Barriers to Learning in a Large Flipped Biotransport Course

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Instructors often cite anecdotal case evidence that an active learning or flipped classroom approach increases the level of student engagement and gives students guided practice applying concepts. Recently, learner- and community-centered strategies such as flipping the classroom have been implemented into biomedical engineering courses. One approach to flipping the classroom involves providing online video lectures to students in order to focus in-class time on presentation of authentic applications and to enable practical implementation by students in an instructor-supported environment. In one such blended learning study, 40-74% of students viewed online videos before class, and the observed increase in scores on selected summative assessments was not significant at the 95% confidence level (Corrias & Hong, 2015). Another study reported positive student responses to muddiest point and group-based activities in class but did not indicate whether gains on summative assessments occurred (Ankeny & Krause, 2014). In general, evidence for improved learning outcomes in flipped classrooms is lacking.

Interestingly, Ankeny & Krause (2014) attempted to measure student attitudes toward class activities using a new tool, the BME Student-centered Strategies (BSS) survey. This approach highlights a need to evaluate the learning environment based on factors beyond summative assessment scores. Such evaluations have documented student resistance to active learning approaches (Silverthorn, 2006). However, the relationship between student resistance and learning is not well understood. A popular early approach was to describe “learning styles” based on students’ self-reported preferences for how to receive content (Felder & Silverman, 1988). Surveys of biomedical engineering students (Dee et al, 2002) indicated that they preferred to receive information visually (through graphics, diagrams, etc.), focusing on sensory inputs (with concrete facts and data), actively (e.g. by doing a team activity), and globally (i.e. focusing on the big picture). Although the idea of learning styles has more recently fallen out of favor, this characterization seems to fit well with the interdisciplinary nature of the BME profession. Studies suggested that student retention in STEM fields requires modifying the classroom environment to be accessible to varying learning styles (Tanner & Allen, 2004). However, the focus remained primarily on what the instructor is doing to deliver content rather than what the student is doing to interact with the content and take responsibility for his/her own learning.

This study tested the hypothesis that students who are resistant to a flipped classroom approach perform less well in a third-year required biotransport course. Negative perceptions by some students of how well course design fit their preferred learning approaches was expected to represent a barrier to achieving effective outcomes.

Research Methods

Course descriptions

A flipped classroom approach was implemented in a third-year required biotransport course that had been taught the previous year in a traditional lecture style. The lecture course had 71 students enrolled, and the flipped course had 94 students. Both the instructor and the content
were the same for both courses. The courses met for 75 min twice each week during the semester. Course content was drawn from two textbooks of transport phenomena in biological applications (Fournier, 2012; Truskey et al, 2009). Topics were based on fundamental engineering concepts in material, momentum, and energy balances.

In the lecture course (control), the instructor delivered content verbally and wrote notes on a tablet PC connected to a projector in front of the class. Students completed 6 homework sets (60% of the grade), 2 midterm exams (20% of the grade), and a final exam (20% of the grade). A weekly discussion section (50 min) was conducted by the graduate teaching assistant to help with homework problems, and open-door office hours were held by the instructor and teaching assistant for at least 2 hr/week. Students did not receive formative feedback other than in these sessions. Students in the lecture course did not complete a pre-/post-test.

In the flipped course (intervention), electronic versions of class notes, links to online sources, and online discussion forums were delivered through a course web site in the university learning management system (UVaCollab, collab.itc.virginia.edu). Some aspects of the grade were based on activities that could be compared to the traditional lecture course: homework problems (25% of the grade), in-class test problems (25% of the grade), and a final exam (15% of the grade). Students also worked in teams to complete a “grand challenge project” (25% of the grade) that consisted of a series of assignments of increasing complexity addressing methods to deliver chemotherapeutic drug to a tumor in a patient. Finally, students completed daily formative assessments in a category called, “Help Yourself Learn” (10% of the grade). Examples of these low-stakes assignments included solving example problems in class, answering concept questions to relate detailed mathematical problems to the big picture learning goal of the day, and reflection questions to promote self-assessment of learning. These assignments were often administered using the online audience response tool QuestionPress (www.questionpress.com). Finally, a pre-/post-test was administered to assess learning of primary concepts of mass conservation and momentum conservation applied to classic problems in biomedical engineering.

Analysis of class composition and self-perception of learning

In order to determine whether background or demographic factors contributed to their self-perceptions or outcomes, students completed a survey at the beginning of the semester that included questions about their backgrounds and their preferences for styles of learning activities in engineering courses (Appendix A). Answers to questions about learning activities were encoded to represent attitudes toward active learning or flipped classroom activities. A two-step cluster analysis was performed, and responders were grouped into “flipped skeptic” and “flipped enthusiast” using a two-step cluster analysis.

Surveys were administered by the University of Virginia Center for Advanced Study of Teaching and Learning in Higher Education (CASTL-HE). Results were not shared with the instructor until after the semester final grades were assigned to prevent the perception that grades might be affected by students’ participation or survey answers. Data were collected and analyzed according to a protocol approved by the Institutional Review Board for Social and Behavioral Sciences (IRB-SBS). Data were not collected from students who opted out of the study.
**Student focus groups**

Focus groups were conducted by two third-party observers from the University of Virginia Center for Teaching Excellence who were not affiliated with the course. Pizza and soft drinks were provided during the focus group interviews. Focus group questions were open-ended and gave students the opportunity to expand on their experiences in the course (Appendix B). Focus groups were recorded and later transcribed for qualitative analysis.

Invitations to participate in the focus groups were sent to all students in the course who had consented to participate in the study. Five focus groups were conducted; 18 students participated in a focus group. Focus group data were encoded using Dedoose and were scored for mention of common themes that students perceived as barriers to learning in the course.

**Results**

**Final exam outcomes in flipped vs. lecture course**

The final exams of both the lecture and the flipped course included five common questions focused on core concepts related to conservation laws and fundamental transport principles. Each question was scored out of 10 points; the total scores were computed out of 50 points. In the lecture class, the mean score was 41.3±4.5 (mean±SD, N=71). In the flipped class, the mean score was 44.3±4.5 (mean±SD, N=94). Thus, the mean score in the flipped course was 7.3% higher than in the lecture course, which was significantly different at the 0.05 level (unpaired t-test, p=2.5×10⁻⁵). The cumulative histogram (Figure 1) shows the shift in the histogram of scores in the flipped relative to the lecture course.

In order to determine whether a difference in academic preparation existed, the aggregate GPAs of biomedical engineering students from the two class years of the study were compared. Students typically take the biotransport course in the 5th or 6th semester of their academic program, so GPAs from 4th semester were chosen for comparison to represent academic record just before taking biotransport. The GPA of the class year representing the lecture course was 3.39±0.42 (mean±SD, N=85). The GPA of the class year representing the flipped course was 3.39±0.39 (mean±SD, N=110). The difference between mean GPAs was not significant (t-test, p=0.93).

**Background and self-perceptions of flipped course students**

Of 94 students enrolled in the flipped course, 83 (88%) consented to participate in the study. Half of study participants were male, and half were female. Most were from northern Virginia, and 90% were U.S. citizens, reflecting the typical composition of a biomedical engineering student class at the University of Virginia. All of the participants

![Figure 1. Cumulative histogram of final exam scores for lecture vs. flipped course.](image-url)
earned average high school grades of A– or higher, and the average college GPA of the cohort was 3.5.

Two-step cluster analysis of surveys about self-perception of learning classified respondents as “flipped enthusiast” (58 students) or “flipped skeptic” (25 students). Chi-squared distributions and independent samples t-test showed no significant differences between the two groups with respect to gender, race/ethnicity, family income levels, father’s education level, mother’s education level, high school grades, class year (junior or senior), and college GPA.

Learning outcomes in the flipped course

Comparison of pre- vs. post-test scores (45 points total) in the flipped course served as a measure of learning outcome. The pre-test mean score was 18.1±5.4 (mean±SD, N=94), and the post-test mean score was 39.6±4.3 (mean±SD, N=94), which represented a significant increase at the 0.05 level (paired t-test, p=1.5×10⁻⁵⁴). This 2.4-fold increase in test scores indicated growth in knowledge of core concepts in the course.

A pre- vs. post-test comparison was not available in the lecture course (control), in part because this comparison was added as part of the course re-design. The pre-/post-test questions in the flipped course were taken from the final exam in the lecture course. The students entering the two courses had similar GPAs as an indicator of academic preparation, and the final exam scores in the lecture course were significantly lower than in the flipped course. It is possible that the learning gains measured by the pre-/post-test were increased in the flipped compared to the lecture course. This would be an interesting hypothesis to test in the future.

Since final exam scores in the flipped course were significantly increased relative to those in the lecture course, scores from the flipped course were grouped, and “flipped enthusiast” scores were compared to “flipped skeptic” scores (Figure 2). Pre-test, post-test, and difference scores were not different between the two groups (p=0.18, p=0.20, and p=0.70, respectively). The cumulative histograms of final exam scores for the two groups were similar to each other (Figure 3) and to the total for the flipped course, and they were shifted relative to the cumulative histogram for the lecture course.

![Figure 2. Total raw final exam scores for lecture vs. flipped course.](image)

![Figure 3. Cumulative histogram of final exam scores for “flipped enthusiast”, “flipped skeptic”, and lecture.](image)
Focus group transcripts were scored for recurring themes discussed by students in response to open-ended questions about their learning experiences and the learning environment in the flipped course. To encourage honest responses, the observer collected focus group responses anonymously. As a result, responses were not coded as “flipped skeptic” or “flipped enthusiast”. Themes that emerged included (1) lack of engagement with digital notes/resources and desire for videos (55 responses), (2) lack of preparation for class (48 responses), (3) complexity of course content (30 responses), (4) concerns about grading (21 responses), and (5) in-class questions being perceived as private exchanges between instructor and individuals (8 responses). Three major themes are described below.

First, students mentioned lack of engagement with digital online notes and resources. Students preferred in-person lectures or videos for delivery of course content. Students mentioned the ease of scrolling forward and backward through videos to reinforce core concepts. Interestingly, they did not revisit online notes multiple times to practice low-stakes problems or to re-read explanations and derivations of core concepts.

Second, lack of class preparation slowed the learning process. For a flipped classroom model to work, students must prepare before class and arrive ready to apply the concepts to a problem or case study (Zappe et al., 2009). Interestingly, students in three of the focus groups identified their lack of maturity as part of the reason for lack of preparation. Several students referred to their inability to self-motivate to prepare for class by completing low-stakes formative assessments instead of spending time on high-stakes assessments in other, traditional-style courses.

Third, students felt that the complexity of the material in the course was a barrier to learning. They suggested that the material was difficult because it was new to them and multifaceted, which made them feel intimidated and unwilling to ask questions in class.

Discussion

Learner-centered strategies in the classroom have been proposed to improve student engagement and motivation. Supported in part by the Vanderbilt-Northwestern-Texas-Harvard/MIT (VaNTH) NSF ERC, a burst of biomedical engineering course designs grounded in problem-based learning approaches emerged in the early 2000s. For example, student engagement with content in a biomechanics course was emphasized by posing authentic challenges based on professional practice (Roselli & Brophy, 2003). Before class, students were asked to articulate initial thoughts and questions about the challenges, priming them for in-class discussion and lecture. Students were then assessed on how well they applied what they learned to a new problem or situation. Although the idea of motivating students to engage with the course content outside of the classroom seems beneficial, the in-class activities in this study were based primarily on the idea that students were preparing to be told the significance of content (Schwartz & Bransford, 1998). Evaluation of the learning environment was based on what the instructor was doing, using the VaNTH Observational System (VOS) (Harris et al, 2002). The emphasis remained on the instructor as knowledge expert rather than on the student as learner.
The decision to implement a flipped classroom in biotransport for this study was stimulated by student behavior in the lecture-style course. As many as 40-50 students attended office hours, using it as a study hall-type period with the instructor moving among the study groups coaching them in response to questions. Impromptu mini-lectures became common, and it became apparent that most learning in the course occurred during these sessions. Flipping the classroom enabled the instructor to allocate class time to problem-solving and mentoring activities during which the students struggled with and learned the course material.

Student learning was increased in the flipped course compared to in the lecture course, as measured by common final exam questions, but student feedback during the flipped course suggested that learner satisfaction was low and that student resistance to the course format was high. However, there was no difference in learning outcomes between “flipped enthusiast” and “flipped skeptic” groups. These observations raised the question of whether increased student learning occurred because of or despite the change in course format.

Focus group responses suggested that students struggled with motivation and engagement with course material, a common difficulty for students in flipped classrooms. Expecting students to engage with course material by exploring online notes and resources instead of by listening to instructor lectures often leads them to question whether the instructor is teaching them or they are teaching themselves (Talbert, 2012). By actively engaging students in discussion and problem-solving during class, instructors can allay some students’ concerns that they are alone in their work without instructor help. In the biotransport course studied here, students reported lack of preparation for class discussions even though they recognized the benefit of low-stakes practice problems and online resources and even though learning goals and rationale were discussed in class and the interactive online syllabus. Instructor involvement with students during their interaction with course material would perhaps help students feel less confused and overwhelmed by the new, heavily quantitative material in this course.

It becomes especially important for instructors to articulate clearly the rationale and goals behind expectations for students to initiate and direct their own learning (Roehl et al., 2013). Even so, students may not value cooperative learning or find it to be a positive experience because of their desire to get “correct” information from the instructor that they can memorize after class (Herreid, 2013). This idea is supported by the focus group responses desiring online videos or in-person lectures instead of or in addition to online reading and web-based resources. In an engineering class focusing on problem-solving approaches, it is challenging to help students develop an intuitive sense for risk-taking and innovation when multiple problem-solving techniques are possible. Although the flipped course structure with many low-stakes practice problems should have encouraged students to try approaches with low risk of failure, it instead led students to feel overwhelmed and confused about what was the “right” way to solve problems analytically. Breaking problems into smaller pieces with more frequent instructor interactions may promote student confidence to try new techniques.

Overall, this study confirmed the idea that active learning approaches such as the flipped classroom are capable of improving learning outcomes, even if learner satisfaction with the course format is relatively low. The important factor is that course designs are focused on what learners do to help themselves learn rather than what instructors do to convey content for consumption.
References


Fournier RL. 2012. Basic Transport Phenomena in Biomedical Engineering, 3 ed., Boca Raton, FL: Taylor & Francis

Harris AH, Cordray DS, HarrisTR. 2002. Measuring what is happening in bioengineering classrooms: an observation system to analyze teaching in traditional versus innovative classrooms. Proc 2nd Joint EMBS-BMES Conf


APPENDIX A: BACKGROUND & DEMOGRAPHIC QUESTIONS

1. **What is your gender?** (Select one.)
   a. Male
   b. Female
   c. Transgendered

2. **What is your current class level?** (Select one.)
   a. First year
   b. Second year
   c. Third year
   d. Fourth (or more) year
   e. Graduate student
   f. Other

3. **Please indicate your sexual orientation.** (Select one.)
   a. Bisexual
   b. Gay or Lesbian
   c. Heterosexual

4. **Are you...** (Select all that apply.)
   a. African American/Black (not of Hispanic origin)
   b. Asian or Pacific Islander (includes the Indian sub-continent)
   c. American Indian or Alaskan Native
   d. Hispanic/Latino (Spanish culture or origin)
   e. White/Caucasian (Persons not of Hispanic origin, having origins in any of the original peoples of Europe, North Africa, or the Middle East)
   f. Race/ethnicity not included above (Please describe:_____________________)  

5. **Citizenship status?** (Select one.)
   a. U.S. citizen
   b. Permanent resident (green card)
   c. Neither
6. **In which geographic region did you primarily grow up?** (Select one.)
   a. Virginia: Northern VA
   b. Virginia: Norfolk/Newport News/Virginia Beach
   c. Virginia: Central VA
   d. Virginia: West/Southwest VA
   e. Washington DC
   f. Suburban Maryland
   g. Northeastern U.S. (not VA, DC, or MD)
   h. Southern U.S. (not VA, DC, or MD)
   i. Western U.S.
   j. Midwestern U.S.
   k. Outside United States
   l. (please indicate country: _______________)

7. **In which of the following categories is your primary major of study?** (Select one.)
   a. Aerospace Engineering
   b. Biomedical Engineering
   c. Chemical Engineering
   d. Civil Engineering
   e. Computer Engineering
   f. Computer Science
   g. Electrical Engineering
   h. Engineering Science – Nanomedicine Engineering
   i. Engineering Science – Materials Science Engineering
   j. Engineering Science – Other
   k. Mechanical Engineering
   l. Systems Engineering

8. **What career do you hope to eventually have after you've completed your education?** (Select one)
   a. Artistic, creative professions
   b. Business, finance-related professions
   c. Education
   d. Engineering, computer programming
   e. Goverment, public service
   f. Law
   g. Medicine, health-care related professions
   h. Psychology, helping professions
   i. Researcher, scientist
   j. I don't know
9. What is the highest level of education you expect to complete? (Select one)
   a. Attend college but not complete degree
   b. Complete a bachelor’s degree (B.A., B.S., etc.)
   c. Complete a master’s degree (M.A., M.S., etc.)
   d. Complete a professional or doctoral degree (Ph.D., J.D., M.D., etc.)
   e. I don’t know

10. What is the highest level of education completed by one or both of your parent(s) or guardian(s)? (Circle one in each column, if applicable.)

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<th>Father or Male</th>
<th>Mother or Female</th>
<th>Guardian</th>
<th>Guardian</th>
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<tbody>
<tr>
<td>Don’t know</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>High school or less</td>
<td>1</td>
<td>1</td>
<td></td>
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<tr>
<td>Some college</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Associates degree</td>
<td>3</td>
<td>3</td>
<td></td>
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<tr>
<td>Bachelors degree</td>
<td>4</td>
<td>4</td>
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<tr>
<td>Masters degree</td>
<td>5</td>
<td>5</td>
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<td>Doctorate or professional degree (JD, MD, PhD)</td>
<td>6</td>
<td>6</td>
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<tr>
<td>Not applicable</td>
<td>7</td>
<td>7</td>
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11. What is your best estimate of your parents’ total income last year? Consider income from all sources before taxes. (Circle one.)

- a. Less than $25,000
- b. $25,000 to $49,999
- c. $50,000 to $74,999
- d. $75,000 to $99,999
- e. $100,000 to 124,999
- f. $125,000 to $149,999
- g. $150,000 to $174,999
- h. $175,000 to $199,999
- i. $200,000 or more

12. Did you receive financial aid for 2013-14 in the form of: (Select all that apply.)

- a. Not receiving financial aid
- b. Loans
- c. Need-based scholarships or grants
- d. Non-need-based scholarships or grants
- e. Work-study
- f. Athletic scholarship
- g. Other (Please specify: _____________________)

13. What were your average grades in high school? (Select one)

- a. A+, A, A-
- b. B+, B, B-
- c. C+, C, C-
- d. D+ or lower
- e. No high school GPA

14. What is your current cumulative GPA on a 4-point scale? (Please enter the number, (e.g., 3.6) in the space):____________________________

15. Do you have previous lab research experience in college-level courses other than the SEAS core (e.g., other than courses such as Introductory Chemistry or Introductory Physics)? (Select one.)

- a. Yes
- b. No

16. Do you have previous non-classroom lab research experience (e.g., from an internship, research for credit, independent study)? (Select one.)

- a. Yes
- b. No
17. When completing course assignments, do you prefer to work (select one):
   1. Alone
   2. In groups or teams
   3. No preference

18. How confident are you in your calculus abilities?

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<tr>
<td>Not at all confident</td>
<td>Neither confident</td>
<td>Extremely confident</td>
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19. How confident are you in your biology abilities?

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<tr>
<td>Not at all confident</td>
<td>Neither confident</td>
<td>Extremely confident</td>
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</table>

20. How confident are you with computational programming (e.g., using Matlab)?

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<tbody>
<tr>
<td>Not at all confident</td>
<td>Neither confident</td>
<td>Extremely confident</td>
</tr>
</tbody>
</table>

21. How comfortable are you with public speaking? (Select one.)
   1. Very comfortable
   2. Comfortable
   3. Indifferent
   4. Uncomfortable
   5. Very uncomfortable
22. When completing course assignments, do you prefer to work (Select one.)
   a. Alone
   b. In groups
   c. No preference

23. How comfortable are you with participating in a class discussion with your instructor and your peers? (Select one.)
   1. Very comfortable
   2. Comfortable
   3. Indifferent
   4. Uncomfortable
   5. Very uncomfortable

24. Why did you decide to enroll in BME2240? (Select all that apply.)
   a. This course is required for my major
   b. This course is an optional requirement
   c. A friend/peer suggested that I take this course
   d. A advisor/faculty member suggested that I take this course
   e. Someone else suggested that I take this course
      (Please specify (e.g., parent, alumna/ae: ________________)

25. What types of teaching practices do you prefer in your courses? (Select all that apply.)
   a. Lecture
   b. Use of audio/visual media
   c. Examples or demonstrations
   d. Working out problems on board/screen
   e. Small group discussion
   f. Peer tutoring
   g. Brainstorming
   h. Question and Answer
   i. Group projects
   j. Clickers
   k. Other (please specify: _______________________________
26. Please indicate the extent of your agreement or disagreement with the following questions:

1=Strongly disagree; 2=Disagree; 3=Neutral; 4=Agree; 5=Strongly agree

a. I often use material I find on the Internet to help me master
course material and learn .............................................................. 1 2 3 4 5

b. I find that working problems during class helps me master
course material and learn .............................................................. 1 2 3 4 5

c. Interacting with other students in a small group helps me learn........... 1 2 3 4 5

d. Being able to interact with and ask my instructor questions
helps me learn .............................................................. 1 2 3 4 5

e. I am enthusiastic about using online resources as part of this
course .................................................................................................... 1 2 3 4 5

f. I intentionally seek out courses that are known to use
technology and/or online resources .............................................. 1 2 3 4 5

27. Have you taken a “flipped” class (i.e., a course in which the lecture is provided ahead of
class and class time is used for more interactive activities) before? (Select one.)

   a. Yes
   b. No
   c. Not sure

28. As you may or may not have heard, this course is being taught as a flipped class. What have
you heard about the structure of this course and the flipped classroom model? [open-end
response]

29. What do you hope to learn in this course? [open-end response]

30. What skills do you hope to acquire in this course? [open-end response]
Appendix B

Focus Group Protocol

Time of Focus Group:
Date:
Place:
Interviewer:
Interviewee:
Role of interviewee:

Brief description of the project:
“The purpose of this research is to collect data on the student experience of learning in a biomedical engineering course that is designed as a ‘flipped’ course. In this qualitative case study, you will be asked to describe how the flipped model influenced your learning in the course; you will evaluate and report your perceptions of lecture-substitution videos, active-learning strategies, and increased interaction with instructors and peers.”

Review of Confidentiality:
“Because of the nature of a focus group, I cannot guarantee that what you say will be confidential, since you will be speaking in front of other people. As much as possible, our actions as focus group facilitators will support confidentiality. Your name will not be directly linked to the any comments made during the focus group. Because of the nature of the data, it may be possible to deduce your identity, and we may know your identity; however, there will be no attempt to deduce your identity, and your data will be reported in a way that will not identify you. You will be audiotaped during the interview or focus group, but your name will not be connected to the audiotape. The data from this focus group will not be shared with the instructor until after the final grades for the course have been submitted. If there is something you would like to share privately with one of us, please do so at the end of the focus group.”

Permission to Record:
“It is important for me to know exactly how you say things, so I would like to record our conversation. If I just take notes or try to remember, it is easy to make mistakes and not reproduce your words accurately. Afterward, my colleague and I will listen to the recording and transcribe everything correctly. Is this okay with everyone?”

Questions:
1. How did you experience using the Internet to find resources to help you complete the class problems?
2. How effective do you think it was to spend time in class working on problems?
3. How much did working with a small group of your peers help you learn?
4. How did being able to ask your instructor questions as you solved problems help you learn?
5. What is your experience of this flipped class?

Conclusion:
“Thank you for participating in this focus group. Your willingness to participate will be very helpful as I seek to understand the student experience in a flipped class. As is outlined in the consent form, if you decide that you do not want your statements included in the data, please contact me. Thank you again.”