Reflections from the "Flipped" Frontline:
Enhancing Student Learning in an Interdisciplinary Course on Nuclear Weapons and Arms Control

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ABSTRACT/INTRODUCTION

Our paper contributes to the growing literature on the effectiveness of the flipped classroom as a means of enhancing the student learning experience and achieving course learning outcomes, with a special emphasis on the effectiveness of the flipped classroom in an interdisciplinary course setting. Our course is a third-year undergraduate course on the political and scientific dimensions of nuclear weapons and arms control offered at the University of British Columbia (UBC) since 2014, developed with support from UBC and in collaboration with the Comprehensive Test Ban Treaty Organization (CTBTO). It enrolls fifty Political Science and fifty Applied Science students, and is team taught by a professor in Political Science and a Professor in Electrical and Computer Engineering. Our paper describes how our course employs a fully flipped pedagogy, with learning materials (mostly in the form of bespoke instructional videos) based online and class time devoted to learning activities conducted in permanent student groups. To assess the student experience in the course, we conducted surveys of the students enrolled in our course and examined course analytics and metrics. Our experience suggests the flipped model is largely successful in enhancing the student experience in an interdisciplinary course setting. However, we also find unique challenges associated with the use of the flipped model in interdisciplinary courses.

The Interdisciplinary Flipped Classroom

Like everyone else in higher education, we did not develop our course in a vacuum. Our normative and conceptual framework was influenced by the burgeoning literature on course design and learning outcomes in general, and blended and flipped pedagogical models in particular. We were also influenced by the aspirations of our university to enhance learning outcomes and the student learning experience, and the provision of support for course development incorporating the current state of the art in pedagogy. As a result, our course is informed by a wide range of educational literature extolling the virtues of interdisciplinary teaching and flipped or blended learning models.

In our course design, we strove for interdisciplinary, rather than multidisciplinary, design and learning outcomes. Interdisciplinary design is distinguished from multidisciplinary design by its integrative, rather than additive, character (Klein 1990). Our design motive was to achieve the integration of physical and life science knowledge and social science and humanities knowledge in course materials and in student learning activities. Our desired learning outcome was to enable students to animate and synthesize knowledge in classroom activities and course assignments to achieve interdisciplinary understanding and thinking, defined by Boix Mansilla et. al. as “The capacity to integrate knowledge and modes of thinking in two or more disciplines or established areas of expertise to produce a cognitive advancement—such as explaining a phenomenon, solving a problem, or creating a product—in ways that would have been impossible or unlikely through single disciplinary means." (Mansilla et. al. 2000). If students finish our course recognizing the need for an interdisciplinary understanding of nuclear weapons and the ability to think about the subject through physical and life science and social science and humanities perspectives, we consider our core outcome fulfilled.

We were also aware of the challenges and limitations of interdisciplinary approaches identified in the literature, and experienced many of them ourselves. We were forewarned that students can have inaccurate perceptions of disciplinary fields, and we knew we faced a special divide across the higher-level silos of the sciences and the arts (Beck-Winchatz and Parra, 2013). We also knew that achieving a truly integrated interdisciplinary course would be very challenging, given the nature of the material and our own need for curriculum time in the course to adequately introduce and address specific subject matter. We worked very hard to attain the balance necessary to fulfill our learning objectives and to compromise when necessary, which is not always an easy thing to do in team-teaching settings (Shapiro and Dempsey, 2008). That said, our experience parallels those who have found that while their courses started as more multidisciplinary in character, they evolved into more truly interdisciplinary courses over time (Nungsari, et. al. 2017). We knew we would face another challenge: interdisciplinary teaching is a tradeoff between breadth and depth (Caviglia and Hatley, 2004). We adopted a “less is more” philosophy to address this challenge, as well as a mutual acceptance that students would not emerge with mastery across the science and arts content of the course.

In our course design, we also strove for high levels of active participation and peer engagement among our students. As a result, we found ourselves attracted to the flipped course design model. This model enhances student learning through (in our case) online instructional resources paired with active participation lesson planning. The whole idea is to reduce the amount of class time spent on passive content-based lectures and increasing the amount of time spent on participatory and interactive learning. To this end, content previously taught in passive lecture classes is “flipped” to online learning materials, while the classroom time is devoted to higher-order engagement with the subject matter through learning activities that animate knowledge (Bergman and Sams 2012). Our course design was consistent with the three key elements of blended learning: integrating face to face and online learning; fundamentally rethinking the course design to optimize student engagement; and restructuring and replacing traditional class contact hours (Garrison and Vaughn 2008). Our experience is consistent with recent review studies showing that the flipped model yields favourable academic outcomes (Akçayır and Akçayır 2018; Zainuddin and Halili 2016). A widely accepted advantage of flipped and blended courses is the ability of students to learn at their own pace and being able to re-visit learning materials on their own schedule (Bergman and Sams 2012; González-Gómez et. al. 2016). Our findings are also consistent with these claims.

We were also mindful of the disadvantages and limitations of the flipped and blended models. Among these was the time investment required to design such courses (Howitt and Pegrum, 2015; Wanner and Palmer, 2015). This was certainly our experience, although we cannot say for certain how much more time it took to develop our course than if we had chosen a more traditional model. Another important problem identified in the literature is the failure of at least some students to review or study the flipped materials in advance, thus weakening the impact of the active participation learning in the classroom (He et. al. 2016). We did not experience this challenge in any significant way, given that each of our classes began with a graded quiz that covered the day’s learning materials. We believe students will complete the flipped learning materials if there is an assessment component incorporated into class time, and our video watch data supports this claim. Challenges presented by technology, particularly in the form of video quality (pedagogical and well as technical) and access have also been identified as another potential shortcoming of the flipped model (Akçayır and Akçayır 2018; Zainuddin and Halili 2016). We did not experience these challenges, largely because of the institutional support we received during course development.

Our Course

Our course was created to address a shared concern about the lack of nuclear weapons and arms control education, both in the public realm and at our university. Our goal was to provide students with an opportunity to better understand and navigate the re-emergence of the subject matter in light of events in Iran, North Korea, and increasing tensions between Russia and the United States. A series of concept development breakfast meetings in 2013-2014 led to a commitment to develop a course at UBC that could later be extended into a broader open access public education tool. The course is founded on our shared philosophy about nuclear weapons education. In our view, nuclear weapons and arms control is a subject that cannot be fully understood or addressed solely through the disciplinary knowledge and methods of the physical and life sciences or the social sciences and humanities. Instead, an interdisciplinary approach is required, one that integrates and synthesizes the contributions of many disciplines, including those across the 'great divide' of the sciences and the arts. This philosophy informed the learning outcomes, design, lesson planning, assessment strategies, pedagogy, content delivery, and active participation techniques used in the course.

Developing interdisciplinary courses such as ours requires institutional support from a wide range of units at the university. Our course was developed with grant support from the UBC Flexible Learning Initiative, and technical and design support from the UBC Centre for Teaching and Learning Technology (CTLT) and the UBC Faculty of Arts Instructional Support and Information Technology office. Both the faculties of Applied Science and Arts and the Departments of Electrical and Computer Engineering and Political Science provided the necessary administrative approvals and teaching resources. Finally, the course was also developed in collaboration with the Preparatory Commission of the Comprehensive Test Ban Treaty Organization (CTBTO) in Vienna, which provided a forum for the instructors to present the course, receive feedback, and engage some of our students in the CTBTO Youth Forum at the annual CTBTO conferences.

The course explores the subject of nuclear weapons and arms control in the wider context of applied science and technology and global and domestic politics. The two organizing principles of the course are scale and motive. Scale refers to the physical and quantitative dimensions of nuclear weapons related to explosive power and effects. This includes the relevant mathematics and engineering, with an emphasis on the application of those principles to the technologies of nuclear weapons, testing, arms control and verification. Motive refers to the history and politics of nuclear weapons development, including nuclear strategy, weapons proliferation, peace and disarmament movements, arms control agreements and treaties, and testing and verification efforts.

Very early in the design process we realized the course would need to be team-taught, as neither of us alone possessed the disciplinary expertise needed to offer the course in a manner that satisfied our shared philosophy about nuclear weapons education. As a result, since its inception in 2014-2015 the course has been team-taught by two faculty members at UBC, Dr. Allen Sens from the Department of Political Science and Dr. Matt Yedlin from the Department of Electrical and Computer Engineering. Both are in the classroom together at all times, accompanied by at least one of the two course teaching assistants.

Consistent with our interdisciplinary philosophy, we believed the course would be of value to both Arts and Applied Science students. Students in Arts would benefit from exposure to the physical and life science principles associated with nuclear weapons, while applied science students would benefit from exposure to the social and political context in which nuclear weapons are embedded. We also believed that students from different educational backgrounds could learn from each other. To realize this vision, the course is open to students from the faculties of Arts and Applied Science, although in practice students from other faculties are also admitted on a case by case basis. Course enrollment is 100, with 50 seats available for Arts students and 50 seats available for Applied Science students. The course is an elective for the Bachelor of Arts degree and satisfies the Science and Society course requirement in the Faculty of Applied Science. The course has proven to be very popular, and has filled since it was first offered, with a long wait list each year.

The course is designed around the flipped classroom model, with most lecture content delivered online in bespoke instructional videos supplemented by readings and other learning materials. The videos are the core content delivery mechanism of the course, with approximately 70 videos created by the instructors to this point. The videos and other learning materials are delivered through the edX learning management system. Practice quizzes (not for grade) are provided after each video so students can test their own retention of crucial information. Assignment support materials and other resources such as assignment descriptions and assessment rubrics are also provided online in edX. Class time is mostly devoted to group active participation learning activities designed to animate the knowledge and concepts and debates introduced in the instructional videos and other learning materials. The student groups are maintained throughout the course, and consist of 12 groups of approximately eight or nine students, half from Arts and half from Applied Science.

We have designed a wide range of classroom learning activities to complement and build upon the content presented in the online materials. These include:

- A two-class ‘jigsaw’ exercise engaging students with ethical principles and debates surrounding the decision to drop the bombs on Japan. Students first meet in groups to research and discuss a leading political or scientific figure of the period, and explore what ethical position they held, or might have held, on the use of the atomic bombs. On day two, these student groups are broken up so there is one figure in each group: they then have to debate and then decide on whether or not to drop the bomb on Japan.
- The development of a public advocacy campaign to oppose the hypothetical resumption of US nuclear weapons testing.
- A prisoner’s dilemma exercise illustrating the dynamics of the distrust, arms races, and the Cold War. This exercise uses specially developed software in which student groups engage in diplomacy and decision making on whether or not to build nuclear weapons, with their collective decisions in a series of negotiation “rounds” determining their “scores” in a classic payoff matrix.
- The construction of a nuclear warhead using a variety of craft materials. Students have to provide a rationale for their choice of design and explain both to the class.
- The location of a North Korean nuclear test using actual International Monitoring System data from one of the North Korean Tests. Students use the seismic signatures from a test to determine the physical location of that test.
- An arms control simulation in which student groups try to reach agreements on limiting nuclear delivery systems in order to reduce the prospects of arms races between them.

The course has approximately 25 exercises of the kind described above. In a typical day in the life of the course, students will come to class having completed the on-line instructional materials for that day. Each class meeting is 80 minutes long, meeting twice a week at mid-day on Tuesdays and Thursdays. The first five minutes of class time is devoted to a short quiz which tests for basic content and serves as both a subject-specific assessment component for grade and an accountability mechanism to ensure students are prepared for the learning activities that day. After a short lecture introducing the contemporary relevance of the topic and briefly describing the exercise, the active participation component of the class begins. The group assignments are submitted electronically at the end of class.

The assessment strategy for the course was scaffolded around our learning objectives as well as our desire to promote peer engagement in student groups. The assessment components were:

- A Group Project. Working in mixed (Arts/Applied Science) groups, students complete one major group research project on strengthening the CTBT and the nuclear testing verification regime. The group project requires the synthesis and application of science and social science methods and knowledge.
- An Editorial Project. Students complete an individual writing project on a self-selected, specific aspect of the nuclear weapons arms control and verification subject matter. The Editorial Project is worth 20% of the final grade.
- The Class Projects and Quizzes. Collectively, the in-class group projects and short quizzes on flipped material combine to account for 20% of the final grade. The quizzes performed a vital accountability mechanism. We felt it was our responsibility to encourage students to come prepared, so having quick quizzes at the start of class was a small investment in the quality of the learning experience.
- The Tests. Three tests are held in class at regularly scheduled intervals during the term. Each exam is divided into two sections: one covering the social sciences and humanities elements of the material and the other covering the math and physical and life sciences elements of the material. The exams are run as “two-stage” exams, in which students first write the exam individually, and then again in their groups. The exams are worth 30% (10% each) of the final exam.

Challenges in Course Development, Design, and Delivery

We encountered a number of significant challenges in the process of developing this course, and the interdisciplinary elements of these challenges were particularly prominent. The most significant challenges we encountered include:

1) *Bridging academic silos*. As teachers coming from different disciplinary backgrounds, we had to establish agreement on course learning objectives, content, and learning activities. A particular challenge was establishing effective linkage, or synergy, between disciplinary methods and knowledge in the course design, learning materials, and the

lesson plans. We wanted to avoid a "you go – I go" pattern that would compartmentalize disciplinary knowledge. This has proved difficult.

2) *Pedagogical challenges*. We have approximately equal numbers of engineering and arts students in the course. How could we design learning activities and assessment strategies that engage students with different background knowledge levels with the disciplinary diversity of the material? Of particular concern was knowledge of math, chemistry and physics, and capacities in writing and historical knowledge.
3) *Content coverage*. We focused on political and mathematical aspects of nuclear weapons and arms control in our course, largely because those are our own respective disciplines. We felt less comfortable developing learning materials in areas beyond our expertise, such as sociology, psychology, and literary studies, or physics, chemistry, and the life sciences.
4) *Facilities.* Accessing a suitable room has proven difficult. There are relatively few spaces at our university optimized for group learning in courses of 100 enrolment or more. Teaching the course in a lecture hall with fixed seating has proven less than ideal, restricting student movement, impeding group discussions, and providing little workspace for projects.
5) *Enrolment challenges.* The course enrollment of 100 students was set as a condition imposed by the university (a function of the resources/student ratio calculations that attend higher education). As a result, the course is larger than it should be, and the number of students in each group is larger than it should be, making it harder for all students to participate in the learning activities.
6) *Navigating administrative structures*. University systems are not designed to easily facilitate the development of interdisciplinary courses across units and departments, let alone programs or large Faculties. Issues such as course approval, credit value, the role of the course in different degree programs, administrative support, and resourcing, all proved surmountable but required significant effort.
7) *Assessment methods*. It was challenging to create meaningful assessment strategies consistent with learning objectives and course materials while at the same time accommodating the asymmetric disciplinary knowledge of students in the class.
8) *Learning material production*. Creating the videos to accommodate different levels of background knowledge proved to be a challenge. As a result, our videos are not as integrated as they could be, with each video designed and completed by one of the two instructors.
9) *Creation of In-class Activities*. The creation of over 25 in-class active participation collaborative peer learning lesson plans, designed to allow students to have interdisciplinary conversations, was our single biggest challenge and proved to be much more time consuming than we anticipated.

The Student Learning Experience: Findings

In our analysis we use data from our Qualtrics student survey findings and EdX metrics. We also have You Tube analytics but omit them in this paper in the interests of space.

Data Observations from Our Qualtrics Survey

We conducted two student surveys independent of the university course evaluation instrument, one in 2016 and another in 2018. In 2016, 15 Engineering students and 19 Arts students responded out of a class enrolment of 50 Engineering and 50 Arts students (for a total response rate of 34%). In 2018, 26 Engineering students and 20 Arts students responded out of a class enrolment of 50 Engineering and 53 Arts students (for a total response rate of 45%). Combining the responses of the two surveys gives us a sample size of 80 students: 41 Engineering students and 39 Arts students. Table 1 below summarizes the results.

		Engineering	**Political Science**	**Total**
Did you watch the online videos before coming to class?	almost always	85.37%	84.62%	85.00%
	most of the time	14.63%	15.38%	15.00%
	some of the time	0.00%	0.00%	0.00%
	almost never	0.00%	0.00%	0.00%
The videos and online resources were helpful in preparation for the classroom activities and presentations.	strongly agree	78.05%	87.18%	82.50%
	agree	21.95%	12.82%	17.50%
	undecided	0.00%	0.00%	0.00%
	disagree	0.00%	0.00%	0.00%
	strongly disagree	0.00%	0.00%	0.00%
The in-class activities improved my ability to understand the math concepts and perform the calculations necessary for the course.	strongly agree	21.95%	23.08%	22.50%
	agree	39.02%	41.03%	40.00%
	undecided	19.51%	17.95%	18.75%
	disagree	9.76%	17.95%	13.75%
	strongly disagree	9.76%	0.00%	5.00%
How would you rate your experience with the in-class group activities?	very helpful	31.71%	35.90%	33.75%
	helpful	56.10%	53.85%	55.00%
	undecided	4.88%	2.56%	3.75%
	somewhat helpful	2.44%	5.13%	3.75%
	not helpful	4.88%	2.56%	3.75%
	Total	51.25%	48.75%	100.00%
		41	39	80

Table 1. Qualtrics combined 2018 and 2016 survey results

The survey results confirm our other available metrics with respect to student video watch rates, and show that watch rates were consistent across Engineering and Arts students. In response to the question “Did you watch the online videos before coming to class?” 85.37% of Engineering students and 84.62% of Arts students responded with “almost always” while a further 14.63% of Engineering students and 15.38% of Arts students responding with “most of the time.” No students in the sample responded with “some of the time” or “almost never.”

Some variation across Engineering and Arts students appeared in responses to the question “The videos and online resources were helpful in preparation for the classroom activities and presentations.” Across the two survey years, 78.05% of Engineering students responded with “strongly agree” while 87.18% of arts students responded with “strongly agree.” A further 21.95% of Engineering students responded with “agree” while 12.82% of Arts students responded with “agree.” No students responded with “undecided”, “disagree,” or “strongly disagree.” While these results indicate students found the videos and resources helpful overall, we believe the variation in the “strongly agree” responses can be explained by the Engineering student’s perception that the math-related videos were less helpful.

There was a significantly wider range of responses by both Engineering and Arts students to the question “The in-class activities improved my ability to understand math concepts and perform the calculations necessary for the course.” However, these results were largely consistent across Engineering and Arts students with variations being relatively small. Among Engineering students, 21.95% of respondents “strongly agreed” while 39.02% “agreed.” A further 19.51% of Engineering students were “undecided” while 9.76% disagreed and another 9.76% “strongly disagreed.” Interestingly, Arts student responses were broadly similar, with a somewhat higher rate choosing “disagree.” Among Arts students, 23.08% of respondents “strongly agreed” while 41.03% of students “agreed.” A further 17.95% were “undecided” while 17.95% disagreed and none “strongly disagreed.” While more Arts students chose “disagree” for this question, the responses overall demonstrate less agreement with the question than previous questions in the survey. We attribute the responses to different dynamics across the Engineering and Arts students. The Engineering student responses may reflect a view that they already knew much of the mathematics, while the results from Arts students may reflect a view that the materials did not provide them with math instruction they needed. This observation would support our claim about one of the key challenges of interdisciplinary education and the flipped classroom model: it is difficult to design learning materials that are of approximately equal educational utility to all students in the course.

When asked “How would you rate your experience with the in-class group activities?” the response from both Engineering and Arts students was largely positive. Among Engineering students, 31.71% the experience “very helpful” and another 56.10% found the experience “helpful.” 4.88 percent were “undecided” with another 2.44% finding the experience “somewhat unhelpful” and another 4.88% finding it “not helpful.” Arts students responded similarly, with 35.90% responding “very helpful” and 53.85% responding “helpful.” 2.56 percent were “undecided” with another 5.13% responding “somewhat unhelpful” and another 2.56

percent responding “not helpful.” This lower level of enthusiasm could be explained by group dynamics experiences, group size and the challenges of dividing effort among group members. Addressing this would require a lower enrolment or additional teaching resources.

Qualitative (Student Comments) Observations from Our Qualtrics Survey

Our 2016 and 2018 surveys also asked students a number of open-ended questions. A review of these comments yielded some interesting results that support the data above, but with some supplementary insights into the challenges of flipped interdisciplinary teaching.

Q5: What suggestions do you have for improving the online materials?

Sixty-seven of a possible 80 students responded to this question. Sixteen respondents provided comments that were supportive, with representative samples including:

> *Nothing…they are great!*

> *Honestly, I can’t think of anything, it was really well done.*

However, one clear piece of feedback was to shorten the length of the instructional videos. This is consistent with other studies indicating that keeping video length short is a significant aspect of flipped class design (Akçayır and Akçayır 2018; Zainuddin and Halili 2016). Fourteen respondents identified this concern. Many of these comments also highlighted the uneven distribution of video watch time across lesson plans, making preparation time for some classes much longer than others. A further three respondents identified the uneven distribution issue as a standalone concern. Our initial reflection on this result is the asymmetry in video distribution reflects the interdisciplinary subject matter: some specific subjects were more interdisciplinary than others, and those subjects required more videos.

> *Make the longer videos shorter in length and instead have several shorter ones.*

> *Some of the videos are quite long, and it seems the time requirement for online materials ranges a fair bit.*

> *Some modules were much longer than others. This can make budgeting time for them trickier than usual.*

> *Perhaps try to condense the information a bit more. While the longer videos made understanding very easy, they at times felt unnecessary and the total length of videos that needed to be watched, as a result, became somewhat overwhelming at times.*

Respondents were less specific on optimal video length, but the few who specifically mentioned length identified the 15-minute or longer videos as the culprits. Respondents were also less specific on the desirable total watch time per class module.

> *Try to make them shorter or spaced out if possible, it's really daunting top open up the next lesson and see six 15-minute videos to go through.*

> *Some of the videos were long at times. Would be nice if they could be kept to 10 minutes each with max 3 videos per class prep.*

One piece of feedback we were not expecting was an interest in more online quizzes, or more questions on each quiz. Eleven respondents requested more quizzes, primarily to enhance reassurance about their identification and retention of key concepts.

> *More online quizzes would be helpful, to help us verify that we have learned the relevant information.*

> *I found myself, surprisingly, enjoying the quizzes very much and actually wishing there were more questions to test myself with.*

> *More questions after the videos would also be recommended. (I kind of found the questions to be fun). They were very useful for remembering concepts and particularly items that need more memorization. It was also useful to know what I hadn't fully understood or remembered – If I had forgotten something I would just go back and look right away.*

A couple of respondents made an interesting link between online materials and class activities, two calling for summaries of the main points of the videos during class, and the posting of class slides on line in the class modules.

Q8: To what extent does your comfort in math influence your ability to enjoy the course?

Sixty-seven of a possible 80 students responded to this question. Over half of the respondents (forty-seven) provided comments indicating that they felt comfortable with the math and it had little impact on their enjoyment of the course. Two respondents did note that despite their overall comfort they felt some anxiety about the math portions of the exams. Typical responses included:

> *The math was pretty basic and straightforward.*

> *As an engineer the math questions were never an issue.*

Not much because the math discussed were relatively simple despite my low level of mathematics.

I enjoyed the math portion. Did find it pretty straight forward at a basic level but I understand why it is that way.

I found it didn't really influence it that much. I'm math illiterate and only felt anxious during the math parts of the quizzes and the exams.

However, thirteen students did indicate a level of discomfort with math that negatively impacted their enjoyment of the course.

Yes.

Strongly.

I am very bad at math.

My experience in math as a political science student affected my ability to enjoy the course. Because I've never excelled in math, I found part 2 of every test difficult.

I would say that it moderately affects my enjoyment of the course. Since I could ask the people in APSC [note: Applied Science-authors] to help, I did not feel as responsible for the material as I might have.

Conversely, there were five respondents who expressed some boredom with the math in the course.

The math was really dumbed down and I wish the math was more intensive.

The math was very simple for anyone in engineering and is therefor [sic] a bit boring, it might be nice to have some more challenging concepts that are presented in additional materials that are not necessary for the course.

This was one of the most significant indications of the challenge of interdisciplinary teaching in our course. The asymmetry in math capacities was a significant factor in the student experience, and a significant teaching consideration. Notably, a small number of respondents (three) indicated that they got help from their more math proficient peers in the student groups.

I'm comfortable with the math (as long as I get the instructions and practice beforehand), also having engineering students in the group to help explain stuff made it a lot easier to understand sometimes.

I get nervous when there is math involved, but working in groups with other who had strong math backgrounds made it easier to understand concepts and refresh my math skills.

But there was also this response:

Already felt comfortable with math concepts and the videos provided a good refresher. The engineering students usually took over the math aspects of in-class activities which limited opportunities to get a better grasp on more complex math concepts.

This is part of a larger pattern we have observed in the class. Frequently, some groups (not all) divide the social sciences and humanities content in an assignment from the physical and life sciences components and divide it, with the engineers doing the former and the arts students the latter. While it illustrates teamwork and a certain capacity for rational utility maximization, this behavior also weakens the peer to peer learning that was part of the motive for the mixed group model.

Q9: What could be changed to help improve your understanding of the math elements in the course?

Out of the 75 students that responded to this question, 26 responded that nothing could be changed. However, there was also clear support for more examples (8 respondents) and more practice opportunities (7 respondents), as well as suggestions for supplementary and/or remedial opportunities (8 respondents).

More online video examples.

More tutorials explaining in detail certain formulas and concepts (e.g. half life, velocity, etc.).

Maybe one example can be taught in class, where the professor breaks down a "problem" on the board.

There was a lot of concepts we were expected to know like simple algebra that most of us haven't done in years. Maybe additional info on how to do those instead of expecting us to know.

Maybe just a quick basic refresher for the arts students. A lot of us have not done math problems sets since high school, so we all needed quick refreshers on how to do simple math problems.

There should be more discussion of the math in class and optional math info sessions. This would help political science students who have never practices math since most likely high school.

Another pattern that emerged was the feeling of some students that the math was simplified to the point of causing confusion. Six respondents made this argument, claiming that the effort made to make the math videos accessible to arts students caused them confusion and uncertainty.

The math should not be treated as some "magical" thing that can be applied to the subject of study. The way much of the math was treated in online videos was confusing for APSC students, and puts a vail [sic] over it for POLI students, making it seem harder than it is.

Don't dumb it down so much. Explain the concept of derivatives.

Don't refer to pi, e and whatever else as "magic numbers." That can just create confusion for people who have not worked with them much before, and from speaking with my non-engineering group members this was the case for most of them. Just explain the constants for what they are and don't overcomplicate things.

We also note that seven respondents suggested the math elements of the course could be harder.

Make the math harder.

Make the math more challenging or at least add optional university level math for those who are confident in it; this could be done as side activities of for bonus marks.

It would be cool to include some very technical calculations like once or twice just to see what they are.

Perhaps more advanced concepts?

It would be nice of the course covered more math than was actually covered.

Q12: What suggestions would you have for improving the in-class activities and group project?

We received much more varied answers to this question, although a clear theme did emerge. Out of the 69 students who responded to this question, eight indicated they were happy or satisfied with the in-class activities. However, 10 students suggested the groups be made smaller to encourage easier discussion and improve participation, both for students who were less active and to mitigate the phenomenon of a small set of students doing most of the talking. A closely related suggestion (4 responses in total) involved a different classroom configuration, to enable improved communication.

> *The only thing I would say is that smaller group [sic] would be more effective. Because the class time frame is often short, we don't have that much time to talk together.*

> *Groups were too big. Groups size was OK for the group project but I found that the size of the group for class activities usually meant that 1 or 2 people could slack off. Also hard to communicate in such a large group in a loud classroom and the current desk layout.*

> *Make the groups smaller. Large groups often only have 2-3 people working on the assignments. Too crowded.*

No other theme received more than five mentions in the survey. Five respondents called for more detailed assessment expectations and/or feedback for the in-class assignments.

> *It would be nice to get feedback on what we submit for the in-class activities. Of course, I understand that this is not at all possible – so just knowing what good answers would be would be appreciated, perhaps posted in advance of the exam?*

> *Some of the group activities felt like busy work. Maybe if we got back the group stuff and were given marks for it we could know if what we were doing was correct but it was all kind of a shot in the dark.*

Four respondents felt they did not have enough time to complete the assignments, and/or did not have enough class time to work on the major group project (two full classes are devote to group project development and discussion).

> *Sometimes not enough time was given to write in detail.*

> *More time for the group project in class.*

Four respondents raised the issue of dominant group members or uneven distribution of responsibilities/engagement in the group activities and the group project.

> *I found that some members would habitually contribute very little to the activities other than putting their names down, which unbalanced the group dynamic. They didn't necessarily not want to work but might just not like talking.*

> *Every class make sure that a different person is acting secretary. I found that one or two people ended up doing the whole assignment because they were typing and the others got off topic.*

Four respondents also raised the theme of division of labour between engineers and arts students. This was the only indication we had of this uniquely interdisciplinary challenge.

> *I think the class activities are great. Although I find that as a Political Science student (and the others in my group) that when the math exercises come up I don't participate in them because I am awful at math and can't get it done in time – that the engineers do it and I don't actually learn it and then feel unprepared for the tests.*
>
> *Some activities were very math based that the engineers had to do all the work.*
>
> *The debate. Strategy-based projects were the most helpful (at least in our group) because everyone was engaged. When they were entirely equation and paper based, the engineers would often do more work because it was easier for them and the arts students would do the writing because that was easier for them.*

Q14: How would you improve this course for the next time it is offered?

This question was answered by 73 respondents and yielded a wide range of responses. We were pleased that the highest concentration of responses (13) expressed that they would not change the course in any significant way. The next largest concentration of responses (9) involved recommendations for specific content changes, for example more coverage of the CTBT, the technical aspects of nuclear weapons, Iran, India-Pakistan, and seismic detection. However, none of these specific content suggestions garnered more than two mentions, although the theme of connecting the material more to current events was generally implicit in many of the comments. No other themes emerged that were reflected in more than four of the 73 comments. Those themes included: changing the activities (4); having more lectures (4); changing the classroom (3); smaller groups (3); shortening the tests (2); and creating math study guides (2).

Q15: What elements of the course did you find most helpful?

This question was answered by 79 respondents and a clear theme emerged. Forty-seven respondents found the online instructional videos the most helpful element of the course. The most prominent explanations were the ability to repeat and review the videos, prepare for tests, and pause the video (unlike a lecture!).

> *The lecture videos were helpful because you could pause them to write down information instead of scrambling like you would in class.*
>
> *The videos were really engaging and informative to prep for the in-class activities. I personally felt that I learned more material and information than a regular lecture.*

The online materials. Allowed me to go back and review/study at any point and also see the material if I missed class.

This being my first experience with flipped lectures, the format really helped me engage with the material on my own time and led me to do more research and reading on the side than I would normally do in lecture-only courses.

The flipped method with the videos. Videos are much more engaging than reading and coming into class with all of the knowledge needed really helped higher level thinking and understanding.

I really appreciated the videos because I noticed I needed more time that a usual 1:30 mins lecture to fully understand and record everything. It would usually take me 3h or more for 1 module but with the small quizzes and notes I could remember everything and ingest it. I also always really took the time at home and it was much more enjoyable that readings and I could focus more. I did much better in those exams than regularly. I am also a non-native English speaker and this may impact why I needed more time.

The next largest category of responses identified the group activities as the most helpful element of the course with 11 responses, often appearing in tandem with mentions of the videos.

I loved the group activities, and the flipped course material, as it really allowed us to engage with the material rather than be lectured at for over an hour.

Group activities were fantastic. They allowed clarification on information, exchange of ideas and perspectives, as well as allowed us to build a relationship with our group members going into the group project. Very fun.

The group activities were a great way of testing knowledge from the videos, and the quizzes.

Six respondents replied with a content-based answer, with responses evenly split between the specific technical aspects of nuclear weapons and the political and historical aspects of nuclear weapons. Three to four respondents also mentioned the Edx platform itself, the online quizzes, the simulations, and the non-cumulative nature of the tests.

<u>Analytics from edX</u>

Edx analytics provides information on video and problem engagement over the course timeline, unique and total viewed data for individual videos and problem response data. The data indicate that the students engaged with the online materials at a high rate, which supports the qualitative and quantitative responses in the Qualtrics survey where students self-reported on their engagement with the online materials.

1. Overall Video Engagement

The edX analytics were taken from the 2017 course offering, which had a final registration of 102 students. Figure 2, shows video engagement across the progression of the course. The videos were coded as having science-focused content (red) and policy-focused content (blue).

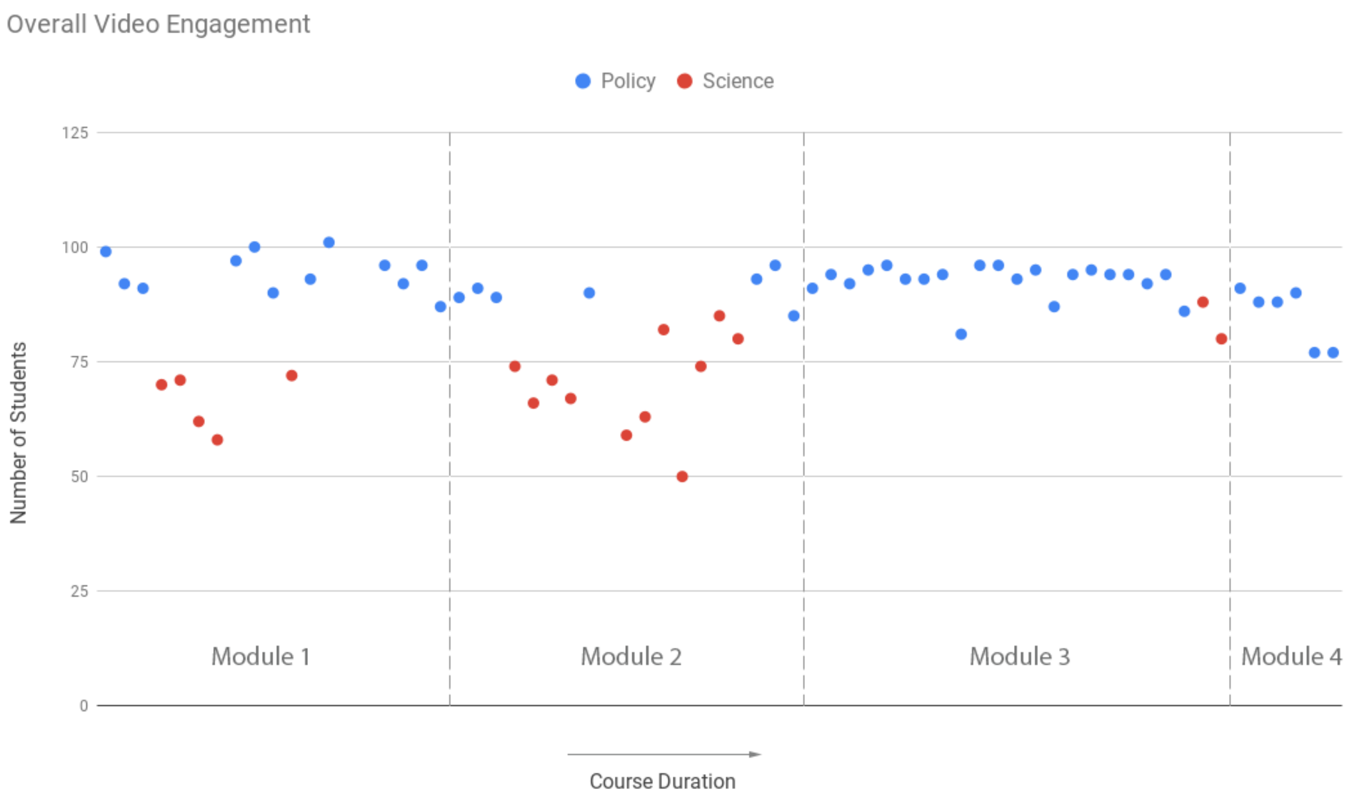


Figure 2 Level of video engagement over the course duration

Overall, the average video engagement across all course videos was 92 students, indicating that a majority of students were engaging with the materials. Length of video did not appear to correlate with student engagement. For example, the longest video in the course, "Nuclear War," 21 minutes in length, had an engagement level of 99 students, while the shortest video in the course, "What is Radioactivity", 1 minute and 32 seconds in length, had an engagement level of only 65 students. Variation in video engagement was somewhat dependent on placement in the progression of course material, with videos towards the end of the course having slightly lower engagement than videos at the beginning of the course.

The nature of the content in the videos showed a greater correlation with video engagement with substantial variation seen between the engagement levels in the science and policy videos. The average engagement for all policy videos was 92 students, while the science videos showed an average engagement of only 71 students. We surmise that this variation is due to Applied Science students not watching the math/science related videos at the same rate.

2. Overall Online Quiz Engagement

Figure 3 shows engagement with the online quizzes across the course (which were not for grade). A student was determined to have engaged with the quiz if one completed response was recorded. While there were only 102 students registered for the course, quiz completion data showed a slightly higher number at the beginning of the course since it included students who registered for the course but then dropped. The peak number of students with data recorded was 111 students for the first problem.

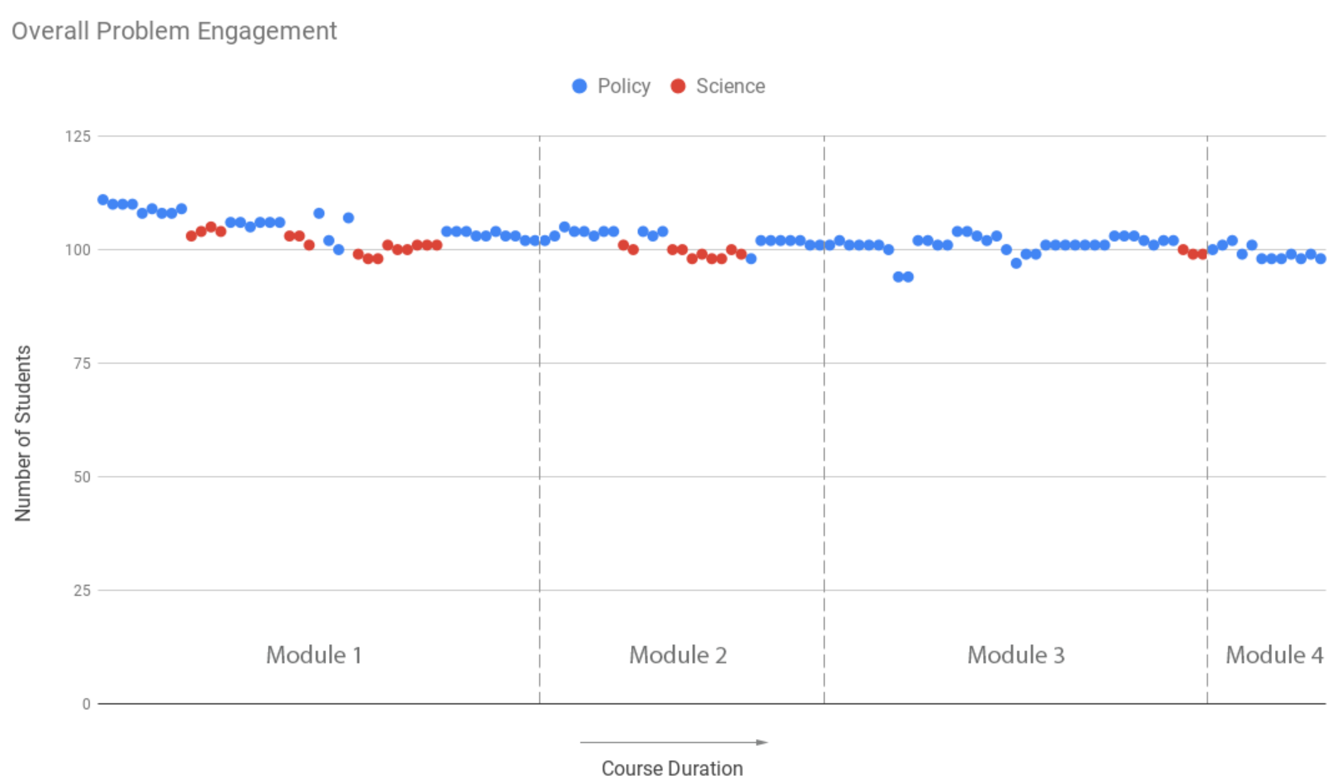


Figure 3. Level of problem engagement over the course

As Figure 3 indicates, close to 100% of students engaged with the problems and engagement remained consistently high across the course. The variability in engagement seen in the video engagement data between science and policy content was not seen to the same extent in the problem data. Policy materials showed consistently high engagement for both videos and problems, while science materials showed high engagement for the problems, but lower and more variable engagement for the videos (as shown above). This indicates that a certain portion of the students were completing the problems related to the science videos, but not viewing the videos.

One explanation for this behaviour could be that the engineering students with a high level of math and science proficiency are using the problems to check their knowledge and then not watching the videos if they feel like they already understand the concepts. We will need to analyze the data in more detail, however, to examine video and problem engagement by engineering and political science cohorts to determine if this hypothesis is correct. An alternate hypothesis to explain the lower watch rate of science videos is that some Arts students may find the material too difficult and therefore did not watch the science videos at the same rate. However, this hypothesis is highly unlikely given the near 100% engagement with the quizzes.

The video and quiz data do show, however, that all students do not engage with the videos and problems in the same way. The variability in engagement with the materials indicates that students employ self-regulation to determine which content to focus on. This ability for students to self-regulate and engage with the materials differently in the online environment may present a challenge in interdisciplinary teaching environments, but also an opportunity to address some of the challenges created by the asymmetric knowledge backgrounds of the Arts and Engineering students through the development of videos dedicated to 'refresher' or 'remedial' needs, and/or the creation of videos dedicated to more advanced subjects but are not required of all students in an interdisciplinary course.

3. Unique and Total Video Views

The video analytics indicate that not only was there a high level of student engagement with the video content, view data for individual videos indicates that a high number of students were viewing either the entire video or sections of the video more than once. Across all videos in the course, the average number of views per student was 1.4 views, indicating that a certain level of re-watching was occurring across videos.

Figures 4a and 4b show unique and total views for two videos within the course. The y-axis indicates student views and the x-axis shows the point in time in the video timeline where the view occurred. Video viewing data was collected in 20 second segments across the length of the video. The light blue area in the figures indicates unique video views, meaning an individual student was only counted one time. The dark blue area in the figures indicates total views for a video and can include repeat views by the same student. The gap between total views and unique views indicates the level at which students are re-watching the content at a particular time point in the video.

While the unique views are relatively constant across the length of the video, only decreasing slightly towards the end, there is much greater variability in total views. The peaks in the total view data indicate areas where there is a high level of re-watching occurring. Initial observations from a small sample of videos indicate these peaks may indicate areas in the videos where there is particularly challenging or complex content, but more investigation needs to be done to determine if any patterns can be observed across all course videos.

Figure 4a Video View Data for "Weapons Design"

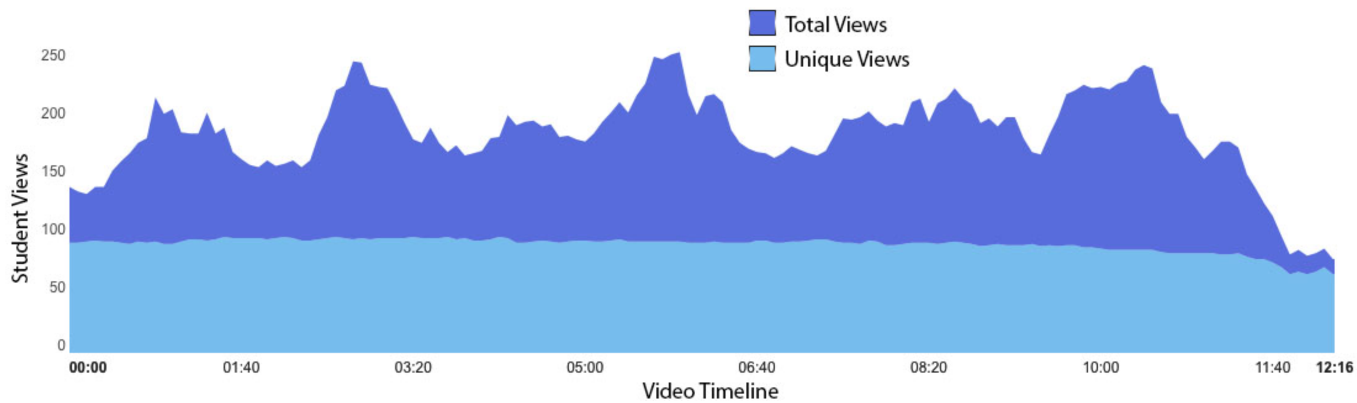
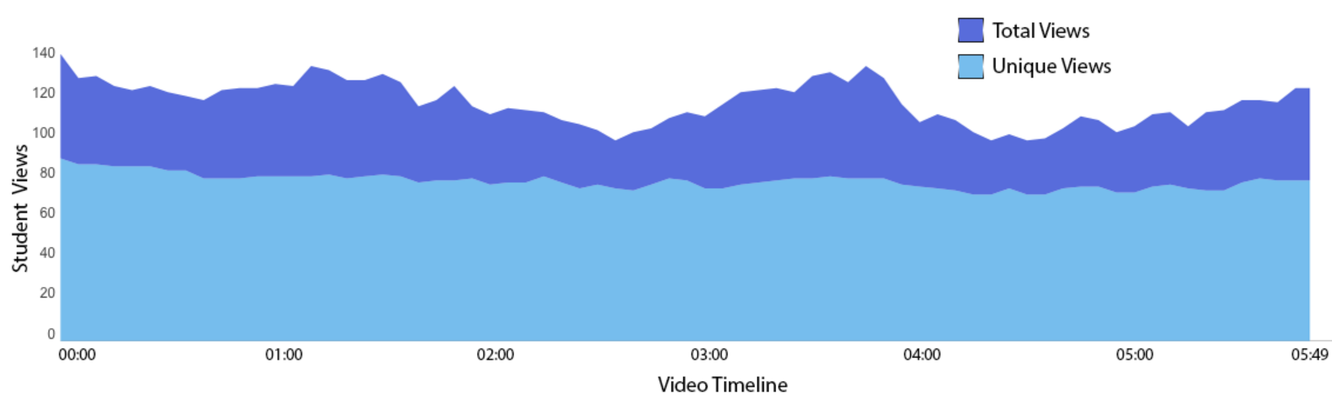


Figure 4b – Video View Data for "Energy of Tsar Bomba"



Observations, lessons learned, and conclusions

Overall, or examination of course analytics and our student survey support the growing literature on the effectiveness of the flipped classroom as a means of enhancing the student learning experience and achieving course learning outcomes. Our experience and our results suggest the flipped model is largely successful in enhancing the student experience in an interdisciplinary course setting. Students watched the course videos and used the online quizzes at a very high rate, and were thus well-prepared for the learning activities conducted in class time. The advantages of online video materials (students can watch on their own time, re-watch, and repeat for study and exam preparation purposes, or because they are English language learners) were all evident in our findings. We believe that the key explanation for the high watch rate and re-watch rate of the videos was the existence of the graded in-class quizzes. We believe these quizzes formed a dual function as an assessment tool and an accountability mechanism ensuring a richer active participation experience for all students.

However, there are also challenges unique to the interdisciplinary classroom. We had to learn not to try to cover everything in the course materials, at least to the extent we would in our own disciplinary-focused teaching. There is so much to know about nuclear weapons, we had to accept that when it came to content, less was more. Students would encounter content through activities and assignments, so lectures and videos had to focus on the "need to know" elements required to enable the further exploration of the subject matter. The need to address content from both the physical and life sciences and the social sciences and humanities meant that there was less space for each in the course timeline and course learning materials. Students were thus exposed to less disciplinary-focused depth than would have been possible in a dedicated Political Science or Applied Science course, but instead gained a richer understanding of the breadth of the subject through more than one disciplinary lens.

We also found that variation in foundational content among the students was a teaching challenge. The gaps that exist in math and science literacy for many Arts students and history and politics literacy for many Applied Science students made the creation of effective flipped materials all the more challenging, but at the same time crucial to the outcomes of the course. On the one hand, good learning materials in a flipped classroom environment meant that students could spend more time, on their own time, with the materials they were less proficient with. On the other hand, developing those materials in a way that was interesting and challenging for students from both disciplinary backgrounds was very difficult.

Furthermore, the presence of two professors, from two different disciplinary backgrounds, in the class at all times enabled students to engage with us on whatever aspects of the subject matter interested them. Our presence also enabled us to comment on content and methods during the class, providing students with different perspectives on the subject matter at hand. This also presented challenges as students often wanted to discuss issues with us in more detail, and this was difficult in the middle of the class exercises. Much of the engagement we had with students was with individual students or a group of students, rather than the entire class. This means that not all students in the class benefitted from those more intimate conversations and engagement with the teaching team.

Finally, the interdisciplinary context of our course created additional challenges for the creation of the in-class activities. Our initial experience with the flipped classroom model has been content centric, a replay of the typical emphasis on content over learning practice, experiential learning, and student engagement and problem solving. Our initial focus was video production and content delivery, albeit in another medium (video instead of lecture notes or presentation slide decks). However, in developing the course we received less support for classroom learning activity design and less exposure to different models of peer learning techniques. We recommend anyone embarking on a flipped course design project to spend at least as much time on the classroom activity side of the flipped teaching coin. In an interdisciplinary context, there is an additional layer to activity design: activities should also include a core interdisciplinary component or objective/outcome.

On a personal level, our experience has been remarkable. The energy in the classroom, the interaction between students, and the thoughtfulness and creativity of student work is higher than we have ever experienced. We learned about the value of spontaneity in teaching and learning, and the need to relinquish some control over the classroom. In a flipped classroom, not knowing what might happen or what the result of a learning activity might be is stimulating for both students and professors. We learned the importance of clarity and transparency. The flipped model places a premium on clear learning objectives and the careful preparation and coordination of online teaching materials, in-class activities, and assessment strategies. All of this is magnified in an interdisciplinary setting, with two different constituencies of students sharing the same learning space.

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