121st ASEE Annual Conference & Exposition
Indianapolis, IN
June 15-18, 2014
Paper ID #9545

A Course in Biomaterials Taught Using the Socratic Method

Dr. William H Guilford, University of Virginia

Will Guilford is an Associate Professor and Undergraduate Program Director of Biomedical Engineering at the University of Virginia. He received his B.S. in Biology and Chemistry from St. Francis College in Ft. Wayne, Indiana and his Ph.D. in Physiology from the University of Arizona. Will did his postdoctoral training in Molecular Biophysics at the University of Vermont under David Warshaw. His research interests include the molecular mechanisms of cell movement and muscle contraction, and effective means for education.

Dr. Michael B. Lawrence, University of Virginia

A Course in Biomaterials Taught Using the Socratic Method

The consensus definition of biomaterial is "a nonviable material used in a medical device, intended to interact with biological systems.[1]" The emphasis on nonviable materials *intended* to interact with biological systems has perhaps guided the development of modern day education in biomaterials science. That is certainly the case of the undergraduate course in Biomaterials taught at the University of Virginia since 2005, which had been delivered in a lecture format guided by a textbook, and using homework and periodic exams as tools for summative assessment. The emphasis was traditional – the material properties of (primarily) musculoskeletal tissues.

The same seems to be true of textbooks and classes taught elsewhere on biomaterials; the emphasis has been on materials science, including tribology, failure, phase transitions, structure of metals, testing and characterization, and a select few specific biologic materials. Bone has proven especially popular, perhaps because of its interesting and explicable material properties, and its high percentage inorganic "nonviable" material. While the clinical and biological case studies presented by such texts are often helpful, they are included as a capstone and are typically limited in scope.

We sought to redesign this course, and in doing so we wished to embrace a broader definition of "biomaterial" with a focus on clinical practice and biological response in addition to materials science. We sought to include materials of biologic origin as well as exogenous materials. We also wanted students to synthesize knowledge ranging from chemical properties to the immune response to understand how clinical problems are solved (or often caused) by a variety of materials. Thus our course objectives included:

1. Knowing and comprehending how biomaterials of natural and synthetic origins interact with and are recognized by cells;
2. Analyzing how the physical and chemical properties of biomaterials lend themselves to specific clinical applications; and
3. Synthesizing knowledge to use materials in novel ways for clinical applications.

However, much of our motivation in the course redesign was philosophical. We and many of our colleagues bemoaned the average student's unwillingness to ask or respond to questions in class. We often expressed frustration with students being reluctant to use what they learned in one class or context in a different class or context. Finally, we were frustrated with our inability to develop metacognitive skills in a normal class setting; after all, engineering requires an understanding of what information is relevant to a problem, as well as identification of what information is missing. None of these are easily developed in a traditional classroom.

We therefore included an additional objective, which is to develop a skill that is often desired of students but the development of which is not supported by lecture or laboratory formats:

4. Explaining, defending, and forming positions on technical matters via oral argument.

We used the Socratic method enhanced by online assessment and discussion tools to meet these seemingly disparate objectives.

Course structure

There were no lectures; rather, instruction relied entirely on preparation according to a case study given to students, and subsequent questioning of individual students by the instructor. Students were provided with a clinical case study one week before class in which the treatment of a patient's condition involved a specific material (e.g. stainless steel). An example case study is given in Appendix 1, and a list of all the case studies is given in Table 1. With only one exception, each case study was derived from the published literature and edited for length and to remove extraneous content. The case studies were delivered by NowComment – a free online discussion tool for online, sentence-level commenting of non-editable media (*http://www.nowcomment.com*). Students were encouraged but not required to comment the case study online. In fact, students were free to prepare for class using any means they chose.

Questions were included with each case study to help guide students' preparation. At first only generic questions were supplied (Appendix 2). However, mid-term we responded to student concerns that it was impossible to prepare for upcoming quizzes given generic guidance by instead crafting custom questions for each case (see the end of Appendix 1 for an example).

	Case	**Materials**	**Also**
1	Laceration of the ear	Skin, stainless steel, silk, collagen, PLGA, polyester	Stainless steel fabrication
2	Bandages in the treatment of large-area wounds	Polyester, polyurethane	Adhesives
3	Treatment of microgenia	Silicone, ePTFE, Medpor	3D printing, rapid casting
4	Bone fractures in children	Bone, stainless steel, titanium	
5	Hip replacement	Bone, cartilage, stainless steel, titanium, PTFE, ceramics	Texture, sintering, porosity
6	Percutaneous coronary intervention and stents	Nitinol, titanium, eluting drugs	Shape memory and superelasticity
7	Aneurisms and Guglielmi Detachable Coils	Platinum, stainless steel	
8	Quantum dots and cancer	Semiconductors, cadmium, photoactivatable drugs	FRET, quantum confinement
9	Liposomes for cancer therapy	Lipids, anthracyclines	
10	Burns and xenografts	Skin, acellular tissues	Skin graft preparation
11	Aortic valve replacement	Pyrolytic carbon, stainless steel, acellular tissues	Transcatheter delivery and placement

Table 1: Case studies used, primary materials covered, and other incidental topics associated with each. Case #6 is included here as Appendix 1.

At the beginning of each class the students were quizzed to ensure they had prepared for the day's discussion (5 questions), and to ensure that they learned during the preceding class period – 5 questions based solely on the previous class discussion. The goal was to keep students fully engaged, even when they were not the randomly chosen discussants. This is especially important when the majority of students have so served, leaving a minority that can still be called upon.

Two non-graded questions were asked at the end of every quiz to determine how students prepared for class:

1. Did you use the student comments on NowComment to prepare for class today?
   a. Yes, I read and commented
   b. Yes, I read but did not comment
   c. No
2. Did you study as part of a group, *aside from* using NowComment?
   a. Yes, I met with a study group
   b. Yes, I had a study group online
   c. No, I worked independently

Six students were randomly selected at class time to be discussants for a given period, meaning they never knew when they would be called upon. Students were allowed one "pass" that they could exercise at any point during the semester, effectively putting off their discussion on a day when they felt under-prepared. The number of students serving as discussants on any given day was 6, which meant that every student in the class would serve as a discussant twice during the semester.

The instructor spent the remainder of the period questioning these 6 students while the remainder of the class watched and listened. When the discussants were unable to answer a question, discussion was opened to the entire class. Throughout the discussion the instructor took brief notes and drew schematics on a digital whiteboard. Much of the drawing was done at the instruction of students; that is, students themselves did not come to the board, but rather told the instructor what to draw and how. We found this to be particularly instructive as it simultaneously gave students opportunities to restate and precisely describe things and also engage them in a way that was not as dependent on exact vocabulary.

After class, students were asked to evaluate their peers' performance as discussants. For each discussant the class was asked to rate their performance by the following scale:

> Please rate how **[student name]** performed as a discussant and in preparation for class. When scoring, please use the 1-10 scale that follows.
>
> 10=outstanding in their discussion and preparation.
> 7=ok, but needs to improve either their discussion or their preparation
> 5=not very effective. Both their preparation and discussion needs to improve significantly.
> 1=completely ineffective as a discussant and unprepared for class

Summative assessment was based on four factors; performance as a discussant, classroom contributions on days when one was not a discussant, quiz scores, and peer evaluations.

The quiz scores were a matter of particular concern to students since without a traditional lecture or textbook from which to prepare, students felt that they were being penalized for their individual approach to preparation; there was no set body of material or prescriptive guide for preparation. Similarly, one student suffered from glossophobia, which could have unfairly penalized them in this class which was based in oral defense. To help alleviate their grade anxieties we implemented a "flexible grading policy" mid semester in which their scores were weighted each of four ways and students given the highest of the four when calculating a *course* grade (Table 2). Our rationale was to allow each student to participate and contribute to class as best suited their strengths, and not be unduly penalized for the class format. While this approach considerably reduced grade anxieties in the class, it neither altered the component assessments themselves nor how they would be used to assess ABET learning objectives. Indeed, 74% of students fared best with the original (pre-"flexible" grading weights).

Component	Mean score (±sem)	Original weight	Quizzes low	Discussion low	Participation low
Discussion	90.8±0.7%	40	60	30	45
Participation	73±3%	10	10	40	5
Quiz scores	74.7±0.7%	40	20	20	40
Peer evaluation	81.0±0.6%	10	10	10	10
% students for whom weight is highest		74%	19%	7%	0%

Table 2: Flexible grading weighting schemes, including the original weight, one favoring students who performed poorly on quizzes, one favoring students who performed poorly on discussion, and one favoring students who performed poorly on participation. Also included is the mean score in each graded category (± sem) and the fraction of students who were awarded course grades according to each weighting scheme.

Demographics of our study group

Our study sample was students who took Biomaterials in the fall semester of 2012. Final enrollment was 54 students. Of these, 52% were female, and 11% were from underrepresented groups. Of these 54 students, 37 were majoring in Biomedical Engineering, 16 were majoring in Nanomedicine Engineering, and one was a non-degree exchange student. Biomaterials is a required course for majors in Nanomedicine Engineering but is elective for students in Biomedical Engineering. All of the Nanomedicine Engineering majors and most but not all of the Biomedical Engineering students would have had an introductory materials science course.

Component scores

There was no significant correlation between individual student scores in any summative assessment category and any other (for example, discussion scores and quiz scores; Figure 1, left). However, students who were highly participatory overall tended to be slightly better discussants (Figure 1, right).

It is worth noting that peer evaluation of the discussants was significantly harsher than evaluation by the instructors (81% vs 91%; Table 2).

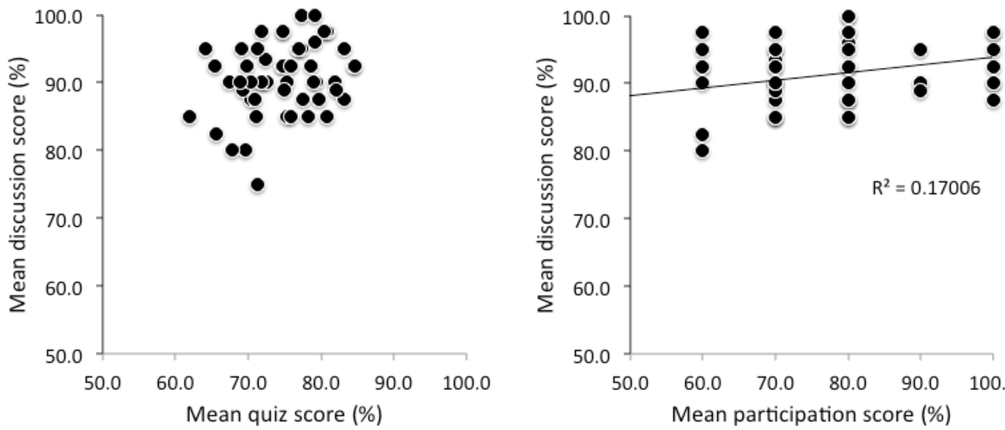


Figure 1: Relationships between summative assessments. Left: There is no correlation between quiz scores and scores received when serving as a discussant. Right: There is a weak positive trend toward increased scores when serving as a discussant and overall class participation.

Retention and recall

We conducted a 12-month post-test of the students from the inaugural class to determine whether learning in the Socratic format improves retention and recall. Twenty multiple-choice questions were selected from across the semester and re-issued to students using the same online quiz protocol that we used during the semester (QuestionPress). This study was reviewed and exempted by our Social and Behavioral Sciences Institutional Review Board (project 2013-0384-00).

Average retention and recall measured mid-semester was 75±4% on the same questions used in the post-test. Retention and recall measured 1 year after class completion was significantly lower – 53±5% ($p=0.009$). This rate of recall measured at 1 year falls within the broad range of such measures reported in the literature [2], and is coincidentally identical to the recall measured by multiple choice questions at 1 year after an undergraduate chemistry course [3].

There was a weak positive relationship between recall on any given question mid-term and recall on that same question 1 year later (Figure 2). If borne out by larger sample sizes, the slope suggests that small improvements in recall mid-term might translate into large improvements in recall at distant time points.

Recall was not dependent on the subject matter. There was no significant difference in recall of information focused on materials science versus that focused on clinical biology measured mid-term ($p=0.54$). Neither was there a significantly different loss of recall over 12 months comparing clinical biology to materials science ($p=0.32$).

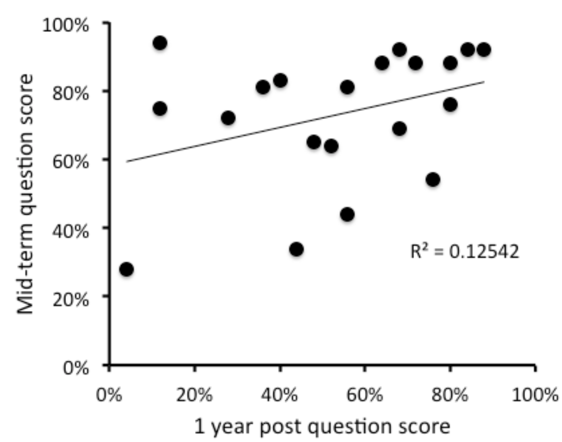


Figure 2: Relationship between scores on 20 select questions given mid-term and one year later.

How students prepared for class: groups, individuals, and NowComment

Students were free to prepare for class in any way they saw fit. We used end-of-quiz questions over the course of the semester to track whether they prepared for class as part of an offline group (in person), an online group, or independently. The results of this tracking are shown in Figure 3. A simple majority (54%) of students prepared for class on their own, The number of students studying in offline (face-to-face) groups declined by ~1.5% per class over the course of the semester. The students leaving those offline groups become evenly distributed between online study groups and independent preparation (0.8 and 0.7% per class increases, respectively, by linear regression).

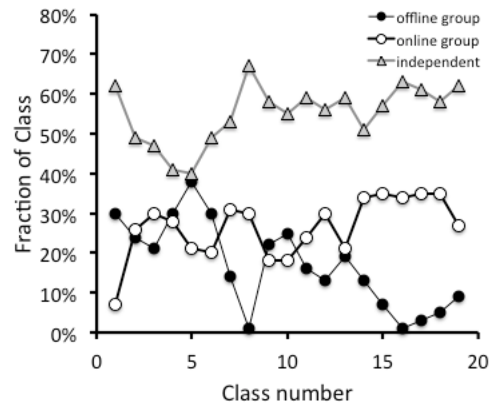


Figure 3: Fraction of students preparing for class using different student-driven group environments – offline groups (black), online groups (white), and independently (gray).

Use by students of NowComment's online discussion features was optional. As seen in Figure 4, the number of students using NowComment (besides for simple case study retrieval) dropped precipitously after the first week of class, and reached exactly zero users by the end of the first month. However, there was a small recovery in student use in week 8. Anecdotal evidence suggested that this was due to the slow dissolution of offline study groups (see preceding paragraph) leaving some students to seek other ways of studying with their peers. To test this hypothesis, we plotted for the second half of the semester the fraction of students participating in offline study groups versus the fraction of students actively using NowComment. Supporting our hypothesis, there was indeed a weak negative relationship between these.

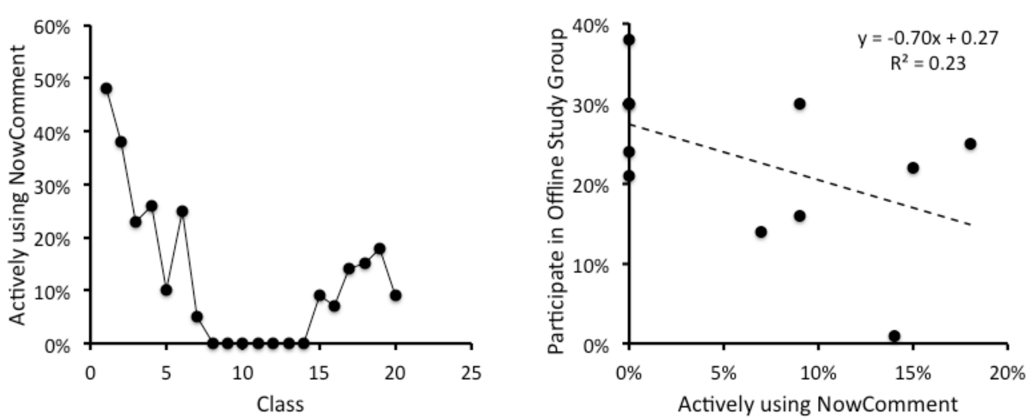


Figure 4: Active use of the online discussion tools on the case studies in NowComment varies with time (left panel), dropping to zero use for nearly a third of the semester. Right: There is a weak negative relationship between participation in an offline study group and active use of NowComment.

Student feedback

Student course evaluations were above average compared to others of comparable level (4000) in all but two categories – grading policy, and instructor approachability.

A typical student comment from the free response portion of the course evaluations read,

> "It was nerve-racking, intellectually satisfying, and the material was incredibly engaging. The challenge of having to integrate knowledge on the spot, at the witness of your peers has been the single most effective method of learning I've had in any of our coursework. It forced us to integrate knowledge from our research experiences and prior coursework to understand all the aspects of a case."

Former students were likewise given the option of providing feedback as the last question of the 1-year survey. With one exception of one student who felt that there was too much emphasis in the class on biological responses, and not enough on materials science, every free response was overwhelmingly positive. One former student responded (with their emphasis),

> "I understand that when I took Biomaterials that the course was set up in an experimental way and there were still some kinks to work though. However, I really appreciated the approach to the class. Technology/internet today allows us to access such a vast amount of information, I think education SHOULD have this much stronger focus on being able to ascertain effective information from the lot and ask the right questions. It's valuable experience to be pushed to speak intelligently/confidently on the basis of short-term research, and making educated yet cautious guesses without overstepping ones bounds. TEXTBOOKS ARE ANTIQUATED. AS ENGINEERS WE NEED TO LEARN HOW TO PROCESS PRESENT FORMS OF INFORMATION!"

Conclusions and recommendations for practitioners

We are not aware of any other examples of the Socratic approach being used in highly technical engineering courses, and find that it offers advantages over traditional instruction to teaching biomaterials. One advantage is that common themes emerge naturally and are voiced throughout the course. A few that came out repeatedly in discussion included:

1. Material stiffness/compliance is important to the performance of the vast majority of biomaterials.
2. Almost every tissue response to any implanted biomaterial is dominated by collagen synthesis and deposition.
3. Corrosion chemistry dictates the tissue response to metallic biomaterials.
4. Material adsorption in the body can be accounted for by either hydrolysis (primarily ester bond breakdown) for synthetic materials or proteolysis for a biologic material.
5. Successful biomaterial-tissue responses are ideally some form of biologic integration controlled by surface chemistry, or alternatively, engineered to trigger encapsulation/foreign body response.

Of course such broad themes mask a sea of technical details that instructors may fear getting lost when compared to a traditional lecture approach. Yet while retention and recall on technical details is not enhanced by use of the Socratic approach in teaching biomaterials, neither is it impeded. We therefore dispute the notion often voiced to us that this approach to instruction fails to broadly educate students in the "essentials" of biomaterials science. Rather, the "essentials" define themselves for the students as they study and discuss real-world biomaterial applications. Even the whiteboard content generated at the direction of students looked very much like what might have been presented in a lecture format, save that they had a hand in creating the structure.

Another advantage is that the Socratic approach is highly diagnostic. It is obvious during the discussion what students understand and what they do not, making it easy to adjust the pace as needed.

We consider the course objectives as having been met, though the threshold for "met" is inevitably arbitrary. Mean daily quiz scores were 74.7±0.7%, and we believe these are a reasonable measure of objective 1, knowledge and comprehension of biomaterials. Analysis (objective 2) and synthesis (objective 3) were both judged by discussant scores, which averaged 90.8±0.7%. Finally, oral argument (objective 4) was assessed by discussant performance, and by significant contributions when a student was not a discussant; the latter averaged 73±3%. A goal for the future is to better delineate our assessments of objectives 2 and 3 through use of rubrics. We would again note that it was these individual assessments that were used in determining having met the class objectives, not the "flexible grading" scores that we used solely for calculating final grades.

In the subsequent (2013) offering of the course there were several changes made. First, the inclusion of peer review scores into student grades was eliminated. The reason for this is that students tended to be unusually critical of one another, seldom left constructive feedback, and did not sufficiently differentiate between strong and weak performances. Second, flexible scoring and case-specific preparatory questions were included from the beginning.

We believe that some improvements in student performance might be obtained in the future by further encouraging the use of NowComment. Its sentence-level discussion and markup tools would probably be of benefit to all students since it encourages just the sort of back-and-forth argument that we are trying to foster. Further, it would lend continuity to out of class discussions as individual study groups form and dissolve. Anecdotal reports suggest that shared Google Docs were the predominant means of online group preparation, though the instructors were not privy to the details of student exchanges through that medium. In contrast, NowComment software has a reporting feature so that instructors can see all of the contributions of individual students throughout the semester; this feature would make it easy to include NowComment participation as part of the student participation score. Needless to say, incorporating substantive contributions to NowComment (or any other class-wide forum) as part of the course score would probably result in near 100% participation if it were enacted.

The Socratic approach is probably not appropriate for every engineering subject. Knowledge-based courses, for example cell biology, are in our opinion still best delivered in a traditional lecture format. Skills courses, such as mathematics, are not generally subject to scholarly debate but rather the subject of practice to reach a correct answer by the correct means. However, any course that can be distilled to case studies, that is best described as conceptual, and where there are multiple solutions to a given problem should find itself amenable to the Socratic approach, even in the quantitative sciences.

From an instructor's vantage, the Socratic approach is (for lack of a better word) great fun! The constant, hands-on engagement with the students is a welcome change from the theatrical model of lecture. The time invested in the course is roughly the same as it would be for an equivalent lecture course, since imbuing oneself with the broad knowledge needed to guide a discussion closely matches what one might otherwise put into developing slides for presentation. Further, the instructor must develop daily quizzes to keep students fully engaged on days when they are not selected as discussants, and must map how they want the discussion to flow. Getting complete coverage of the material requires that the discussion not be free ranging, but rather gently guided by the instructor; this takes significant planning.

Literature cited

1. Williams, D. F. & Biomaterials, E. S. for. Definitions in biomaterials: proceedings of a consensus conference of the European Society for Biomaterials, Chester, England, March 3-5, 1986. (Elsevier, 1987).
2. Custers, E. J. F. M. Long-term retention of basic science knowledge: a review study. Adv. Heal. Sci. Educ. **15,** 109–128 (2010).
3. Arzi, H. J., Ben-Zvi, R. & Ganiel, U. Forgetting versus savings: The many facets of long-term retention. Sci. Educ. **70,** 171–188 (1986).
4. Kooshkabadi, M. & Chen, J. Staged PCI Case Study. ZOLL LifeVest at <http://lifevest.zoll.com/medical-professionals/Staged_PCI.pdf>

Appendix 1: Example case study

PCI and Stents

Modified from an original case study published by Mohammad Kooshkabadi, MD and Jack Chen, MD [4]

Northside Cardiology and St. Joseph's Hospital Heart and Vascular Institute, Atlanta

Background

Balloon angioplasty has been an enormously successful surgical intervention for the treatment of advanced atherosclerosis. In brief, the procedure supplants a traditional cardiac bypass operation in which the patient's own blood vessels (saphenous veins most commonly, mammary artery in some cases) are excised and used to make a bypass loop around a blocked coronary artery. In this approach, the vascular lesion and blocked zone is untouched.

Percutaneous coronary intervention (PCI) snakes in an intravascular catheter through the lesion and opens up the blockage. The next step is to place a stent as the site where the artery was previously blocked to keep it open. Balloon angioplasty triggers a condition known as restenosis in which for 35% of the patients the vascular lesion recloses within 6 months of the procedure. The invention of the deployable stent solved the problem in part by leaving a mechanical brace holding the walls of the blood vessel apart. Among the numerous innovations in stenting technology, most notable (and litigated) have been the development of Drug Eluting Stents that suppress the proliferation of blood vessel wall cells that occasionally lead to occlusion.

History of present illness

A 45 year old male with hypertension, dyslipidemia, peripheral vascular disease, and a 15 year history of type II diabetes presented to his primary care physician for a previously scheduled appointment for his diabetes. He had been experiencing cold like symptoms including shortness of breath and wheezing over the previous two days. An EKG was performed at his physician's office and revealed ST elevation. The patient was sent to the Emergency Room (ER) by ambulance for further evaluation.

Physical examination

Upon arrival at the ER his troponin level was 2.35 and his EKG revealed an STelevation MI. The patient was comfortable and pleasant. He did not believe he was experiencing an MI. He denied chest pain, nausea, and dizziness. He was still experiencing shortness of breath. He was taken emergently to the cardiac catheterization lab.

Studies/results

Cardiac catheterization revealed total occlusion of the left anterior descending artery (LAD) with 90% stenosis in the mid circumflex artery (LCX) (Figure 1). The right coronary artery (RCA) was totally occluded (chronically) at the ostium (Figure 2). There was good collateralization from the left-to-right coronary system. His ejection fraction was 35%.
Emergency coronary bypass was considered, however surgical consultation was not available and a decision was made to proceed with staged percutaneous coronary interventions (PCI). The first procedure was performed using thrombectomy with an aspiration catheter (Figure 3) and subsequently deployment of two drug-eluting stents in the LAD (Figure 4) resulting in TIMI-III flow and 0% residual stenosis (Figure 5).

Figure 1
Culprit lesion is 90% ulcerated, thrombotic proximal LAD stenosis (solid arrow). There is also an 90% mid-LCX stenosis (white arrow)

Figure 2
RCA is chronically occluded ostially (arrow)

Figure 3
Aspiration catheter (arrow) is advanced down the LAD to remove friable thrombus prior to stent deployment

Figure 4
Stent deployment (arrow).

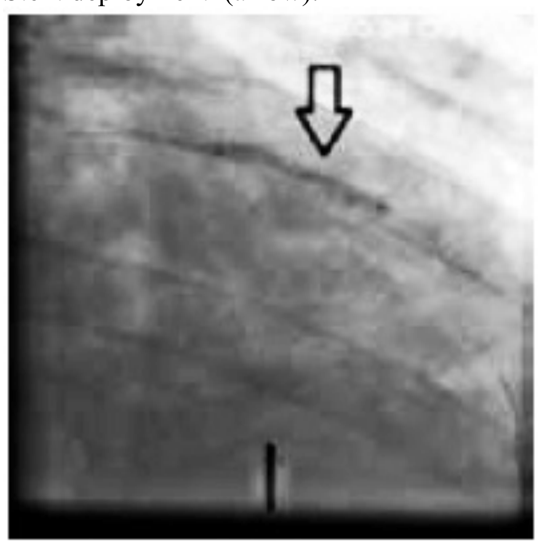
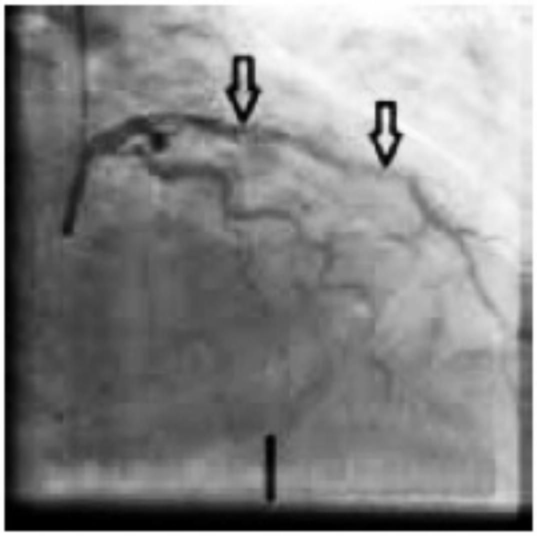


Figure 5
Final result of LAD after deployment of 2 overlapping drug-eluting stents (arrows)



Impressions/plan
The patient was transferred to the CCU and underwent diuresis along with a consultation with endocrinology for elevated glucose. On the fifth day of his hospitalization, the patient was discharged to home wearing a wearable cardioverter defibrillator (WCD), (manufactured by ZOLL, Pittsburgh, PA, marketed under the brand name LifeVest®). He was scheduled to have an office visit in two weeks and would follow-up with his physician in his health system for continued general care. In 90 days he was to have his ejection fraction reevaluated. If at that time his LVEF remained ≤35%, an ICD would be considered for permanent sudden cardiac arrest (SCA) protection.

Questions to guide preparation of this case

Brief case summary
1. Problem
2. Intervention – in more detail than given in the case study itself, how is (or was) the procedure performed?
    a. Catheterization
    b. Thrombectomy
    c. Angioplasty
    d. Stenting
3. Outcome – consider not only this case, but also what is the outcome in a statistically averaged sense?

History of the intervention
1. Who first used a coronary stent in human surgery ?
2. Who got the first patent on the device?

Composition and manufacture of "regular" stents
1. Material(s) used in their manufacture
2. Physical and mechanical properties
3. How is the material made into a stent?

4. Consider also (but with less emphasis) the composition and manufacture of the delivery system.

Short and long-term biological response

1. How does the body respond to the material?
2. What adverse tissue and immunologic reactions are possible?
3. What is restenosis and what is the biological mechanism?

Composition and manufacture of drug-eluting stents

1. How does the underlying material differ from regular stents?
2. What drugs are eluted, and how does elution work?
3. What is the outcome?
4. Are there adverse effects?

Appendix 2: Generic questions to guide student preparation

These are generic questions to guide student preparation that were used in the first half of this course, and that guided the structure of case-specific questions in the second half of the course.

A Brief case summary

1. Problem
2. Intervention
3. Outcome
4. Biomaterial(s) involved

B History of the intervention

1. What is the history of intervention for such problems?
2. What biomaterials have been used over that time?
3. If the biomaterials have changed over that time, why?

C Biomaterial properties

1. What are the important properties of the biomaterial in this instance (*Note: not all of the listed categories are equally important)* ?
    1. Structure and composition
    2. Chemical
    3. Physical and mechanical
    4. Biological
2. How are these properties measured experimentally?
3. Where does the biomaterial originate, or how is it made?
4. Biological response
    1. How does the body respond to the biomaterial?
    2. What adverse reactions are possible?
5. Alternative approaches to the problem
    1. What current alternative approaches exist?
    2. Can you think of possible alternative biomaterials or approaches to the problem (for example, is the biomaterial held or placed in the most advantageous location?)?