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A Project-based Learning Method to Teach Concepts of Viscoelasticity and its Applications to Seniors and Graduate Students in Biomedical, Civil, Chemical, and Mechanical Engineering

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Introduction

Viscoelasticity is a new multidisciplinary course offered in the College of Engineering at Rowan University. Viscoelastic behavior is observed in a broad range of materials, such as polymers, biomaterials and construction materials. The objective of the course is to not only provide an understanding of the linear and non-linear viscoelastic concepts, but also the direct engineering applications of these concepts. The course covers linear and non-linear viscoelastic constitutive modeling for different modes of loading, such as compression, tension and shear and interconversion between parameters measured from these different modes of loadings. These interconversions are very useful because measuring properties under different modes of loading under a broad range of temperatures is very time consuming and resource intensive. The process of calculating viscoelastic parameters from measured data was also explained along with classical solutions and the use of time–temperature superposition.

This course is a multi-disciplinary course taken by seniors, masters and doctoral students in biomedical, civil, chemical, and mechanical engineering. There were twelve undergraduate and seven graduate students in the class. The course was divided in two parts; the first part of the course covered the concepts of linear viscoelasticity, rheological models, non-linear viscoelasticity, and time temperature superposition. In the second part of the course all students, in groups of two or three, were required to do a class project and discuss them in class, which required them to apply the concepts learnt from this course.

The goal of this paper is to disseminate to instructors in other departments or universities a methodology and some of the tools that the instructor successfully employed in such a math intensive interdisciplinary course. These tools made the course more interesting and provided a better appreciation of the complex math in this course.

Many instructors have taught viscoelasticity concepts [1-3], but all of them were within a single field, such as biomedical engineering, or a single material at an undergraduate level. This paper is unique in the sense that, it is for both undergraduate and graduate students and it covers four disciplines: Biomedical, Chemical, Civil, and Mechanical Engineering. The course outline is shown in Table 1 below.

Textbook and Weightage of Grading

The required text for this course was Creep and Relaxation of Nonlinear Viscoelastic Materials by William N. Findley, James S. Lai, and Kasif Onaran. In addition, there were several E-books available for free at the Rowan University library that was utilized, such Theory of Linear Viscoelasticity by Ferry.

Table 1. Course Outline

Week	Proposed Topics
1	Introduction – Mechanics of stress and deformation
2	Linear viscoelastic constitutive models
3	Stress analysis - case studies / Beams and tubes
4	Interconversion between linear creep and relaxation, and properties measured between static and dynamic
5	
6	Time-temperature superposition
7	
8	Midterm Exam
9	Nonlinear viscoelasticity
10	
11	Effect of temperature on non-linear viscoelastic materials
12	Interconversion between non-linear creep and relaxation
13	Experimental Methods / Development of models based on experimental data
14	
15	Final Exam

The seniors and graduate students take this course together. The graduate student did a report for a class project, which was optional for undergraduate students. The grading weightage is shown in Table 2.

Table 2. Grading Weightage (in percentage)

	Undergraduate	Graduate
In-class problems	15	10
Mid-term	20	20
Final exam (Comprehensive)	20	20
Homework	15	10
Quizzes	10	10
In –class projects (additional paper by graduate students) :	20	30

In-class problems

The instructor provided in-class problems towards the end of the class that they worked in teams of two or by themselves. These problems were based on the concepts covered that day. They were in-lieu of the example problems that instructor would solve in a traditional instructional setting. Before the end of class, the student had to show the instructor that they solved the problem to receive full-grade for that set. They were not graded on whether they got it right the first time without any help.

This tool was very useful because it provided the students an opportunity to think through the complex math and solve the problems while it was fresh in their minds with the help from me and their classmates. The students did struggle through these problems, but, there was a lively interaction in the entire class which would not have happened, if it was done in a traditional lecture setting. This pedagogical technique is not unique and has been done in classes by many, but the instructor wanted to emphasize that in this particular case, it truly added value in making the complex math involved more meaningful in understanding its applications.

For the first four weeks of the course, the instructor conducted traditional instruction for 1.5-2 hours, and the rest of the time was for in-class problems and quizzes. When the grad project presentations were introduced, the class time was same, except that quiz time and in-class problem times were reduced to accommodate grad student presentations.

Class Projects

The twelve undergraduate students were divided into six groups, and seven graduates (three Doctoral and four Master of Science) were divided into three groups. The students self-selected their team members in a group. Except for one group, all the students within a group were within a single discipline. Except for one group with three students, all other groups had two students. Depending on the expertise of the different students, three groups each tested asphalt and asphalt concrete, and one group each tested bio-polymer, nanofibers, and foamed pillow. The main reason for the majority of the groups did the project in asphalt and asphalt concrete, because the instructor's research laboratory has the resources to allow testing of these students. All the testing time for the students was outside the class time. To ensure that the students get the most of out of their hands-on experience, the experimental protocol was vetted thoroughly. The civil engineering technician also assisted the students in testing. For each of the materials, the objectives was the following:
1) Determine whether the material is linear viscoelastic?
2) Determine if time-temperature superposition is applicable?
3) Develop a rheological model, and
4) Explain impact of the above results in practical applications.

The scope and depth of testing was discussed with the instructor before finalizing the testing protocol. The students were strongly encouraged to discuss the scope of testing with their respective graduate adviser, if assigned, to determine if results from the project or concepts learnt from this class would be relevant in their own research.

Each group presented their progress to-date to the entire class every week for five to ten minutes each. They discussed their experimental set-up, challenges and successes of testing, and results collected to-date. Based on the feedback from the students and instructor, on several occasions, the testing protocol and analysis methodology was refined to achieve the overall objectives of the project. In the final day of class, the students did a final project presentation.

All the students learnt by open discussion of these projects. They clearly saw how viscoelastic concepts can be utilized to a broad range of materials. The viscoelastic models involve complex mathematics, while they are crucial part of the course, the instructor wanted to clearly show the applications of these models and how using these models impact day-to-day life, may it be, construction materials or bio-materials. In addition to the course evaluations, the instructor conducted an assessment of the impact of these projects on student learning of the complex concepts of viscoelasticity.

Overall performance of students

Table 3 shows the grade distribution of graduate and undergraduate students. The undergraduate students had an average grade of 88% and the graduate students had an average grade of 94%.

Table 3: Grade distribution of graduate and undergraduate students

		Graduate Students	**Undergraduate Students**
A	93+	5	5
A-	90+		2
B+	86.7+		1
B	83.3+		2
B-	80+		
C+	76.7+	1	1
C	73.3+		
C-	70+		1
D+	66.7+		1
D	63.3+		
D-	60+		
F	<60		
	Total	6	13

Evaluation Tool for Class Projects

In the sections below, the questions and responses to the course evaluation is presented.

Questions about Efficacy of the Class Projects

A survey was distributed to the students specifically regarding the format of the class project. The survey tool along with the nineteen responses are shown in Table 3 below. The first two questions directly addressed the efficacy of these projects in understanding the concepts and whether the format was helpful (responses are shown in Table 4). The students were also asked for a reasoning behind their responses for the instructor to get a better understanding of what can be done to improve the project.

Table 4. Response to Efficacy of Class Projects

	Number of responses	
Response	**The class projects help me learn the math behind the viscoelastic models**	**The structure of the project presentation on a weekly basis was useful**
Disagree	1	0
Neutral	2	5
Agree	10	5
Strongly Agree	6	9
Total	19	19

Response to the question: Explain your answer. Why?

- Weekly presentations kept me on schedule for the final presentation and helped answer questions as I ran into issues.
- It was cool to know about curve fitting, Laplace transforms and other deviations.
- Getting feedback on a regular basis helped keep the project on track and allowed us to learn more about why we were getting the results we were getting.
- Got us prepared for final and kept us thinking.
- It helped stay on task and assured the work being done wasn't being done incorrectly.
- We had to relate the data to the viscoelastic models which gave us an in depth understanding of the viscoelastic behavior. Project presentation was very useful as it kept us in check with the project.
- Project presentation on weekly basis was certainly helpful since it not only makes the professor to be aware of the project progress but it helps the students to address the hardships in the project.
- The project was very confusing because the data didn't match anything given by SPSS.
- Weekly updates were helpful to make sure it was not left to the last minute and to be kept on the right track, but weeks when there were delays on the project due to scheduling was highly stressful.
- Weekly presentations allowed us to stay consistent with testing and analysis rather than leaving it for the end. Also, allowed us to come to the professor with questions and concerns.
- Kept us on track and routinely working on the project.
- Weekly updates got us good feedback often. The project also helped us prepare for the final.
- At the start of the project I was very unsure of what to do or how to us SPSS. Weekly review helps so we can discuss with you and you can point us in the right direction.
- It forced groups to make progress every week which was helpful.
- The weekly presentations started to get repetitive as a whole presentation each time. Meeting with groups may have been a better way to track progress with groups.
- The weekly updates were beneficial to an extent. However preparing for a presentation weekly took away from that would be otherwise spent on studying class materials.
- Weekly updates were good and allowed for consistent feedback, but no progress was made a lot of the time due to issues with curve fitting on SPSS.
- It was helpful but I feel like a handout.

Reflection on the Question about Efficacy of the Class Projects

Success: After reviewing all the comments, my overall thoughts were that they liked the weekly presentation. It provided structure and not only the instructor, but also other students can provide feedback. Instructor noticed lively and interactive discussion from students about the objectives, scope, test results, and analysis of the different projects. The students were learning from other projects, and on several occasions modifying the experimental protocol or analysis methodology based on the discussion in class.

Challenges: Some students struggled with the analysis and needed more guidance. However, some of the comments are clearly related to lack of student management. This was more evident, at least anecdotally in undergraduate students, than graduate students.

Question about Objectives of the Class Projects

The second set of questions focused on whether the objectives of the different projects was clearly defined. This question was critical because, the instructor wanted to provide overall framework and not be too specific, allowing students some flexibility to design their own experiments, considering that the project had to be completed in eight weeks. Table 5 shows the responses to the questions.

Table 5. Response about the objectives of the project.

	Number of responses
Response	**Were the objectives of the individual project clearly defined?**
Disagree	3
Neutral	6
Agree	5
Strongly Agree	5
Total	19

In addition, the instructor asked what was the worst and the best part of the project. This question helped elaborate the success of the project what elements need improvement going forward. Those are outlined below.

Responses to the question: What was the Best part of the project?

- Best part was figuring it out.
- It gave a hands-on use of the data so the math made sense and wasn't just numbers.
- The best part of the project was the research portion of the study. I came across a lot of new information when I was researching methods to achieve all the tasks involved in the project.
- The project really helped pull together the entire course and make everything we learned make sense.
- Weekly meetings helped.
- Applying what we learned in class.
- Physical testing allowed a more in depth understanding of material properties and how they are affected.
- Interaction with professor is the best part I have ever experienced.

- The best is that we got to learn a new program.
- The goals were very well defined. Real life experiments and dealing with data was the best part.
- Professor was helpful.
- Seeing how the math actually relates to a real world application instead of just conceptually.
- The best part was the informality as it is a very difficult subject.
- The best part was using equipment we've never used before and learning more about an everyday item (memory foam).
- The best part was using a new piece of testing equipment – it was very interesting. I got to learn a lot about my material and other groups' materials.
- The best part was curve fitting at sigmodal. Worst part was pseudo stiffness parameter.
- Fitting curves because I understood that more

Responses to the question: What was the Worst part of the project?

- Worst part was the uncertainty and not knowing if what I was doing was correct.
- The field attempts ate up a lot of the semester.
- The goals of the project were not clearly defined until after the project had been given.
- Making the overall goals clear earlier on would have been nice.
- A more clearly defined objective for individual projects would be helpful.
- Figuring out the master curve with minimum percentage of error is the toughest part that I faced and more qualitative.
- There is a learning curve when using new materials and machines, so it felt like some time was wasted with bad tests.
- Was difficult.
- It has minimal relevance to me since I am going into Environmental.
- The worst part was acquiring the material on time.
- The worst part was issues with scheduling a time to test material, since we needed technician to use machine and time it took to receive item (2 weeks).
- The worst aspect was time allotted. Availability to work got very difficult towards the end especially since we did not get our material until the very end.
- The worst part of the project was just that the material was going over my head and was unsure how to make correlation between parameters.
- The worst part of the project was the time consuming nature of the study because I was unfamiliar with some of the tasks that were required by the project.
- The project was just a lot of data fitting. It did not really help me understand many concepts about viscoelasticity.
- The worst part was initially interpreting the data given but once we did that SPSS was a lot of trial and error.
- Worst: SPSS

Reflection on the Question about Objectives of the Class Project

The "Best" and the "Worst" part clearly showed that, as expected, students perceived the "open-endedness" of the project very differently. Some enjoyed the flexibility, and others got frustrated and would have preferred more structure. Some comments, such as "*Applying what we learned in* *class*" was very positive and it appears that the class project worked as intended. The instructor acknowledges that, these projects were a challenge for other students and consumed more time than they had anticipated. However, instructor believes, that seven weeks was more than sufficient time for the class project, and some of the concerns about time may be attributed to poor time management by the students.

Course Evaluations

Table 6 and Table 7 shows the graduate and undergraduate student course evaluations followed by comments from students. The course evaluations were conducted through a pre-established university-wide online teaching evaluation system.

Comments from Graduate and Undergraduate Students about the Course

Graduate students

- Good professor, who really had good stuff on the corresponding subject.
- It was hard but got to learn a lot regarding visco-materials

Undergraduate students

- Very interactive and thought provoking
- Lesson goals were difficult to communicate but it was done.
- Subject material was extremely difficult and hard to learn. It was taught well put the material itself was hard to learn.
- It is difficult but doable.
- Nothing against Dr. Mehta, subject matter was very hard.

Reflection on Course Evaluations and Lessons Learned

Based on the numeric scores and the comments, the graduate students, both Master of Science and Doctoral Student appear to appreciate the difficult content and its application in their respective research projects. On the other hand, some of the undergraduate students were clearly overwhelmed by the intensity of the math that was involved in this course. The instructor would provide a little more structure to the projects, especially the experimental ones.

Summary

Viscoelasticity course is very math intensive course and the concepts could appear abstract leading students to lose interest. The comments, especially from the undergraduate students almost, unanimously state that the content was very difficult. The instructor anticipated this problem and therefore developed an outline so that the latter half the course could focus on applications of the theory so that the students can get an appreciation of what was learnt in the classroom.

Table 6. Graduate Student Evaluations

Graduate Students (Total: 4/7)							
No.	Question	Always (5)	Very Often (4)	Sometimes (3)	Rarely (2)	Not observed (1)	Average (out of 5)
1	The instructor taught the subject in way it was easy to learn?	3	0	1	0	0	4.50
2	Instructor gave clear explanations	3	0	1	0	0	4.50
3	Instructor asked questions to promote thinking	4	0	0	0	0	5.00
4	Instructor addressed student questions and comments	4	0	0	0	0	5.00
5	Instructor provided useful feedback to students	4	0	0	0	0	5.00
6	Instructor treated student with respect	4	0	0	0	0	5.00
7	Instructor actively engaged student	4	0	0	0	0	5.00
8	Instructor engaged students to express ideas or opinions	4	0	0	0	0	5.00
9	Instructor was prepared for class	4	0	0	0	0	5.00
10	The instructor communicated course and lesson goals	3	0	1	0	0	4.50
11	The instructor taught class in a way that helped students make connections to their personal or professional lives	4	0	0	0	0	5.00
12	Instructor was open to student feedback about the course and instructional methods	3	1	0	0	0	4.75
	Average						4.85

Table 7: Undergraduate Student Evaluation

Undergraduate Students (Total: 7/12)							
No.	Question	Always (5)	Very Often (4)	Sometimes (3)	Rarely (2)	Not observed (1)	Average (out of 5)
1	The instructor taught the subject in way it was easy to learn?	1	3	1	2	0	3.43
2	Instructor gave clear explanations	0	3	4	0	0	3.43
3	Instructor asked questions to promote thinking	3	3	1	0	0	4.29
4	Instructor addressed student questions and comments	2	4	1	0	0	4.14
5	Instructor provided useful feedback to students	2	3	2	0	0	4.00
6	Instructor treated student with respect	5	1	1	0	0	4.57
7	Instructor actively engaged student	2	5	0	0	0	4.29
8	Instructor engaged students to express ideas or opinions	3	3	1	0	0	4.29
9	Instructor was prepared for class	3	4	0	0	0	4.43
10	The instructor communicated course and lesson goals	1	3	3	0	0	3.71
11	The instructor taught class in a way that helped students make connections to their personal or professional lives	1	3	0	2	1	3.14
12	Instructor was open to student feedback about the course and instructional methods *(only 6 responses for this one)*	3	2	0	1	0	4.17
	Average						4.00

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