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Restructuring a Pedagogical Course to Benefit Engineering Ph.D. Students and Faculty

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EGR 9200 Teaching Engineering in Higher Education, an introductory course in engineering pedagogy for engineering Ph.D. students, was restructured to increase student engagement. Specifically, the class was converted to an inverted (flipped) format to increase active learning, and an assessment hierarchy was introduced where students created lessons on a pedagogical topic and delivered them to a partner, enabling partner-based and self-assessment prior to delivering an updated version of the lesson to the entire class. These changes resulted in a noticeable improvement in the quality of lessons and in student engagement. A second benefit from this restructuring is that the course materials (i.e., recorded lectures) were made available online to allow current faculty, specifically junior faculty, to learn pedagogical concepts alongside the rest of the class when a different instructor was used for each course offering. Finally, the posted online materials provide an opportunity for other faculty to learn pedagogical concepts on their own time. Collaboration with experts in diversity, equity and inclusion enabled additional materials for the course to promote the growth of underrepresented groups in engineering. Successes and lessons learned in the restructuring effort are outlined.

Introduction

Richard Felder famously stated that traditionally “college teaching may be the only skilled profession for which no preparation or training is provided or required.” [1]. As a result, universities have addressed this issue through establishing a variety of programs that provide teaching training for PhD students, which is much more effective in developing their teaching skills than relying on them to mimic their former instructors [2]. While many of these programs aim at improving the teaching ability of current graduate teaching assistants in lab courses [3] as well as a more holistic approach involving student-led discussions about the TA experience [4], other programs focus on a more general method for preparing PhD students for careers in academia with an emphasis on teaching training. Some universities provide teaching experience by thrusting graduate students into the instructor of record role for small courses [5], but a gentler and more common approach is a formal program featuring pedagogy and skills development. For example, Variawa et al. [6] mentions an engineering pedagogy course as part of a year-long sequence for training PhD students for academic careers. In addition, the University of Cincinnati has a “Preparing Future Faculty” program [7, 8] that prepares graduate students for academic careers.

At Villanova University, the course EGR 9200 Teaching Engineering in Higher Education , the focus of this study, was initiated in Spring 2013 as the first in a sequence of two one-credit courses aimed at providing engineering Ph.D. students an opportunity to learn about engineering pedagogy and to apply it in the classroom. The students who complete the two courses earn a certificate along with their Ph.D. degree. The course sequence had been offered five times, with the most recent offering in Fall 2020/Spring 2021 being the focus for this study.

EGR 9200 provides the theory and some practice in applying engineering pedagogy to lesson delivery and syllabi development. The course cohort is taught well-established methods to improve student engagement and learning [9, 10], to reduce cheating [11], to address all learning styles [12], to promote inclusiveness in the classroom [13], and to structure courses around psychological principles such as Bloom's taxonomy [14]. The EGR 9200 course schedule also includes three guest lectures to introduce the students to issues and opportunities outside of standard teaching:

1. A leader of the Villanova University Counseling Center discussed the myriad emotional and psychological issues facing university students.
2. A guest lecture from a staff member at Villanova's Learning Support Services office discussed the philosophy and role of their office in aiding students with learning and mental disabilities.
3. A faculty member that leads the engineering service learning program presented on the learning opportunities associated with service learning projects.

As part of this course, students select modern engineering pedagogical topics (e.g., MOOCs, inverted classroom, and fostering creativity) to teach to the rest of the class as a "lesson." The students deliver a lesson twice during the semester: the first implementation is for a 15-minute "microlesson" on the topic, and the second implementation is a 45-minute "full lesson" on the same topic that uses the class feedback from the first lesson to improve and expand the microlesson. In both cases, the instructor meets individually with the students after lesson delivery to condense the class feedback to enable the students to focus on 2-3 key areas for improvement.

The course's general topics and format had reached a steady-state after multiple offerings, and the following teaching and learning issues were found after the Fall 2019 offering:

1. The course was held in a distance learning (DL) room to enable students to do self-assessment after teaching their lessons. The DL format, however, limited the students' creativity in lesson development by preventing kinesthetic learning and making it difficult for them to move around the room to directly engage the class.
2. The course format did not reflect the pedagogical techniques it introduces: the lectures are largely traditional PowerPoint presentations and lack significant active learning.
3. Many, if not most, engineering faculty have not had any significant formal teaching training nor been exposed to the topics of the course. The course for the first four offerings was only taught by a total of two instructors. Therefore, a major opportunity existed for improving overall engineering instruction – and, by extension, student learning – at Villanova if the course was reformulated to provide engineering faculty with easy access to course materials.
4. The Fall 2019 course offering, with its regular 2.5 hour time block, had several one-off time conflicts for students (e.g., research meetings). A shorter time block would alleviate these issues.

A major course redesign was therefore implemented in Summer 2020 to address the above issues:

1. Make the course more interactive through an inverted, or flipped, classroom format where students read the course textbook and watch lectures outside of class. This approach enables the class meetings to be fully devoted to active learning to provide better student engagement [15]. The approach also grants the instructor of record an opportunity to improve their teaching by participating in active learning alongside the students. The inverted classroom concept has been implemented in many previous documented studies (e.g., [16-19]), with some studies suggesting an improvement in student performance (e.g., [20]). It is known in the literature that active learning greatly improves knowledge retention [15, 21], and students generally prefer in-class activities over in-class lectures [22]. However, this study represents the first use of the inverted classroom in a course for introducing pedagogical concepts to PhD students.

   The flipped format makes course materials available online. If the materials are readily accessible, then the instructor role can be rotated among faculty for subsequent offerings. This approach enables teaching training opportunities for junior faculty, merging PhD student teaching training with that for junior faculty instead of running separate programs (e.g., [23, 24]). In addition, the availability of online materials can be used by other engineering faculty to improve their own teaching. Finally, this format reduces in-class time, mitigating one-off time conflicts to benefit attendance.

2. Provide the students (and the instructor who works alongside them) more opportunities to modify their specific lesson using an assessment hierarchy where participants pair up and critique each other in advance of obtaining class-level feedback. This way, students obtain feedback on their lessons in multiple stages to provide additional practice and support.

The two goals of the study are (1) increased student engagement within the course, and (2) improved quality of student teaching. These goals were evaluated by improved attendance (Goal 1), student interaction (Goal 1), and lesson delivery (Goal 2) from the Fall 2020 offering (new format) compared to the Fall 2019 offering (old format). An additional deliverable from the study is the creation of the framework for ensuring that the general engineering faculty can benefit their teaching from having access to course materials in an organized manner.

Approach

The inverted format features (1) pre-recorded lectures with embedded quizzes, and (2) mandatory one-hour interactive in-class sessions. Students are required to pass the embedded quizzes and to apply different pedagogical techniques to their own lesson to ensure effective learning of pedagogical topics. The in-class sessions are therefore primarily devoted to sharing their applied knowledge. Note that the students learn by applying different pedagogical methods to their own lessons to improve their understanding of how the different methods can affect the delivery and to enable them to choose the methods that best fit their personal teaching style. The students do not actually deliver most of these modified lessons to the class due to time constraints. Instead, they reflect and discuss what they have learned from this process.

The assessment hierarchy was also initiated to help students increase their ability to effectively teach content to an audience. The students are organized into pairs, and each student presents his/her lesson to the partner while the presentation is recorded. These meetings were necessarily virtual due to COVID-19 restrictions on campus, so this recording was done through web meeting software. However, an alternative and broader vision of the activity could also involve students recording each other's lessons through smart phone recordings in an in-person setting within a classroom. In either case, the partner provides feedback for the student presenter, makes the recording available for the student presenter, and the student presenter provides self-feedback based on their experience delivering the lesson and from watching the recording. It should be emphasized that these partner meetings are held outside of regular class meetings as part of the effort to shift the course time commitment outside of the regular class meeting times, thereby shortening in-class meetings and offering more flexibility for the students to do the coursework.

The partner and self-evaluation comprise the first stage of the assessment hierarchy. The student presenters update their lessons through this first stage to provide an improved version to the entire class in the second stage in the hierarchy. The hypothesis behind this approach is that the major issues associated with the lesson are addressed in the partner and self-evaluation stage, whereas the improved lesson in the class evaluation stage allowed for (1) more nuanced constructive criticism from the entire class, thereby improving the confidence of the student presenters to deliver high quality lessons; and (2) improved learning on special pedagogical topics by the entire class.

The Fall 2020 course schedule, shown in Table 1, indicates the different topics of study throughout the semester. 21 modules were created that correspond to each of these topics. These modules, created using Camtasia® software, each feature a 10-15 minute recorded PowerPoint slide presentation followed by a five-question multiple-choice quiz. The quiz results are automatically imported into Blackboard as a SCORM package for inclusion in the course overall grading scheme. The modules were prepared in consultation with the Villanova Institute for Teaching and Learning.

Figure 1 shows the three groups beneficiaries of impact anticipated from the restructuring. These three groups each have a cohort size and relative level of impact:

1. <u>The rotating instructor (small cohort, high impact)</u>: each annual offering of the course will have a different instructor, with the preference given to junior faculty since the course participation will benefit their teaching for the longest period. The junior faculty would in theory also be eager to be named the course instructor since it represents a relatively light load for the level of contact hours associated with Villanova instruction. A separate document for new instructors has been prepared to help guide the instructors through administering the course while participating in the in-class activities, viewing the online modules, and using their own course lectures in microlesson and full lesson development to enable the improvement of their existing course assignments.
2. <u>Independent learners (medium cohort, low impact)</u>: The materials for the course will be offered online, so interested faculty, staff, and students can acquire the freely-available course materials and perform the modules (these modules will become available in April

2021). The intended audience can include existing faculty that do not fall into the rotating instructor group, students not eligible for the course (e.g., MS students), and even faculty from outside the university. This program could therefore promote the college and lead to collaborations with other engineering institutions.

3. PhD students (large cohort, high impact): these are the students that enroll in the course and have a high level of benefit in their teaching as they prepare for their career in academia. One can see that whereas this group is the traditional primary beneficiary of the course, the restructured format adds the rotating instructor as a primary beneficiary.

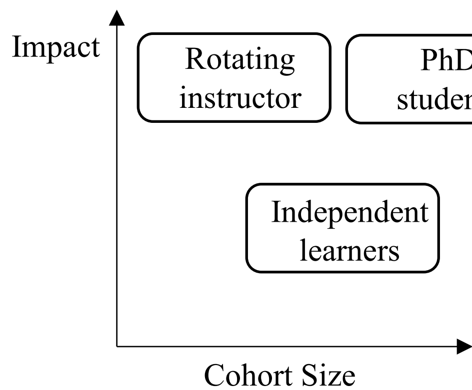

Figure 1. The three groups of beneficiaries from the restructured course.

Table 1 also indicates the time required to complete the in-class meetings, which is significantly reduced compared to the 2.5 hrs. required for each class meeting in the old course format. However, a meeting time of at least two hours was needed in 3 cases: the introductory lecture, the microlessons meeting, and the full lesson meetings. It is important to have microlessons and full lessons done synchronously as it promotes student-instructor interaction and active learning. Unfortunately, the resultant need for these isolated long course meeting means that the course needed to be scheduled for the full 2.5 hr. time slot, meaning that future versions of the course need to reduce the time slot to increase enrollment and to avoid time conflicts with students' research obligations.

Table 1: Schedule for the PhD Teaching Course

Week	Theme	Topic(s)[1]	In-Class Time
1	Overview: You as a Student	N/A	2 hr., 8 min.
2	Overview of Our Students and U.S. Engineering Schools	2-1 Overview of Engineering Education in the U.S. 2-2 Hougen's Principles 2-3 Engineering Demographics	1 hr., 20 min.
3	Personality Types and Learning Styles	3-1 Personality Types and Learning	1 hr., 15 min.
4	Teaching to Preferred Learning Styles and Cognitive Levels	4-1 Teaching vs. Learning Styles 4-2 Learning and Cognitive Levels	1 hr., 15 min.
5	Start the Semester Off Right by Focusing on the Students	5-1 Moving from Teaching to Learning 5-2 The First Day of Class	1 hr., 10 min.
6	Microlesson Presentations	N/A	2 hrs.
7	Guest Lecture (University Counseling Center), Overview of Course Planning	7-1 Mapping Out a Course 7-2 Creating a Syllabus 7-3 Diversity, Equity and Inclusion	1 hr., 45 min.
8	Guest Lectures (Service Learning, Learning Support Services)	N/A	1 hr., 10 min.
9	Delivering the Course and Ensuring that Students Learn	8-1 Effective Assessment 8-2 Lecturing Basics 8-3 Lectures as Performances	1 hr., 15 min.
10	Opportunities for Student Learning	10-1Effective Questioning 10-2Teaching Outside the Classroom 10-3Active Learning	1 hr.
11	The Rougher Side of Teaching	11-1Handling Student Cheating 11-2Feedback on Teaching	1 hr., 25 min.
12-13	Full Teaching	N/A	2.5 hrs. each
14	Special Topics	14-1Teaching Design 14-2Faculty Careers	1 hr.
[1]Topics are assigned as modules in advance of the in-class meeting.			

The modules in Table 1 were also grouped into clusters for engineering faculty to peruse at their own convenience, enabling faculty to bolster their skills in specific areas such as creating a new course, adjusting their own course to reach all student learning styles, and general good course management. These clusters are listed in Table 2. A cluster was also made for engineering diversity, equity, and inclusion, which was developed in partnership with the engineering college's committee on diversity, equity, and inclusion, along with the university office associated with the same topic area. The diversity, equity, and inclusion module has been promoted to all college faculty to improve their knowledge on the subject area to improve their ability to make their courses more inclusive in nature, addressing the lower levels of Maslow's Hierarchy of Needs [25] for all students, thereby enabling all students to learn.

Table 2: Clusters of Learning Modules for Existing Faculty Development

Cluster Name	Modules
Diversity, Equity, and Inclusion	2-3 Engineering Demographics 7-3 Diversity, Equity, and Inclusion
Creating a New Course	7-1 Mapping Out a Course 7-2 Creating a Syllabus
Enabling All Students to Learn	3-1 Personality Types and Learning 4-1 Teaching vs. Learning Styles 4-2 Learning and Cognitive Levels 5-1 Moving from Teaching to Learning
Effective Course Delivery	8-2 Lecturing Basics 8-3 Lectures as Performances 10-1 Effective Questioning 10-3 Active Learning
General Good Course Management	5-2 The First Day of Class 8-1 Effective Assessment 11-1 Handling Student Cheating
Miscellaneous	2-1 Overview of Engineering Education in the U.S. 2-2 Hougen's Principles 10-2 Teaching Outside the Classroom 11-2 Feedback on Teaching 14-1 Teaching Design 14-2 Faculty Careers

Results

The results and analysis associated with the two goals are as follows:

<u>Goal #1: Increased student engagement within the course, as measured by improved attendance</u>. The enrollment for both Fall 2019 and Fall 2020 offerings was only six students, so it was easy to track attendance and to assess engagement. The Fall 2020 offering had only one excused absence, whereas the Fall 2019 offering had multiple absences due to time conflicts with research meetings and personal issues. While the small sample size and uncertainty associated with periodic time conflicts do not conclusively show that this goal is achieved, the positive results suggest that the improved attendance may be likely in the long run. A long-term analysis of enrollment that shows increased course registration by the college's PhD student cohort would be an additional metric to suggest improved student engagement.

It should be mentioned that the Fall 2020 offering, despite being only a DL offering due to COVID-19, had a higher class energy level than the earlier offering even though the DL format is generally less engaging [26-28]. All six enrolled students provided significant contributions to the in-class activities and discussions, and their web cameras remained on during the entire duration of every class meeting. The restructuring is therefore serendipitous considering the unintended shift to DL-based courses due to COVID since the old PowerPoint-based format would almost have certainly been less engaging for the students.

Goal #2: Improved quality of student teaching. The most direct comparison in the quality of teaching is in the issues identified during the microlessons as illustrated in Table 3. While in retrospect a quantitative assessment following a rubric would have provided a clearer metric for improvement in microlesson quality, one can clearly see that the table shows that the issues associated with the Fall 2019 offering (poor communication, unprepared slides, and poor time management) are more significant than those associated with the Fall 2020 offering (minor issues such as the amount of text on the slides). One common criticism in the Fall 2020 column is the lack of audience engagement, which comes about when the more glaring issues with the lesson (many of which are seen in the Fall 2019 Offering column) have been addressed. It should be noted that the full lessons were also of generally higher quality in the Fall 2020 class. Therefore, the assessment hierarchy appears to be beneficial to growing the students' teaching ability.

Table 3: Issues Identified with Class Microlesson Presentations

Student ID	Fall 2019 Offering	Fall 2020 Offering
1	Minor issues	Add more text to slides
2	Poor verbal and non-verbal communication, difficult to follow	Minor issues
3	Unclear slides, need to project more confidence, make presentation pace more consistent	Use less text and a larger font
4	Poor time management, grammatical mistakes on slides, presentation based on opinions rather than facts	Use less text and have more audience engagement
5	Unprepared, busy slides	Have more audience engagement
6	Goal/objective unclear, poor verbal communication	Use less text and have more audience engagement

Student feedback was also considered in evaluating the success of the restructuring. Both Fall 2019 and Fall 2020 offerings did not have enough enrollment for formal anonymous course evaluations, but feedback was nevertheless collected from the students in a non-anonymous way. Below are comments from the students upon completion of the course:

- "enjoyed class, liked concept map, quizzes are good so didn't spend much time in class talking about theory, whereas quizzes are about background, good structure of class, first time doing Zoom class but liked breakout rooms to make things more dynamic & connect with other students one-by-one."
- "course is great, shows that lot of work put into it, students appreciate that we got to know them."

- "helpful and useful course, went very well. Wait a few seconds before choosing answer, and it went well." Note that the comment on waiting a few seconds refers to handling the issues of SCORM quiz scoring in Blackboard.
- "lots of reading & HW assignments, but good to allow understanding concepts prior to video & answering questions."
- "things this way are better than in in-person classes. Learned a lot."
- "love the course very much. Good hybrid of online teaching. Flipped classroom is very efficient, videos w/ book worked well in advance of discussions. Efficient way for students to get knowledge & do exercises."

The third bullet above refers to a technical lesson learned with the course restructuring. Many students had issues in getting their SCORM results recorded, the cause of which our IT staff was unable to pinpoint. The student had the suggestion that the pace at which questions were answered is key in enabling the recording of SCORM results. If students answer the questions at too rapid a pace, then the system essentially locks up, preventing the recording of scores for that session. Blackboard lists the quiz as permanently in progress, so there is no workaround to get the scores. Therefore, future offerings of EGR 9200 should emphasize that the students wait a few seconds between answering quiz questions.

A second lesson learned related to creating the modules for use by non-course registrants. The modules were placed into public drive for all to access with read only permissions. The videos were restructured such that the users could take the quiz and were provided with immediate feedback without recording of the results. This strategy, while useful in allowing many current faculty members to learn engineering pedagogy, could be an issue for future PhD students taking the course. Therefore, future instructors may need to make new quizzes for the modules, which would be most easily done during the class meetings.

Conclusions and Future Work

The new approach for delivering a course on teaching pedagogy that could benefit PhD students pursuing careers in academia appears to be successful in enabling the improved delivery of student teaching. Furthermore, the results for student engagement appear promising but need further evaluation in continued offerings of the course. The engagement of faculty in self-training using the course modules and the implementation of rotating junior faculty instruction in future offerings of the course remains to be seen, but the structure of the course now allows for this possibility. The course instructor will work with the engineering college's administration to promote the availability of these modules and provide faculty incentives to work through them. Future work therefore involves engagement of the "independent learners" group through advertising to other institutions and providing incentives for the faculty to view and participate in the modules.

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