goo.gl/dRlihx.

In-class Exercises
In-class exercises (ICE) are used as a way to bridge students from knowledge gained while watching the videos to their own design projects. Specifically, the ICEs strengthen students' understanding of the design process and professional skills by requiring them to practice these steps. Examples include applying knowledge to a new problem, evaluating a completed design scenario, and completing a table based on a new scenario. To date, we have developed 30 ICEs. ICEs can be found at https://goo.gl/dRlihx.

Implementation of Flipped Model Materials
Videos
Table 2 charts the video analytics for three selected modules from fall 2015; they were selected because they exemplify typical patterns. (Complete analytics are shown for all videos used in fall 2015 in Table A1.) The main learnings from these analytics are:

- 80-100% of the students started each of the instructor videos.
- Within a playlist, there is a drop-off in the percent of students who started the instructor videos from the first to the last video. In other words, fewer students began a video the farther it was in an assigned playlist series.
- For the first instructor video in the series, the average watch time was 80-100% or more of the length. The exception for this was the Pugh screening and Pugh scoring videos, which were lower (~50% of the length).
- Most students did not watch the student team or example videos. Most team videos were turned on by only 25-50% of the class. When the videos were started, typically less than 50% of the video was watched, based on average watch time.
- 95% of students watched the videos on computers, whereas only 5% watched the videos on handheld devices (data not shown).

Quizzes
Table 3 charts the quiz analytics for the modules in fall 2015. The main learnings from these analytics are:

- Almost all students (typically 85-100%) took the quiz. Since completion (not score) was part of the grade for the course, this was not surprising.
- Grades were typically >80% on a quiz, with an average value of 90%. The coefficient of variation ranged 5-20%.

Table 2. Selection of video analytics from fall 2015. The number of student starts is the minimum of the reported number of unique views or the number of students in the class (82).

Playlist Title	**Video Title**	**Length of Video (min:sec)**	**# of Student Starts**	**% Students Who Started Video**	**Average watch time (min:sec)**
Pairwise comparison chart	Introduction	7:07	82	100	5:23
	Setting Up and Running Them	5:00	76	93	3:55
	Discussion	5:39	70	85	4:49
	Student Team: HWHC	9:22	53	65	3:08
	Student Team: Safe Soap	10:16	27	33	3:27
	Student Team: IV Drip	8:37	20	24	2:15
Brain-storming	Brainstorming	5:18	76	93	5:54
	Methods	4:43	71	87	3:57
	SCAMPER	3:18	65	79	3:10
	Student Team: Safe Soap	4:24	46	56	2:53
	Student Team: HWHC	5:17	31	38	3:27
Testing	Testing	5:00	82	100	4:16
	Categories of Measurement	6:56	71	87	3:57
	Involving Users in Testing	5:51	67	82	3:24
	Testing Results and Iteration	3:19	62	76	2:09

Table 3. Quiz analytics from fall 2015.

Playlist Title	**Number of Submitted Quizzes**	**% Students Who Submitted Quizzes**	**# Questions on the Quiz**	**Score (Average $\pm$ Std Dev)**
Engineering design process overview	79	96	10	9.2 ± 0.9
Clarifying team assignments	78	95	10	8.5 ± 1.2
Understanding the problem and context	76	93	14	11.4 ± 1.1
Design criteria & User-defined scales	76	93	12	10.34 ± 1.2
Pairwise comparison chart	71	87	6	5.3 ± 0.6
Teamwork	73	89	8	7.8 ± 0.5
Brainstorming	70	85	8	6.9 ± 1.1
Decomposition	80	98	6	5.3 ± 0.7

Morphological charts	80	98	5	4.1 ± 0.9
Pugh screening matrix	78	95	8	7.6 ± 0.7
Pugh scoring matrix	72	88	7	6.2 ± 1.0
Presenting a design proposal	79	96	16	13.0 ± 1.8
Prototyping - Overview	82	100	14	13.6 ± 0.9
Prototyping - Tools	82	100	5	4.9 ± 0.3
Low fidelity prototypes	82	100	7	4.4 ± 0.9
Project planning	64	78	14	12.7 ± 1.4
Testing	79	96	10	9.8 ± 0.5

In-class Exercises

Twelve ICEs were implemented in fall 2015. Due to the purpose of ICEs and their implementation during class, there are no analytics on the ICEs. Students kept those papers for references for their own work. Qualitative feedback from students suggested that ICEs elucidated common pitfalls, which were then often avoided.

Discussion of Implementation of Flipped Classroom Model

Implementing videos via the course management system was easy and straightforward. Overall, we were pleased that most students were starting the instructor videos and that the average watch time on each video was 50-100+%.

We were disappointed that many students did not watch the student design team videos, or if they did, they watched only a small fraction of the overall video. We are uncertain as to whether the placement of the student team videos at the end of the playlist led to this phenomenon, or whether students did not find these videos as valuable. Another possibility is that students were not motivated to watch the team videos because the quizzes probed information usually found only on the instructor videos.

Overall, students performed well on the quizzes. The overall average score of 90 is impressive, especially since the quizzes were marked for completion only and lumped into a class participation grade. When many students missed an answer to a question on a quiz, the topic was addressed in class and/or considered for a rewrite (if the question was ambiguously stated).

The instructors were pleased with the implementation of the ICEs. When circulating among the class during the ICEs, it was clear to the instructors that most students had watched the videos and absorbed the content, as deep conversation about design topics were occurring.

As other faculty begin to adopt the flipped classroom model, we encourage a conversation about how students use videos and other media-rich materials outside of class. Neither self-report surveys nor our data taken from YouTube analytics can give a complete picture of how students use and learn in this model.[9] However, the results reported here suggest strong student participation in a flipped classroom for a first-year engineering design class.

Acknowledgments

This work is supported in part by an NSF DUE grant (#1244928).

References

[1] B. B. Stone, "Flip your classroom to increase active learning and student engagement," in *28th Annual Conference on Distance Teaching and Learning*, Madison, 2012.

[2] C. Merrett, "Using Textbook Readings, YouTube Videos, and Case Studies for Flipped Classroom Instruction of Engineering Design," in *Proceedings 2015 Canadian Engineering Education Association Conference*, Hamilton, Ontario, 2015.

[3] A. Amresh, A. Carberry and J. Femiani, "Evaluating the effectiveness of flipped classrooms for teaching CS1," in *Frontiers in Education Conference*, Oklahoma City, 2013.

[4] G. Mason, T. R. Shuman and K. Cook, "Comparing the Effectiveness of an Inverted Classroom to a Traditional Classroom in an Upper-Division Engineering Course," *IEEE Transactions of Education*, vol. 56, no. 4, pp. 430 - 435, 2013.

[5] B. Love, A. Hodge, N. Grandgenett and A. W. Swift, "Student learning and perceptions in a flipped linear algebra course," *International Journal of Mathematical Education in Science and Technology*, vol. 45, no. 3, pp. 317-324, 2014.

[6] D. Wagner, P. Laforge and D. Cripps, "Lecture Material Retention: a First Trial Report on Flipped Classroom Strategies in Electronic Systems Engineering at the University of Regina," in *Proc. 2013 Canadian Engineering Education Association (CEEA13) Conference*, Montreal, 2013.

[7] C. Reidsema and L. Kavanagh., "Flipping the Classroom at Scale to Achieve Integration of Theory and Practice in a First Year Engineering Design and Build Course.," in *American Society of Engineering Education Conference Proceedings*, Indianapolis, 2014.

[8] K. Calabro, "Flipping the Classroom on an Established Introduction to Engineering Design Course," in *First Year Engineering Experience Conference*, Pittsburgh, 2013.

[9] R. Elliott, "Analysis of Student Perceptions and Behaviors in a Flipped Classroom Undergraduate Information Technology Course," in *American Society of Engineering Education Conference Proceedings*, Indianapolis, 2014.

[10] A. Saterbak, M. Embree and M. Oden, "Client-Based Projects in Freshman Design," in *American Society of Engineering Education Conference Proceedings*, San Antonio, 2012.

[11] "Youtube Analytics API," [Online]. Available: https://developers.google.com/youtube/analytics/v1/dimsmets/mets.

[12] "Youtube Watch time reporting," [Online]. Available: https://support.google.com/youtube/answer/1714329?ref_topic=1714326&guide=1714169.

[13] A. Saterbak and M. Wettergreen, "Teaching Freshman Design Using a Flipped Classroom Model," in *American Society of Engineering Education Conference Proceedings*, Seattle, 2015.

Appendix

Table A1. Video analytics from fall 2015.

Playlist Title	Video Title	Length of Video (min:sec)	# of Student Starts	% Students Who Started Video	Average watch time (min:sec)
Engineering design process overview	Engineering Design Process Overview	8:27	70	85	10:39
Clarifying team assignments	Clarifying Team Assignments	5:42	82	100	8:00
	IV Drip Client Interview	11:54	76	93	9:31
Understanding the problem and context	The Problem Space	3:12	82	100	4:20
	The Design Context Review	5:09	82	100	6:18
	Design Context Review Example	6:28	82	100	6:33
	Research Methods	6:08	82	100	5:29
	Design Problem Statement	5:03	80	98	4:58
Design criteria	Introduction	3:06	82	100	2:53
	Lightweight	1:28	64	78	1:21
	Measurable Units	3:04	64	78	2:38
	Inexpensive	1:45	62	76	1:32
	Student Team: IV Drip	6:56	59	72	4:14
	Student Team: HWHC	3:58	65	79	2:45
	Student Team: Safe Soap	6:50	62	76	4:01
User-defined scales	User-Defined Scales	3:13	74	90	3:40
	Student Team: Safe Soap	5:58	63	77	3:46
	Student Team: HWHC	4:01	55	67	2:31
Pairwise comparison charts	Introduction	7:07	82	100	5:23
	Setting Up and Running Them	5:00	76	93	3:55
	Discussion	5:39	70	85	4:49
	Student Team: HWHC	9:22	53	65	3:08
	Student Team: Safe Soap	10:16	27	33	3:27
	Student Team: IV Drip	8:37	20	24	2:15
Teamwork	Team Roles	3:16	70	85	3:13
	Team Meetings	3:39	74	90	3:11
	High Performing Teams	4:15	70	85	3:41

Playlist Title	Video Title	Length of Video (min:sec)	# of Student Starts	% Students Who Started Video	Average watch time (min:sec)
Brainstorming	Brainstorming	5:18	76	93	5:54
	Methods	4:43	71	87	3:57
	SCAMPER	3:18	65	79	3:10
	Student Team: Safe Soap	4:24	46	56	2:53
	Student Team: HWHC	5:17	31	38	3:27
Decomposition	Decomposition	7:21	82	100	7:53
	Student Team: Safe Soap	4:46	47	57	2:55
	Student Team: HWHC	3:20	39	48	1:25
Morphological charts	Morph Charts	5:29	82	100	5:44
	Student Team: Safe Soap	2:43	36	44	1:30
	Student Team: HWHC	5:54	29	35	2:19
Pugh screening matrix	Engineering Decision Making	6:55	82	100	5:44
	Screening Matrices Set Up	4:32	82	100	3:34
	Spoon Challenge Introduction	4:23	66	80	2:08
	Running Screening Matrices	11:05	44	54	2:41
	Running Screening Matrices Correctly	9:16	57	70	4:21
	Student Team: Safe Soap	3:30	24	29	1:50
	Student Team: HWHC	2:48	18	22	0:37
Pugh scoring matrix	Setting Up Scoring Matrices	7:17	82	100	6:29
	Running Scoring Matrices	9:34	82	100	5:31
Presenting a design proposal	Presenting a Design Proposal	34:08	N/A	N/A	N/A
Prototyping - Overview	Prototyping	8:04	78	95	6:23
	Safety	8:21	73	89	5:37
Prototyping - Tools	Tools Overview	3:33	71	87	2:41
Low fidelity prototypes	Fidelity of Prototypes	6:36	74	90	6:00
	Low Fidelity Prototyping Example	2:55	44	54	1:55

Playlist Title	Video Title	Length of Video (min:sec)	# of Student Starts	% Students Who Started Video	Average watch time (min:sec)
Project planning	Introduction	5:07	72	88	4:43
	How to Set up a Gantt Chart	6:48	67	82	5:50
Testing	Testing	5:00	82	100	4:16
	Categories of Measurement	6:56	71	87	3:57
	Involving Users in Testing	5:51	67	82	3:24
	Testing Results and Iteration	3:19	62	76	2:09