# Online modules enable prerequisite review and mastery during design courses.

**Dr. Stephanie Butler Velegol, Pennsylvania State University, University Park**

Dr. Stephanie Butler Velegol received her BS in Chemical Engineering from Drexel University in 1996 and her PhD in Chemical Engineering from Carnegie Mellon University. She taught for 2 years as a visiting Professor in Chemical Engineering at Bucknell University. She has been teaching Environmental Engineering courses in the Civil and Environmental Engineering Department at Penn State University since 2009. She is pioneering the use of on-line courses for summer courses, flipped courses throughout the semester and professional development in Pennsylvania. In addition, she has advised over a dozen students on the use of Moringa seeds for sustainable water treatment in the developing world.

**Dr. Sarah E Zappe, Pennsylvania State University, University Park**

Dr. Sarah Zappe is Research Associate and Director of Assessment and Instructional Support in the Leonhard Center for the Enhancement of Engineering Education at Penn State. She holds a doctoral degree in educational psychology emphasizing applied measurement and testing. In her position, Sarah is responsible for developing instructional support programs for faculty, providing evaluation support for educational proposals and projects, and working with faculty to publish educational research. Her research interests primarily involve creativity, innovation, and entrepreneurship education.

**Ms. Mary Lynn Brannon, Pennsylvania State University, University Park**

# Online modules enable prerequisite review and mastery during design courses.


## Abstract

All engineering capstone courses are designed with the expectation that students will use knowledge they have obtained in prerequisite classes to design an engineering solution. However, students often come into the design course without mastery of the prerequisite material. Faculty then use class time to review this material, reducing the time that can be spent on the objectives of the course such as engineering design, professional correspondence, and improving technical writing and presentations skills. To solve this problem, we have created a set of online instructional materials that can be used by students in an Environmental Engineering capstone course to ensure that they have mastered the prerequisite material before and while engaging on the design project.

In this case the students designed a water treatment system to remediate acid mine drainage entering the headwaters of a local river. This design required knowledge of mass balances, reactor design, acid/base chemistry and particle setting. To test for mastery of these prerequisite topics, a pre-quiz was given on these topics during the first week of class. These quizzes were graded for mastery and returned to the students. The students were directed to a related online video that reviewed the specific engineering topic covered by each question. The students then took a quiz on the same topics during the 3rd week of the course that counted as part of their grade.

We will discuss how the use of the videos affected their mastery of the material, as assessed by their post-test performance. In addition, we will discuss how the students interacted with these online modules as assessed by student surveys and focus groups. Finally we will include the benefits and costs from the faculty perspective. This will allow us to make suggestions for applying this technique to other disciplines within engineering and other Environmental Engineering courses.


## Introduction

Successful engineers possess not only technical skills but also the ability to apply these technical skills to real life problems. In her book *The 21st Century Engineer*, Patricia D. Galloway states that, "While engineers remain strong in terms of their technological skills, they are generally weak in terms of their management and communication capabilities."[1] (p. 2) In most engineering curriculums, these management and communication capabilities are best learned in the capstone, or design courses that students take during their senior year. In the typical design course, students apply the wide range of technical skills they have learned in their prerequisite courses to solve an engineering challenge. During this process, they learn to manage people by working in groups and to communicate their findings through both written reports and oral presentations.

One of the challenges is that, although students have successfully completed the prerequisite courses, they may not have mastered (or cannot recall) the necessary technical skills required in the design of an engineering solution. Faculty then use class time to review this material. This reduces the time that can be spent on the objectives of the course such as engineering design, professional correspondence, and improvement of technical writing and presentation skills. One simple reason students may not recall the technical skills is because they may not have been exposed to it in prior courses! In large engineering departments, one course may be taught independently by different faculty members who may teach slightly different content in a unique manner.

Even if the students were exposed to the technical material in the prerequisite courses, they may not be able to easily recall the information. In his book, *Development of professional expertise: Toward measurement of expert performance and design of optimal learning environments*, Ericsson states that only experts can easily recall information and that: "everyone, even the most talented individuals, needs to invest 10 years of active engagement in a domain to become expert."[2] (p. 412). Students simply can't recall this technical material because they have not been actively engaged with the material for enough time.

Our goal in this paper is to describe how we decreased the amount of time students spend *in* class reviewing prerequisite material in an environmental engineering design class. We accomplished this by creating a set of online instructional materials that students use to ensure that they have mastered the prerequisite material before and while engaging on the design project.

We will discuss the improvement of students' recall of technical content and their use of these videos. In addition, we will discuss how the students interacted with these online modules as assessed by student surveys and focus groups. Finally we will include the benefits and costs from the faculty and curriculum perspective. This will allow us to make suggestions for applying this technique to environmental engineering design courses and to other engineering disciplines.

## Materials and Methods

### Description of Design Course

The study took place at a large, mid-Atlantic research-oriented university. Sixteen students, all seniors in Civil Engineering, were enrolled in the environmental engineering design course during Fall 2013. The students were asked to design a water treatment system to remediate acid mine drainage (AMD) entering the headwaters of a local river. A number of agencies had previously framed a conceptual design that involved water collection/pumping, aeration, sedimentation, and wetland polishing before final discharge to the river. The students were asked to design the aeration, sedimentation, and wetland polishing components for this treatment system.

Design teams made up of four students were required to turn in two written reports and give a 15 - 25 minute oral presentation on each report. In these reports, the students were asked to determine physical and operational parameters for each unit process capable of meeting specific design objectives, estimate capital and operating costs for each unit process, and figure out how to situate each and all the unit processes on the site.

The program outcomes mapped to this course include:

- An ability to design a system, component, or process to meet desired needs
- An ability to function on multi-disciplinary teams
- An ability to communicate effectively
- An understanding of professional and ethical responsibility
- Knowledge of contemporary issues
- A recognition of the need for, and an ability to engage in, life-long learning

**Description of online modules and assessment of student's mastery of material**

After careful discussion between the prerequisite course instructor and the design instructor, specific topics were chosen that covered technical content required for the design of the water treatment system. To test for mastery of these prerequisite topics, two unique quizzes were prepared with questions related to these topics as shown in Table 1. These multiple choice questions were carefully created to directly link the technical topic to the specific water treatment design. For example, the question testing their ability to design a CSTR was related to limestone neutralizing acid mine drainage-impacted water (See Table 2).

**Table 1: Student learning objectives for the Quiz 1 and Quiz 2. Quiz 1 was given on the first day of classes and did not count. Quiz 2 was given during the 3rd week of classes after the students were given the opportunity to watch the online modules.**

| Quiz 1 Question | Quiz 2 Question | Students should be able to: |
|---|---|---|
| 1 | 1 | Balance a chemical equation and determine mass of a product given mass of a reactant. |
| 2 | 2 | Determine the mass of a product given the mass of a reactant. |
| 3 | 3 | Calculate the concentration in mg/L as $CaCO_3$ given the concentration in moles/L or mg/L. |
| 4 | n/a | Calculate the settling velocity given the particle density and diameter. |
| 5 | 4 | Calculate the size of a CSTR (aeration basin) given the residence time and 1st order reaction rate constant<br>or<br>Calculate the final concentration of a reactant in a CSTR given the flow, size and the 1st order reaction rate constant. |
| 6, 7 | 5 | Calculate the volume of a plug flow reactor given the flow rate and the reaction rate.<br>or<br>Calculate the time required in a PFR to obtain a given concentration. |
| 8 | 6,8 | Calculate the fraction of a component given multiple reversible reactions. |
| 9 | 7 | Calculate pH and pOH given concentration of $H^+$ or vice versa. |

**Table 2: CSTR question #1 on Quiz 1 and Quiz 2 were similar in technical topic and directly related the question to the design.**

| | |
|---|---|
| Quiz #1 | Assume that the limestone and AMD-impacted, $CO_2$-enriched water are reacting in a CSTR. What volume is required for a 1st order decay rate constant of 5 $sec^{-1}$ if the flow rate is 100 gpm, the concentration of dissolved $CO_2$ entering the reactor is 5000 ppm and the concentration of $CO_2$ exiting the reactor is 10 ppb?<br>a. 0.17 million gallons<br>b. 10 million gallons<br>c. 0.33 gallons<br>d. 20 gallons |
| Quiz #2 | Assume you have a CSTR where you add lime to remove iron from AMD. Assume the volume of the CSTR is 5 million gallons and the flow rate of the AMD is 100 gpm. Assume $Fe^{3+}$ removal can be modeled as first-order with respect to the dissolved concentration of $Fe^{3+}$ with a first-order rate constant of 0.1 1/hr. Assume the reactor is operating at steady state. If you have an influent concentration of $Fe^{3+}(aq)$ of 100 ppm, what is the concentration leaving the reactor?<br>a. 0.02 ppm<br>b. 8.2 ppm<br>c. 1.2 ppm<br>d. 2.4 ppm |

Quiz 1 was given to the students on the first day of class without a warning by the instructor of the prerequisite course. The students were also given an equation sheet that included all relevant equations and conversions. The students were told that the quizzes would not count for their grade and that their score would not be shared with the instructor of their design course. The quizzes were graded on a 0 – 2 scale: 0 = not correct, 1 = partially correct, 2 = totally correct. The quizzes were returned to the students on the 2nd day of class with this scoring. The students were directed to a related online video that reviewed the engineering topic covered by each question. This allowed the students to specifically review the material they did not master.

The online videos had been developed previously for use in online summer courses and flipped courses during the semester. The videos were created in a technology room and involved the instructor writing on a tablet screen on notes in an outline format. The outline notes were provided to the students. Most of the videos included a smaller screen shot of the instructor in the bottom right of the screen. Each module was approximately 90 minutes long but was broken down into titled 5 – 20 minute video sections. Having shorter video segments has been supported in the literature on classroom flip [3, 4].

Quiz 2 was given three weeks after the first quiz during an evening exam time. The questions were very similar to the 1st quiz (See Table 2) with a few exceptions. For example, the settling question (Question 4 on Quiz 1) was removed because it was found that all the students had mastered that material. In addition, Question 7 asked the student to calculate the distance in a PFR given the time. This question was removed in Quiz 2. Instead the students were asked to calculate the fraction of components in Question 8 in Quiz 2. The students were told that this quiz would count as one homework assignment. This equaled about 3% of their final grade.

**Assessment of student's use of online content**

We were able to identify which students utilized the video resources using the tracking feature in the university's course management system (ANGEL). Note that the tracking only allows us to determine if the students clicked on the link for the video; we cannot ascertain whether the students actually watched the video or how long they watched the video.

In addition, we used both focus groups and online surveys to assess students' perceptions and use of online videos. There were two different focus groups with a total of 11 students participating. These focus groups took place during the 9th week of classes (out of 15 weeks). Pizza and drinks were provided to students as well as an additional 0.8% points on their grade for participating in the focus group. The focus groups were led by an instructional support specialist in the College of Engineering's teaching and learning center.

The online assessment consisted of multiple choice, Likert questions and open ended questions. The survey was created using Qualtric, a commercially available software package. Twelve out of sixteen students completed this survey for a response rate of 75%. Those who participated received an additional 0.8% points for completing the survey. Appendices A and B show the questions asked in the focus groups and on the online survey, respectively.

**Faculty and College involvement**

This study required the collaboration between two faculty members in the department. These two faculty members received funding from a Teaching and Learning Center within the College of Engineering. In addition, a staff member from the Center helped to create and administer the Focus Groups and the online surveys.

**Results**

**Students' performance on quizzes**

Figure 1 shows that students improved their performance on the Quiz 2. Most of the students could balance a chemical reaction, calculate a concentration as $CaCO_3$ and predict the settling velocity of a particle in Quiz 1. The biggest improvement was observed with the CSTR, PFR and speciation problem.

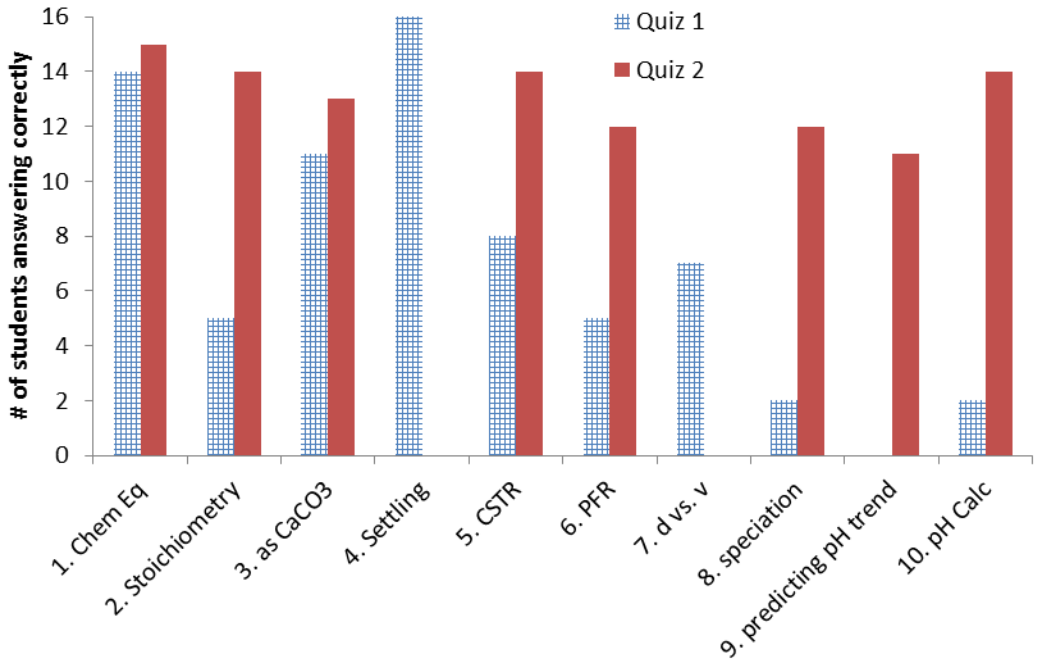


**Figure 1: Number of students answering quiz questions correctly. Questions 4 and 7 were not included on Quiz 2 and Question 9 was added in Quiz 2.**

Most of the students watched at least some of the videos provided after Quiz 1. Figure 2 shows that almost half the students accessed all the video content. There is a slight trend towards having a greater number of students accessing the videos on topics that were not mastered in Quiz 1. However, half the students accessed the video corresponding to the settling question, even though all of them had mastered that question. In addition, in the survey 2 out of the 12 students who completed the survey reported that they did not watch any of the videos.

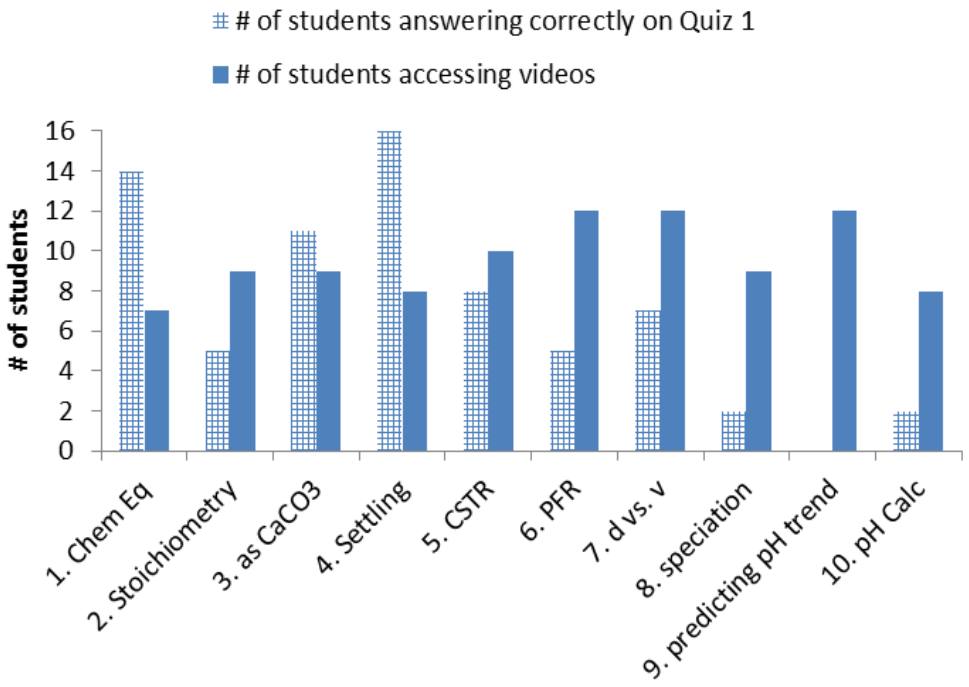


**Figure 2: Number of students who viewed videos corresponding to each question. At least half the students watched all the modules.**

**Students' perception of prerequisitite testing and online modules for mastery.**

In general, most of the students not only used the online resources but reported seeing benefits in reviewing the prerequisite material during the capstone class. The students were also asked specifically if watching the online videos helped in their understand of the course concepts. Ten out of twelve students answering the survey indicated that the videos did help them. The two students who indicated that the videos did not help them stated that they used the notes only and not the video as they prepared for Quiz 2.

During the focus groups, students expressed some disapproval of having Quiz 1 unannounced on the first of classes. In the survey, most of students expressed either displeasure or surprise by the first quiz because they did not feel prepared. However a majority said they didn't mind too much knowing that the quiz did not count towards their grade.

Students were also asked in the online survey: "What are the benefits of having the online videos early in the semester?". In general the students responded that it was a nice refresher as shown in Table 3. The students recognized that they could refresh on the prerequisitite topics at their own pace that would prepare them for the capstone project. One student expressed that the timing of Quiz 2 was too early and didn't benefit the project since the project started later in the semester.

**Table 3: Example student comments when asked "What are benefits of having the online videos early in the semester?**

| |
|---|
| *Refreshing on pre-requisite's **at my own pace**.* |
| *It allowed me to **re-learn the material quickly** and access exactly what I needed to know to be prepared for my capstone course.* |
| *It was a good refresher and allowed the **teacher to focus on new things** while we can review old material* |
| *They helped me review quiz material and **reminded me of topics I did not remember.*** |

## Benefits for the faculty and department

The faculty member teaching the design course found that he was able to focus more of his time on more important aspects of the design project. This included having more guest speakers and more time for students to work together. In previous semesters, he would review topics just to be sure that all students were on the same page. This semester, he was also able to make more accurate assumptions about what the students knew and didn't need to spend time reviewing pre-requisite topics with the students.

Another unintented benefit was that faculty members in the department were able to review the necessary prerequisite topics. Although the curriculum is reviewed from time to time, this exercise brought two faculty members together and made the prerequisite course stronger.For example, gas transfer was important in the design of the water treatment plant but had not been covered in the prerequisite courses. This topic will now be covered earlier in the curriculum to ensure that the students have the technical skills required for the design course.

## Conclusions and Recommendations

This is the first time we have attempted to provide online materials to students to review and master prerequisite materials for a design course. We found that students improved their understanding of key concepts required for the design course. This freed up time that the faculty member would normally use reviewing material so that more focus could be placed on the active parts of the engineering design. Although the students were surprised by a quiz on the first day of class, they understood and appreciated the technique to help prepare them for the design.

One reason this technique worked so well is that the online modules had been prepared for other purposes (e.g. online summer courses and flipped courses). Because the preparation of these modules will take time, it is best if they are used for mulitple purposes. This Spring our department plans to continue this process in the Structures and Water Resources Capstone.

**Acknowledgements:** To be added later

**Bibliography**


1. The 21st-Century Engineer: A proposal for Engineering Education Reform. ASCE Press Patricia D. Galloway 2008. pg 2.
2. Ericsson, K. A. (2010). Enhancing the development of professional performance: Implications from the study of deliberate practice. In K. Anders Ericsson, (Ed.), Development of professional expertise: Toward measurement of expert performance and design of optimal learning environments 412 (pp. 405–431). New York, NY: Cambridge University Press.
3. Velegol, S.B., Zappe, S. E., Mahoney, E. (2013) The Evolution of a Flipped Classroom: Evidence Based Recommendations. *Advances in Engineering Education.* Accepted.
4. Leicht, R., Zappe, S. E., Messner, J., & Litzinger, T. (2012). Employing the Classroom Flip to move "Lecture" out of the Classroom. *Journal of Applications and Practices in Engineering Education.* 3(1): 19-31.

**Appendix A: Focus Group Questions**

Hello, I am_____ the facilitator for our discussion today. Thank you for coming today. Your comments and feedback are very important to us. (give some info about yourself and the LCTR). The purpose of this focus group is to get feedback from students that will help us improve this course for future semesters. We are specifically interested in student's perceptions of the use of the out of class videos. (Pass out consents.)
This conversation is voluntary and confidential. Your instructor will not know if you are participating. A summary of the focus group will be shared with the instructor after the semester is over and will not contain any identifying information. This focus group will be audio recorded. Only the facilitator will have access to the recording. We also ask that you keep the focus group confidential and not discuss other's specific comments outside of this group.
May we please have your permission to make an audio recording of this focus group? If someone says no they will have to leave.
I would like us to begin by introducing ourselves. Would you please go around the table and tell us your name?

Regarding the instructional practices in this course:

1. The conversation today will focus on the online videos and quizzes.

2. Would you please tell me about the online videos and quizzes that you had at the start of the semester.

*Initial Reactions*

3. What was your initial reaction to this technique? What did you feel about having two quizzes right at the start of the semester?

4. Was this instructional practice something you've seen before?

5. Did you feel that you already knew the topics that were covered in the videos?

*Helpfulness to Learning*

6. How were the videos helpful to your learning?

7. How is the content of the videos helpful to your current work in the class?

8. How is the content of the videos helpful to your work on the class project? (ask only if the project does not come up).

*Use of Videos*

9. How often did you use the videos? More than once?

10. Did you stop part way through and go back or did you view a video in one sitting?

11. Now that we've gotten this far into the semester, do you ever go back and review those videos? Why or why not?

*Conclusion and Suggestions for Improvement*

12. Have any of you seen these videos before in a prerequisite course? If yes, did seeing these videos in the past help you to remember the material more? Were there any other benefits with having access to the videos from a course from prior semesters?

13. How can this process of providing online videos/quizzing be improved for future classes?

14. What other topics would you like to have on video for review?

15. Would you have liked to have videos available in your pre-req classes? Why or Why not?

16. Any final comments about the videos or anything else in the course?

**Appendix B: Qualtric survey given to the students.**

1. What is your name? Your name is needed for extra credit.

2. Did you access any videos at the start of the semester?
   Yes, if yes please state which ones.
   No

3. Did you go back and access the videos later in the semester?
   Yes
   No

4. At what point in the semester did you access the videos?

5. How often did you access the online videos?
   - 1-2 times
   - 3-4 times
   - More than 4 times
   - I did not access them.

6. What were the benefits of having the online videos early in the semester?

7. Did watching the online videos help your understanding of the course concepts?
   If yes, why?
   If no, why not?

8. What was your reaction to having a quiz on the first day of the semester?

9. What was your reaction to the quiz during the second week of the semester?

10. What were the benefits of having the quizzes early in the semester?

11. How can the process of providing the online videos be improved be improved for future semesters

How can the process of providing the quizzes be improved for future semesters?
In this class, ...

*(Strongly Disagree  Disagree  Neither disagree nor agree  Agree  Strongly Agree)*

12. I sought help from my instructor more often than in other classes.
13. I sought help from my peers more often than in other classes.
14. I felt like we repeated information from last semester.
15. I felt like we had less overlapping information as compared to other course I have taken.
16. Having the videos made me more responsible for my own learning.
17. Having the videos online helped me to be more successful on the other class assignments.