Student Collaboration as a strategy to achieve learning outcomes in Biomaterials Courses

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Abstract

Seniors in the mechanical engineering department at university A and junior biomedical engineering majors at institute B were given two common assignments in their biomaterials courses. The first assignment asked students to act as respective clients and materials consultants for a biomaterials problem. Groups of student “clients” presented their problem to groups of student “consultants” who were required to pose a materials based solution or answer related questions. Students then summarized their professional interactions and findings in memo style reports addressed to their respective instructors.

The second assignment addressed the learning objective that students "demonstrate an understanding of laboratory techniques used in biomaterials and biomechanical engineering". This assignment asked groups of students at institute B to execute an experimental protocol related to materials tensile testing and then write up their findings in the style of an academic journal article. Students at university A received these written reports and were instructed to use them to generate a step by step protocol that they could use to replicate the original results. These students were then asked to reflect on the how well the information was communicated and where gaps occurred in their understanding of how to replicate the original experiment. Students from both groups were assessed based their clarity and ability to reproduce results.

Background:

This study takes an interdisciplinary and cross institutional approach to achieving learning outcomes and reinforcing the importance of professional communication in survey style undergraduate Introduction to Biomaterials courses. The Biomaterials courses each cover a range of selected topics including an extended review of polymeric biomaterials starting with fundamental concepts surrounding polymer material properties such as viscoelasticity; a detailed analysis of metallic alloys used in biomechanical applications including knee and hip prosthetics; and a review of glass-ceramics, bioceramics and bioactive glasses. The courses aim to give students a broad understanding of fundamental materials science concepts as they relate to biomedical engineering and arm them with the ability to select, with justification, an appropriate material for various biomedical applications.

At university A, the course is taught twice a week in seventy five minute lectures. Twenty senior mechanical engineering students take the course as a technical elective. The prerequisite for the course is an introductory materials course that all mechanical engineering students are required to take generally during the fall of their sophomore year. The first half of the semester in the senior course is taught by a materials faculty, and reviews metals, ceramics and polymers. Case studies are discussed to show how materials selection decisions may be made in the biomaterials realm. Cobalt chrome alloys are contrasted against titanium alloys, for example, in the case of an implant materials selection decision. Bioactive ceramics and glasses are compared to dense, inert alumina as well as resorbable polymers.

The second half of the course at university A is taught by biomechanics and human physiology faculty. The course becomes focused on orthopedics and pulmonary device case studies. Several lab activities support the lectures. Dissection of deer knees and other parts of animal cadavers is used to provide hands on learning.

At institute B, the junior level biomaterials course is compulsory for all biomedical engineering majors and is taken in conjunction with a Biomedical Engineering Labs course that covers basic laboratory skills for biomedical engineering. The course is ten weeks long and is taught by an Assistant Professor of Biomedical Engineering with a background in biomaterials. Like at university A, this course is similarly designed to be a survey of selected topics in the field of Biomaterials and Biomedical Engineering. The course begins with an extended review of polymeric biomaterials starting with fundamental concepts surrounding polymer material properties including viscoelasticity, followed by an overview of synthetic polymers, natural polymers, and finally, hydrogels. A focus is given to which materials might be selected for biomedical applications with an emphasis on drug delivery systems. Accompanying labs included stress-strain testing, viscoelasticity (stress relaxation, hysteresis), anisotropy, bone cement, and drug delivery. A unit on cardiovascular application of biomaterials gives way to a unit on the regulation of medical devices and biomaterials testing for industry. The course then progresses on to metals with a detailed review of selected topics in orthopedics and cardiology. Cardiovascular stents and arthology of the hips and knees and hips are covered followed by an overview of ceramic biomaterials, specifically, those used commercially.

In addition to introducing students to the field of biomaterials, a goal of this course is to help students to develop skills in reading peer-reviewed journal articles and to understand the peer-review process as a whole. Teacher led "journal clubs" are held twice throughout the quarter where students are asked to read and respond to questions about a topically relevant journal article prior to coming to class. Once in class, the group dissects the article and works to understand its nuance; weighing strengths and weaknesses of the research. These are generally regarded by students as a strength of the course according to end of term course evaluations.

Because the field of Biomaterials spans a wide range of topics, the decision was made at both university A and institute B to use a case-study approach to the course. In both courses, textbooks are not required, and recommended texts are instead cited throughout each course. In both courses, the recommended readings are from Ratner [1], Dee [2], Saltzman [3], Enderle [4], Callister [5], Temenoff and Mikos [7], and several journal articles.

Collaboration, and team based assignments have been shown to improve student learning with diversity of the team being a high indicator of student success [8]. Several studies suggest that pedagogies emphasizing collaboration provide an opportunity for students to apply their knowledge and skills while also preparing them for the realities of twenty-first century professional settings [9-12]. Additionally, problem-based learning has been shown to improve student outcomes [13] with interdisciplinary teaming as a high indicator for improving innovation and competence [12]. Based on these findings, this study uses collaboration both within and across the two schools on problem based assignments. It was expected that students would benefit from the intercurricular collaboration both in terms of their learning outcomes and in terms of their appreciation for professional discourse and technical documentation and communication.

Methods

Seniors in the mechanical engineering department at university A and junior biomedical engineering majors at institute B were given two common assignments in their respective biomaterials courses. While these students have different majors, both courses are introductory level and therefore, no prior knowledge was assumed for either cohort. The variable that likely contributed most to differences in the baseline knowledge of their work was the fact that the biomedical engineering majors were nearing the end of their course while the mechanical engineering majors were just beginning, due to differences in academic schedules.

Client/Consultant Assignment

The first assignment asked the students to act as respective clients and materials consultants for one of four biomaterials problems. Small teams from each of the two schools were paired up (by the instructors) and told to electronically interact in their assigned roles. Groups of student "clients" presented their problem to groups of student "consultants" who were required to pose a materials based solution. The roles ranged from attorney, engineer, lab researcher, startup CEO, etc. and were mixed between the two schools. Students contacted their consultant or client at the other school and asked questions about a materials failure issue. The students in all roles then constructed professional memos to their instructor describing the interaction and the outcome of the process. The assignment for students at university A was to generate a corporate style memo that summarized the interaction. If they were clients, then they wrote memos that described what they were told by their paid consultant. If they were consultants, then they wrote memos that summarized questions they were asked and their answers. In all cases, students were told to write a short memo that documented the interaction in the same way that they would be expected to if they were a professional in a professional setting.

Both cohorts of students also responded to surveys asking them to reflect on the process. Students at university A received an optional Blackboard survey asking them to respond to questions 1) working with students from another school was a good use of student and faculty time, 2) assuming a role as a consultant or client was a good way to learn about materials, 3) this collaboration assignment should be repeated next academic year, and 4) collaborating between two schools to communicate information is effective at helping students remember technical information with scores from ‘1’ (strongly disagree) to ‘5’ (strongly agree). The students at institute B responded to prompts asking them to 1. reflect on the overall process, 2. describe if and what they learned, and 3. identify if they helped someone at the other school learn anything new. This assignment was aimed to assess the course learning objective that students should be able to “recommend materials for biomechanical engineering applications” and to cultivate a student appreciation for documentation and professional discourse. The original assignment described can be found in Appendix A.

Laboratory Assignment

The objective of the second assignment was to have students appreciate the importance of creating documentation, for internal consumption, that communicates technical protocols. The second assignment also addressed the learning objective that students "demonstrate an understanding of laboratory techniques used in biomaterials and biomechanical engineering". The assignment asked groups of students (4 students/group) at institute B to execute an experimental protocol related to materials tensile testing and then write up their findings in the style of an academic journal article (Appendix B). The instructor at university A received these written protocols (n=9) and randomly assigned them to groups of students (2-3 students/group). The students at university A were requested to read the report that they were assigned, and to generate a memo, in a style similar to that expected in a corporate work setting, (‘corporate style’) that described the experimental protocol followed by the students at institute B. The students at university A were told to imagine that they were graduate students whose objective was to replicate an experiment, or researchers inside a company whose task was to communicate an experimental protocol to a technician who would then be required to perform the lab experiment. It should be noted that due to logistical constraints, these students could not physically replicate the experiment. Students at university A were then asked to rate the quality of the reports that they had analyzed, mainly for their respective ability to understand and replicate the experiment (Appendix C). All written reports were anonymized and assigned at random. The respective roles were assigned due to the logistical concerns including the timing of the courses at each school and the availability of lab equipment. Finally, the instructor at institute B assigned scores to the methods section of all written reports according to a set rubric (Appendix D).

Results

Client/Consultant Assignment

Table 1 summarizes the homework data from students at both schools. The comments in the table indicate the general scope of the professional interaction. In some cases, the students when acting in the role as a source of information went out and did research to answer the posed questions to the best of their abilities. For example, when one of the roles was to recommend CoCr over Oxnium alloy, the student found out the chief advantages of CoCr as a material of choice for an implant and reported as such. This interaction allowed for the student to put his or her own time into reading and researching the relative advantages and disadvantages of two possible alloy selections. In all cases, the instructors were able to determine the questions asked and answered from the interaction and identify at least one clear "finding" from the exchange.

Table 1: Summary of the client-consultant interactions between students at university A and institute B

	Role	Scenario	Questions Asked/Received	Findings
University A	consultants	Cartiva	two teams	how to decrease infection; best metals for biocompatibility
	doctors	total knee replacement	asked about reason for revision surgery on knees; asked about femoral CoCr components;	received response from RHIT team with CoCr recommendation and reasons why it is a superior choice
	market exec	CoCr vs Oxnium	does either material have enzymatic degradation over time? one study reported as such; hepatocytes;	metallurgical information discussed and imparted
	consultants	nitinol stents	asked about design life and how they are effective	he was asked why he chose nitinol, and if it has properties- he responded yes
	attorney representing manufacturer	nitinol stents	asked questions about failure;	
	attorney or consultant	nitinol stents	was contacted by defendants from RHIT; nitinol stents; ruled out manufacturing issue and recommended heart failure of patients as cause	
	engineer	stainless steel hip implant	discussion of manufacturing processes	metallurgical information discussed and imparted
	attorneys	hip stem failed from cyclic loading;	recommended finding out about traceability and materials used in the manufacture	
Institute B	FDA regulator	Cartiva	Asked for verification of safety and efficacy	Summarized claims of safety and efficacy
	Manufacturing engineer	Cartiva	Asked questions regarding FDA requirements	Summarized information regarding regulation of the cartiva big toe joint
	Manufacturing engineer	Cartiva	Asked questions regarding reasons leading to revision surgery	Made recommendations for how to minimize risk of revision surgery
	Attorney representing manufacturer	stainless steel hip implant	Asked questions about patient lifestyle	Summarized research about hip implant failure and made recommendations.
	Independent materials expert	stainless steel hip implant	Asked about materials testing, regulation, and clinical studies	Summarized types of material failure, regulation, and clinical trials
	Materials expert at a company	stainless steel hip implant	Made suggestions regarding a potential material defect	Summarized reasons for implant failure and made recommendations for further investigation

	Attorney representing the family of a patient	stainless steel hip implant	Asked questions regarding manufacturing	Summarized potential reasons for material failure
	Marketing executives	CoCr vs Oxnium	Asked for revision data	Reported that the revision rate is not different between the two different materials
	Marketing executive	CoCr vs Oxnium	Received questions about causes of revision surgery.	Summarized reasons for TJR failures
	Marketing executive	CoCr vs Oxnium		Summarized the benefits of using Co-Cr TJRs
	Marketing executive	CoCr vs Oxnium	Received questions about causes of revision surgery.	Co-Cr have a lower incidence of stress shielding than Oxinium
	Independent materials expert	Nitinol	Received role playing comments about the reasons that a TAVR might fail	Responded with role playing responses about potential material failures
	Independent materials expert	Nitinol	Asked questions regarding material versus design failure	Summarized and assessed the potential for material failure versus design failure
	Attorney representing the company	Nitinol		Summarized non material reasons for failure of nitinol stents, benefits of nitinol material, and current FDA status of the material
	Attorney representing the company	Nitinol	Asked questions about nitinol stent testing and design life	Summarized the answers and made recommendations that the company terminate product of the device in question
	Attorney representing the families of a patients	Nitinol	Asked questions regarding manufacturing	Summarized potential reasons for failure
	Materials expert at a company	Nitinol	Sent role playing comments about the reasons that a TAVR might fail	Summarized reasons that failure would be use to patient and procedural error rather than design and material issues

An optional and anonymous Blackboard survey was posted for students at university A. The survey consisted of four questions to gauge student interest in this unique project of collaborating across schools and cohorts of students. The number of responses was nine, out of a total of 22 students. The questions and survey results are shown in Figure 1. When responding to the statements: 1) working with students from another school was a good use of student and faculty time, 2) assuming a role as a consultant or client was a good way to learn about materials, 3) this collaboration assignment should be repeated next academic year, and 4) collaborating between two schools to communicate information is effective at helping students remember technical information; no student response was less than a ‘3’, ‘neither agree nor disagree’ and most responses were ‘4’, ‘agree’.

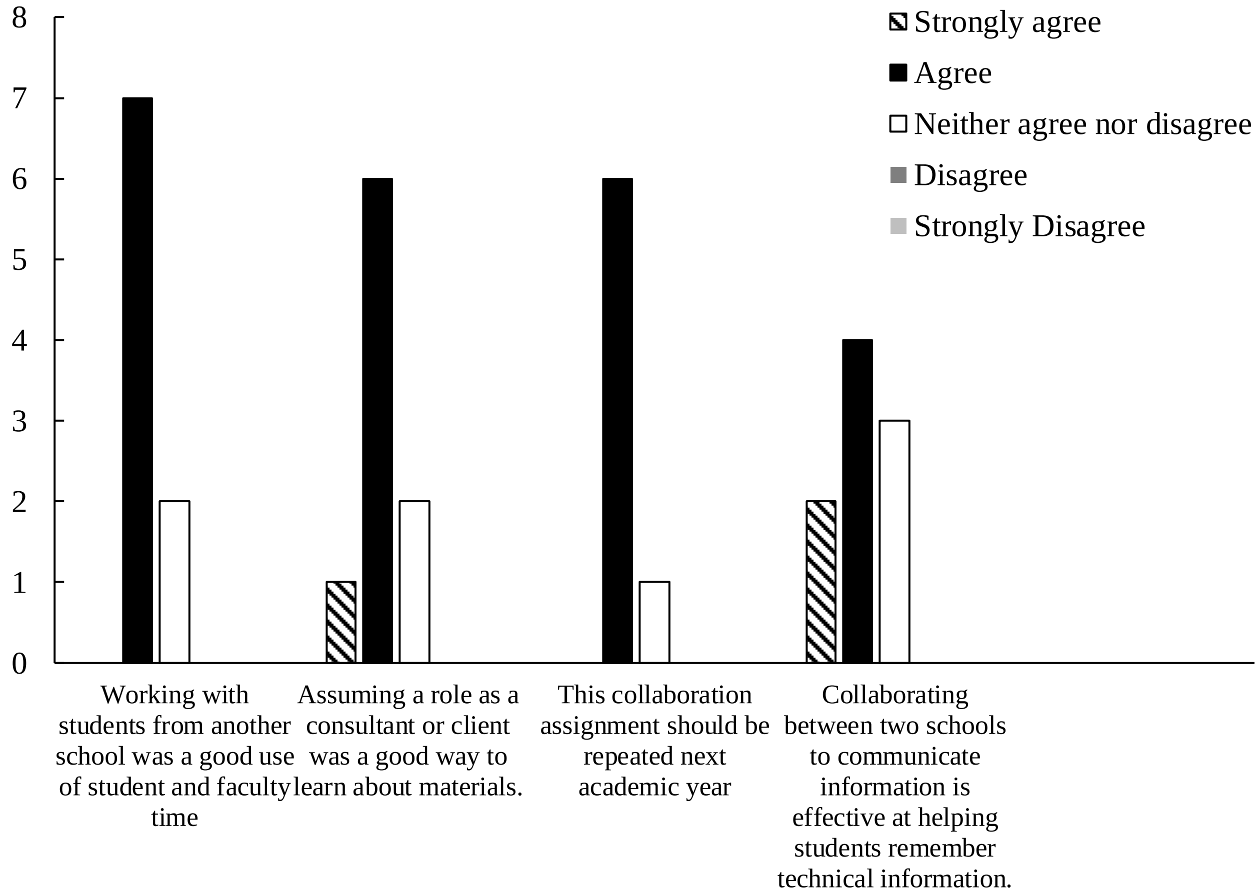

Figure 1. Results of optional, anonymous Blackboard survey at university A. 9/22 students responded to this survey.

Figure 2 shows the breakdown of student responses at institute B to the *client-consultant* assignment prompt asking them to 1. reflect on the overall process, 2. describe if and what they learned, and 3. identify if they helped someone at the other school learn anything new. Of the 40 students enrolled in the Biomaterials course at institute B, 35% percent described the process of interacting with another school and role playing as positive, 57.5% mentioned acquired new knowledge, and 20% felt that they had helped students at university A learn something new or correct a misunderstanding. 37.5% students also commented that communication and time constraints were the largest hindrances to the success of this assignment.

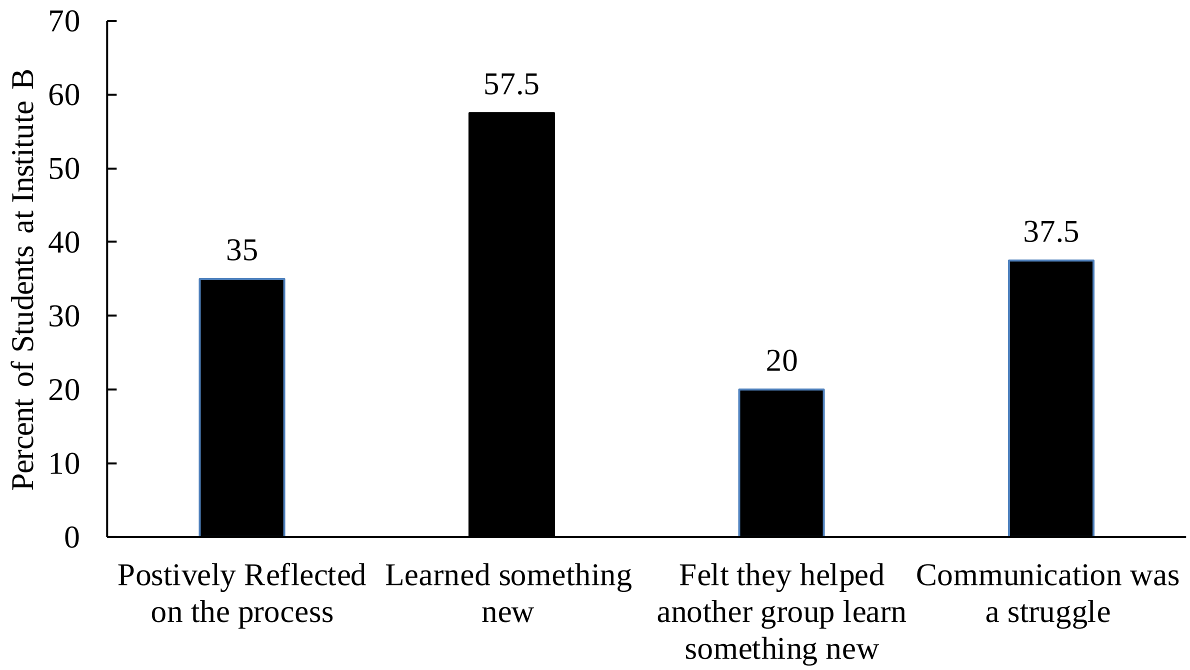

Figure 2: The student responses at institute B to the *client-consultant* assignment prompt asking them to 1. reflect on the overall process, 2. describe if and what they learned, and 3. identify if they helped someone at the other school learn anything new.

Laboratory Assignment

Figure 3 and Table 2 summarize the results of the second assignment in which students from university A were asked to replicate a protocol and also asked to rate the relative quality of the submitted lab report from institution B. The four categories in which they were required to provide a rating between 0 and 10 were in the categories of 'clarity', 'replication', 'format' and 'overall impression'. The averages are based on ratings provided by eight teams at university A, in which they rated eight lab reports from institution B. The summarized data preliminarily indicates that the reports from institution B made a relatively positive overall impression. The ability of students from university A to replicate the experiment, based on the lab report from institution B alone, was also relatively positive with a numerical score of 8.3 ±1.3. The student scores agree with the instructor score (8.4 ±1.9).

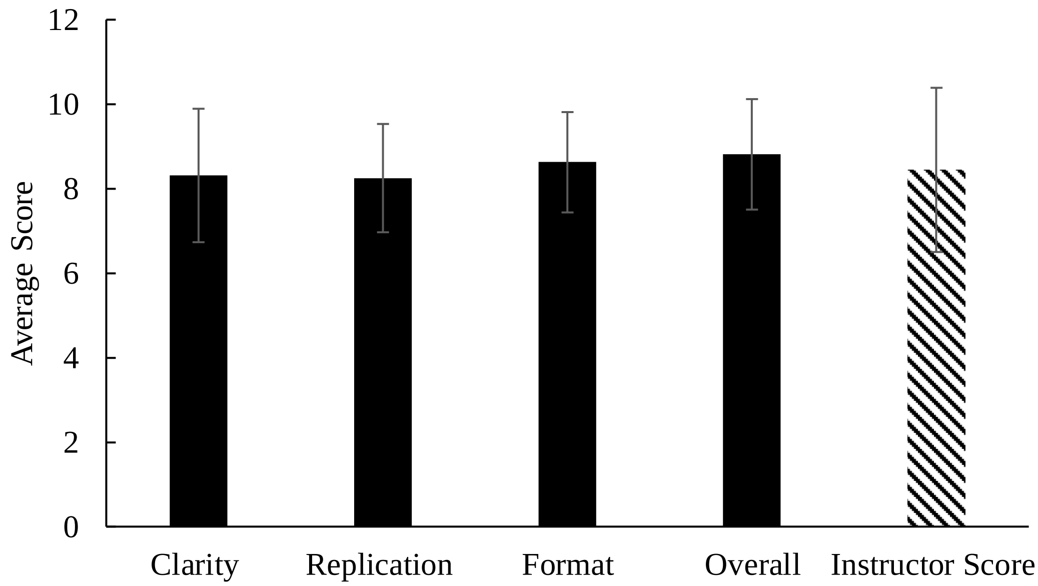

Figure 3: Average ± standard deviation ratings of lab reports from institution B in categories of clarity, replication, format and overall impression. The ratings were provided by teams of students at university A and the instructor at institute B. The averages are summarized in Table 2.

Table 2. Summarized results from lab protocol assignment. These values indicate the average scores ± standard deviation assigned by students at university A to the laboratory reports produced by students at institute B as well as the overall score assigned by the instructor at institute B.

Clarity (0-10)	8.3 ±1.6
Replication (0-10)	8.3 ±1.3
Format (0-10)	8.6 ±1.2
Overall impression (0-10)	8.8 ±1.3
Instructor Overall Score (0-10)	8.4 ±1.9

Discussion

The anecdotal results of the first assignment, in which students at university A were asked to submit a corporate style memo that professionally responds to a given materials failure context, show that students took the assignment seriously. There were many benefits of this assignment for reinforcing concepts that would otherwise be covered on a traditional homework. For example, a given student at university A might respond to a question from a student at institute B about stress shielding. Through each of these two example students articulating the major issues surrounding stress shielding and the implications from a materials selection decision, the students come to see themselves as capable of performing the duties of their selected professions (based in the discipline of Biomechanical Engineering).

As an example of the anecdotal data that preliminarily indicates that students took this assignment seriously, the following section of text from a student-produced corporate memo is as follows:

"...high nitrogen stainless steel, with an elastic modulus of 190 GPa, coupled with a liner/socket of cross-linked polyethylene. The implant was cemented, although press-fits have become recently more common. The specific alloy in this case, 201 Nb, was selected for its corrosion resistance. The manufacturing was performed on a five-axis CNC based on patient data…"

The assignment allowed for students to make connections between materials, properties and manufacturing and to communicate that directly with other students.

Additionally, many of the students embraced the role-playing (client or consultant) aspect of the activity and demonstrated an ability to engage in professional discourse. Several student groups even made up company names, logos, and job titles for themselves which added to the playfulness of the assignment. A representative example from a "*Materials Research Scientist*" at "*Dosyen Lifesciences Biomaterials Division*" corresponded with "*Groom & Bryde LLP"* and the resulting memos generated by the student groups demonstrated a clear ability to ask questions, summarize information, and make appropriate recommendations. A representative sample follows:

"…Our professional opinion, with all the evidence stated above, is that the manufacture did not 'properly' take into account all factors when creating the 201Nb High Nitrogen Stainless Steel Hip Stem implant. It is known by them that over time ionization with the body can cause serious health issues, especially with Chromium and Nickel which make up 21.2 % of the implant. This alone should raise serious flags in the design phase…"

The results of the optional Blackboard survey at university A (Figure 1), suggest that the collaboration project may be effective at helping students remember technical information. The students that participated in this optional survey were generally positive about the assignment, and preliminarily indicated that it uniquely helped them learn the material of this course. In this survey, 7/9 students agreed that working with students from another school was a good use of their time, 7/9 strongly agreed or agreed that the role playing aspect of the assignment was a good way to learn about materials, 6/9 agreed that this assignment should be repeated next year, and 6/9 strongly agreed or agreed that the collaboration was an effective tool to help them remember technical information. According to an informal and open-ended survey at institute B (Figure 2), 35% of students from institute B reflected positively on the client/consultant activity. Only 2 student responses were considered negative and the rest did not comment one way or another. Negative sentiments about this assignment were likely due to the struggles with communication between cohorts (37.5% of survey takers indicated this as an issue). 57.5% of these students reported learning something new from this assignment, which was also anecdotally evident from an instructor perspective based on answers given on exams and comments made in class than demonstrated knowledge of material that was not covered directly in course lectures. While only 20% of the students reported a sense that they helped their counterparts learn something new, the authors expect that this number was actually higher than reported. It is sometimes difficult for students to discern when learning occurs in others when it is not explicit.

For the homework in which teams of students from university A rated lab procedures from institute B, Figure 3 and Table 2 summarizes the statistics in several categories including clarity, replication, format and overall. The data in Table 2 indicates that the overall impression is the highest average rank, at 8.8 and that the lowest average numerical ranking is for replication at 8.25. The replication score rates the team's ability to theoretically replicate the experiment based on what was in the lab report. The student scores were consistent with the instructor assigned scores, preliminarily indicating that the students at institute B were able to successfully communicate their understanding of the relevant laboratory techniques.

Both assignments demonstrated successful reinforcement of the relevant learning objectives identified. From the client/consultant assignment, depending on the scenario, students demonstrated an ability to select (and justify the choice of) biomaterials appropriate for given situations or interactions between living and non-living systems. Additionally, although the assignment was not directly related, in some instances they also demonstrated competence in two other learning objectives including: 1. explain and contend with selected professional regulatory, legal, and ethical issues associated with biomaterials testing and development, and 2. describe the current state of the art in orthopedic and cardiovascular implants, and identify the biomaterial-related challenges associated with these applications. The laboratory assignment reinforced the learning objective that the students should be able to "demonstrate an understanding of laboratory techniques used in biomaterials and biomechanical engineering". Overall, these assignments appear to positively reinforce the concepts emphasized in each of the courses described.

Challenges and Future Directions

The authors acknowledge that the varying backgrounds of these students (juniors versus seniors, mechanical engineering majors with a background in materials versus biomedical engineering majors, learning on a quarter versus a semester calendar) may have confounded the data to some extent. A major challenge was aligning the assignments such that they fell during appropriate yet overlapping times in each course. Several students commented favorably on the role playing exercise, but felt that communication between schools was a struggle. Due to the timing of the courses (a semester course beginning in mid-January at university A and a trimester ending in mid-February at institute B), time constraints also limited the assignment. Future iterations of this project would benefit from allowing for a longer time frame in which to complete the project.

For the consultant/client homework, some of the students were initially unsure about how to write the summary report, and to whom the report should be addressed. Future years of offering this assignment would provide an example of the corporate style memo, and would clearly indicate that the memo should be nominally addressed to the course instructor (acting as a supervisor).

For the lab protocol replication assignment, it would be more beneficial if the readers of the reports were required to perform the experiment based on the initial report. This would clearly indicate to all parties the importance of good communication and provide a more objective means of assessing that communication.

The authors also acknowledge that the anecdotal and subjective assessment of the results pose a significant limitation to this study. Future analysis could also include a formal inquiry as to whether or not these exercises had a significant impact on student learning. A pre and post assessment compared to a control group would be an interesting tool to make this determination.

Preliminary conclusions

Using consultant and client role playing appears to be a good way to get students to independently read and assess information, and appears to be a good way to get students to see career possibilities in which professional communication is critically important.

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Appendix A

Consultant/client

<u>Consultant/client active learning</u>

In this assignment, your team will assume the role of either a consultant or a client. If your team is a consultant, you will receive information regarding a biomaterials issue. Your task is to make a recommendation. If your team is a client, you will be presented with a problem. Your task is to ask questions of a consultant.

To meet the requirements of the assignment, your team will submit a short report that documents the process. In either role, you are responsible for creating intellectual property. As a consultant or a client, your responsibility is to accurately and professionally document information and recommendations. Your team will be required to interact with someone at a different university via Skype, FaceTime or email. During the interaction, you must ask at least one question to a team member at a different university. You may also be asked to answer a question from someone at the different university.

Due: short written report, in professional memo style, that documents the interaction

Example questions:

1. Does the failed material appear ductile or brittle? What would you look for?
2. Is there evidence of fatigue? What would you look for?
3. Is there any evidence of an environmental or corrosive effect? What would you look for?
4. What are the alternative materials for this application?

Case	Consultant	Client
failed hip stem A high nitrogen stainless steel hip stem failed after only 3 years after implantation in a 65 year old woman.  **Fig. 1.** General view of fractured stem surface	Independent materials expert – your goal is to demonstrate that the patient's implant failure was due to a manufacturing issue. – **role Z** materials expert at the company in question – your goal is to demonstrate that the failure was not due to a design error. – **role Y**	attorney representing the family of a patient – your goal is to defend your client in a lawsuit against the manufacturer. – **role T** attorney representing the company in question – your goal is to defend the company from a lawsuit. – **role S**

Co-Cr vs Oxinium© Orthopedic implants made of both Co-Cr vs Oxinium© are on the market. Oxinium© is rumored to be superior and fail at lower rates, but is it?	orthopedic surgeon – your goal is to decide which implants are best for your patients. – **role X**	marketing executive at a prosthetic manufacturing company that manufactures Co-Cr TJRs. – your goal is to convince the surgeon to use your product. – **role R** marketing executive at a prosthetic manufacturing company that manufactures Oxinium© TJRs. - your goal is to convince the surgeon to use your product. – **role Q**
Cartiva big toe joint	manufacturing engineer – Your goal is to keep FDA approval for your product. – role **W**	FDA regulator – your goal is to ensure that cartiva is compliant with FDA standards. – **role P**
Nitinol stents Case: A batch of newly designed artificial heart valves have been failing in younger patients at a statically significantly higher rate than in patients over 70 years old.	independent materials expert – your goal is to demonstrate that the patient's implant failure was due to a manufacturing issue. – **role V** materials expert at the company in question – your goal is to demonstrate that the failure was not due to a design error. – **role U**	attorney representing the families of a patients in a class action lawsuit – your goal is to defend your clients in a class action lawsuit against the manufacturer. – **role O** attorney representing the company in question – your goal is to defend the company from a lawsuit. – **role N**

Appendix B

Lab Report Requirements – Due at the beginning of lab next week

A complete lab report (in PDF format) will be submitted to the Moodle Dropbox. The lab report must include a coversheet with the names of each contributing member. You must follow the "Guidelines for Laboratory Reports" document found on Moodle. The grading rubric used for this report is also available on Moodle. All six sections described in the guidelines are required for this

report. Helpful hints for some of the sections of the report:

Methods: *Briefly d*escribe the protocol with settings information. You should also include specimen data (specimen identifier, width, gauge length, etc.) in tabular form.

Results: The following information should be included in the results section:

- Force-Displacement plots (all samples must be on the same plot).
- Stress-Strain plot (all samples must be on the same plot). Provide sample calculations (and related figures) that explain how the stress-strain plots were developed.
- Determine the uncertainty associated with the UTS of the samples (clearly show *and explain all the steps* necessary for this calculation). Uncertainty analysis is *only* required for UTS.
- Calculate the Elastic Modulus and yield strength (using the 0.2% offset method) for each sample. Show a sample calculation for determining the Elastic Modulus and yield strength. Report your findings for UTS, Elastic modulus, and yield strength in tabular form. The table should also show a statistical summary (averages/standard deviations/UTS uncertainty).

Discussion: *In addition* to discussing the results of the testing, the following questions should be discussed:

- Discuss the UTS and the associated uncertainty. How does the uncertainty compare to the value for the UTS? What could be done to decrease the uncertainty in this experiment?
- Using the material property table provided in lab, identify the polymer tested. Provide the rationale for your selection.
- Classify the material(s) as ductile or brittle. Explain your rationale.
- Identify and discuss three potential sources of error in this experiment. Your discussion should include a method of minimizing the impact of these sources of error on the results.

Appendix C

Assignment: read the lab report that your team was assigned, and then provide feedback as follows:

1. write an internal document in the format that could be submitted at work that includes the lab experimental procedure used in the report; the internal document must also include your judgment and recommendations.
2. complete the feedback table that will be given to the authors of the report; be professional in your evaluations.

feedback table

parameter	**rating on scale of 1 to 10**	**comments**
clarity of written protocol described in report (1 = unclear, 10 = very clear)		
ability of a reader to ***replicate*** the experimental protocol (1 = unable to replicate, 10 = very able to do so)		
format and grammar (1 = poor word usage choices, wrong use of punctuation, etc.; 10 = excellent grammar and vocabulary, perfect)		
overall impression (1 = bad impression, 10 = excellent impression)		

Your team is assigned a lab report to read. From the report, generate an internal document includes a step by step protocol to replicate the experiment. Use the article provided and online resources to ensure that instructions for sample processing, elongation rate, machine settings (i.e. which load cell to use, etc.), and data processing are documented. Could you have replicated this experiment with just this article? What information was missing? Please be professional in your assessments.

The context of this assignment is to imagine that you are in graduate school, and responsible for performing materials experiments. As a grad student, the design of your experimentation will be based on reading articles and reports from other researchers. This assignment replicates this possible future experience.

Appendix D

The rubric used by the instructor at institute B to assign scores to the methods section of the written reports.

Methods:

0	1	3	5
Missing or incomplete, or written as a bulleted or numbered list of instructions, or provides very little critical information.	Either includes more than one piece of non-critical information, or is missing more than one piece of critical information. Improvements in clarity possible.	Either includes some non-critical information, or is missing some critical information. Minor improvements in clarity possible.	Fulfills all requirements for Methods: includes all important experimental procedures at an appropriate level of detail. Clear, concise, complete, professional.