

## **Impact of a Sophomore BME Design Fundamentals Course on Student Outcome Performance and Professional Development**

**Dr. Christa M Wille, University of Wisconsin, Madison**

Christa Wille is a Biomedical Engineering doctoral student at the University of Wisconsin-Madison. She received an undergraduate degree in Biomedical Engineering and went on to get her clinical doctorate in Physical Therapy at the University of Wisconsin-Madison. She advanced her clinical skills through a Sports Physical Therapy Residency at UW Health. Although continuing to practice Physical Therapy, Christa has returned to academia to continue to pursue research focused on gait analysis and the biomechanics of running related to various injuries including hamstring strains and injuries of the knee.

**Dalton James Hess**

**Mr. Jake Mitchell Levin, University of Wisconsin-Madison**

**Dr. Amit Janardhan Nimunkar, University of Wisconsin, Madison**

Amit J Nimunkar received his B.E. in Electronics Engineering from the University of Mumbai, India in 1999, M.S. in Bioengineering from the University of Toledo, Ohio in 2000 and Ph.D. in Biomedical Engineering from the University of Wisconsin-Madison, Wisconsin in 2009. He is currently the Associate Faculty Associate in Biomedical Engineering at the University of Wisconsin-Madison. His teaching specialty is on the topic of Biomedical Engineering Design and Bioinstrumentation and has taken initiative to develop hands-on blended learning based courses on the same topics. His research interest is on global health and engineering and had worked on projects in Honduras, Ethiopia, India and Vietnam. He has received the Recognition Award for Achievement in Global Engaged Scholarship in 2013 through the Wisconsin Without Borders at the University of Wisconsin-Madison, the Professor of the Year Award in 2012, through the Biomedical Engineering Society at the University of Wisconsin-Madison, and a number of teaching awards.

**Dr. John P. Puccinelli, University of Wisconsin, Madison**

Dr. Puccinelli is the Associate Chair of the Undergraduate Program in the Department of Biomedical Engineering. He began here as student near the start of the UW-BME program and earned his BS, MS, and PhD in BME. He is interested in hands-on instruction – teaching and developing courses related to biomaterials and tissue engineering, as well as design. He has been awarded numerous departmental and college level teaching awards. He was recently inducted as a fellow to the UW-Madison Teaching Academy.

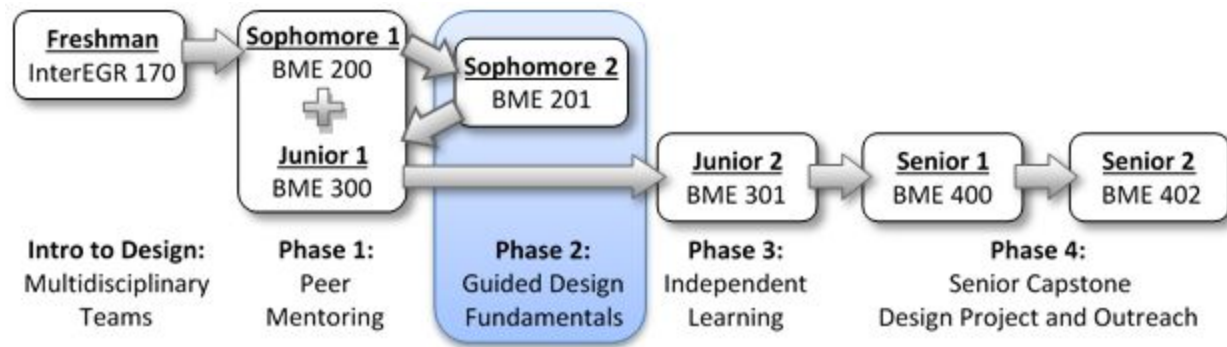
## **Impact of a Sophomore BME Design Fundamentals Course on Student Outcome Performance and Professional Development**

Biomedical Engineering (BME) students at the University of Wisconsin-Madison take seven semesters of required team-based design courses. Historically, students would develop technical skills as needed based on their project. Through engagement with our constituents we developed a more direct instructional approach at delivering essential engineering tools early in the curriculum. We previously reported on the creation of this new required second semester sophomore lecture and laboratory course with a guided design project: BME 201, “Biomedical Engineering Fundamentals and Design” (to replace one of the client-based experiences). Since then, this course has evolved to cohesively combine all three components into modules that represent the breadth of BME, including: electronics, programming (MATLAB, LabVIEW, and Arduino), mechanics (SOLIDWORKS, machine shop use, and biomechanical testing), biomaterials and tissue engineering (literature research, biosafety, aseptic technique, optics and material interactions) as well as other professional design skills. Despite being a relatively new course, we have seen overwhelming success related to student outcome performance in design by students since the implementation of this course versus its client-based counterpart. In addition, self-reported survey data from students upon completion of BME 201 felt this course was effective at improving their skills and their abilities to meet student outcomes. Finally, students also felt that this course was effective at influencing their academic and future career goals.

### **I. Introduction**

Biomedical Engineering (BME) students at the University of Wisconsin-Madison participate in a unique design curriculum consisting of team-based design courses for seven semesters (Figure 1) [1-2]. Freshman year students work in interdisciplinary teams to solve community-based design challenges. Then, from sophomore through senior year, our students design, build and test their innovative solutions for clients in the healthcare profession, local biomedical industry, community and from our faculty. Within our design curriculum, sophomores (in the fall) work on teams with juniors - forming mentored relationships [3], while seniors participate in outreach as well as prepare their work for a publication. Each course provides a unique challenge or experience to coincide with the real-world design project.

Regardless of education level, students are expected to learn the necessary topics unique to their proposed design project, such as technical skills pertaining to electrical, mechanical, chemical and biological-based simulation, design, measurements, machining and fabrication. Historically, students would develop these skills as needed or via workshops offered through the department. Through engagement with our advisory board, alumni, and BME Student Advisory Committee (BSAC), it became evident that more formal and direct training on essential engineering tools was needed early in the curriculum, yet at a point where knowledge such as calculus, chemistry and physics could be applied. As a result, in 2012, we transformed our required second semester sophomore open ended design course into a two-credit lecture and laboratory course with a guided design project: “BME 201: Biomedical Engineering Fundamentals and Design” [4]. After a thorough introduction to design freshman year [5] in a classroom setting and a mentored project first semester sophomore year, students participate in BME 201 (Figure 1).



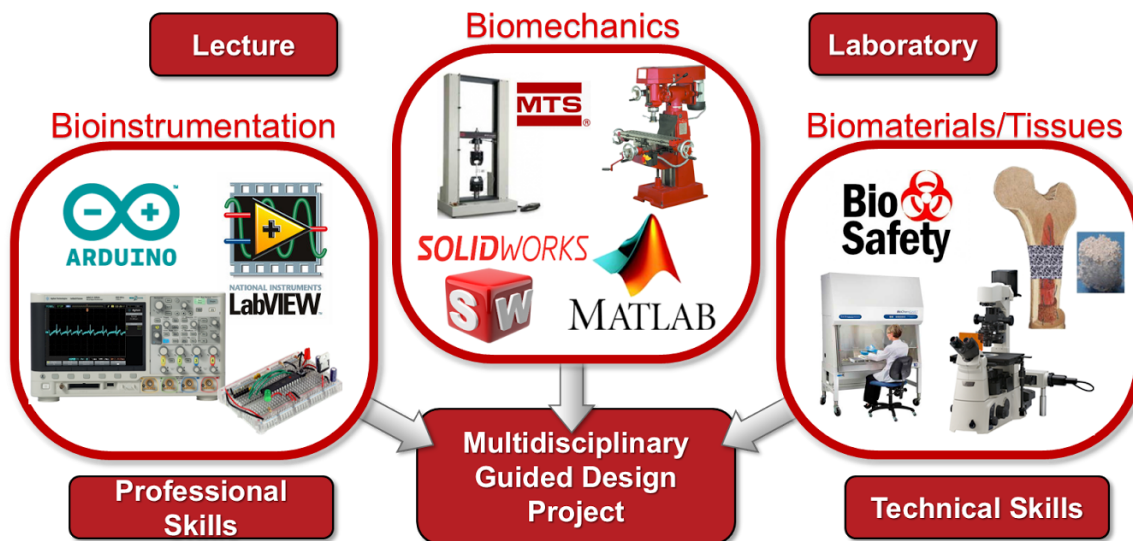
**Figure 1.** The BME Design Curriculum - seven semesters of team-based design. During freshman year students work on a client-based projects in teams composed of students from six engineering programs. In Phase 1, sophomores are mentored by junior students in hybrid teams, In Phase 2, which is the focus of this paper, sophomores work in teams of 5-6 on solving the same guided problem through the application of intradisciplinary technical skills. In Phase 3, the juniors start on a more complex project that typically spans into senior year and Phase 4: capstone design [1-4].

Over the last five offerings of BME 201, this course has evolved to cohesively combine three components (lecture, lab and a design project) into modules throughout the course that represent the field of BME, both from a curricular and industry standpoint. To effectively teach the students in the course and maintain current course content, we utilize a three tiered instructional approach: instructors, three teaching assistants, and up to 20 undergraduate student assistants, all bringing their educational and industry experiences to the course. The student assistants rotate throughout the course depending on the current topic and their level of related expertise. Instructors in this course help guide students through each specific module focused on teaching students the necessary components of the engineering topics or tools at hand. Students are then encouraged to apply the knowledge gained from each module toward a specific aspect of their design project.

Since many professional and technical skills are generally not taught in courses early on in engineering curricula, the purpose of BME 201 was to do this in a hands-on way, while at the same time helping the students find their passion. By introducing students to the various aspects of BME, they receive early exposure to our curricular track/subspecialties including Medical Instrumentation, Imaging, Biomechanics and Human Factors, and Biomaterials/Cellular/Tissue Engineering. With a thorough introduction to various technical and professional skills as well as each subspecialty, it was hypothesized that there will be an improvement in student performance later in the curriculum and that students can make informed decision while selecting appropriate track and career path. We have compiled data from our department's Assessment Committee who evaluate student outcome performance throughout the curriculum (sophomore through senior year) from student populations with the new BME 201 (post-201) and students in the previous client-based sophomore course (pre-201). We have also assessed the overall effectiveness of this course with student surveys showing the influence of the course on student curriculum and career choices.

## II. BME 201 Course Format

The format of the course consists of three main components: lecture, laboratory, and a guided design project as shown in Figure 2. The lecture is designed to prepare the class for the following weeks laboratories, and the laboratories are designed to provide the technical expertise necessary to solve a component of the design project. Along the way, both the technical content and professional design skills are supported by online videos and readings. The complete course schedule and design project scope are available in the Appendix.



**Figure 2.** Illustration representing the content covered in BME 201 as it relates to the three main curricular track options. Bioinstrumentation - Electronics, test equipment, Arduino and LabVIEW; Biomechanics - Mechanical testing, SOLIDWORKS, MATLAB, and machine shop training; and Biomaterials/Cell/Tissue Engineering - BioSafety training, aseptic technique, physiological conditions, basic material interactions and microscopy. The lecture and laboratory sessions help prepare the students to solve the guided design problem. All areas of the course build both technical and professional design skills.

### *Lecture*

The 50-minute lecture each week is utilized to preface the laboratory portion of the course in a blended, active learning fashion, including instructor delivered content and problem solving. This model allows the laboratory to cover each design skill in greater depth. To prepare for the class, each student is responsible for reviewing pre-lecture materials which may include a short video, reading, or activity sheet. As the semester progresses, lecture content transitions from more technical skill development to having a greater emphasis professional skills such as writing and presenting.

Supplementary lectures were recorded during the first offering of BME 201 in 2012 and have been updated as needed by faculty and students. These videos explain engineering in the broader

context and opportunities (research and career) in each curricular track with firsthand accounts from past students on how to succeed in the field. One video is assigned each week that aligns with the current module. The students are required to write a short reflection covering the following three questions: What are the main points?, How is the material useful to you?, What more information do you think should be included?.

### *Laboratory*

The three-hour laboratory each week develops a diversity of hands-on skills covering the basics of each discipline and associates the lecture and laboratory exercises toward the guided design project, a physical prototype of a medical research device. Laboratory topics were developed through interactions with and input from our student advisory committee (BSAC), student surveys, industry including co-op and employer surveys and the external advisory board. The skills that were utilized most frequently by students in their past design projects, internships and co-ops were made a priority and developed into guided exercises.

During the first week of lab, students are divided into multidisciplinary, diverse, six-person groups to develop well balanced teams; these include at least one person from each track interest as well as varying stages of experience. Students are required to review materials for each laboratory exercise before attending the lab period. The materials for the laboratory are provided in a digital manual within LabArchives Electronic Laboratory Notebook [6]. Each folder/laboratory consists of background reading and/or external online content, pre-lab quiz questions, the laboratory protocol, post-lab quiz questions, report guidelines, and references. The laboratories themselves are generally done individually or in pairs, but the students are always seated in their team pods and we encourage peer-to-peer learning. The lab exercises do not explicitly solve their design problem, but provide a framework for which the student teams have freedom to make informed engineering decisions based on the literature, safety, cost, functionality, precision, accuracy, etc. The lab exercises generally do not require the full three hours, which allows the student teams to work together on applying the laboratory to the design project in the presence of instructional support.

### *Guided Design Project*

One of the aims of the course is to integrate the various skills acquired in the laboratory portion of the course into an open-ended guided design project. Thus, this combines and assimilates the professional and technical design skills taught in the course over the entire semester thereby promoting life-long learning. The students working on the project are in their six-person multidisciplinary laboratory groups. While they assign the traditional team roles used in our design curriculum (leader, communicator, advisory committee and accounting), we provide them flexibility to rotate team roles throughout the semester as necessary and as the course aligns more with the interests.

For the design project itself, we devised a multidisciplinary problem statement that utilizes all the skills our constituents felt were most important, as well as one that covers the previously mentioned curricular track areas. The problem statement is: “*Design a synthetic bone graft. The*

*bone graft must maintain mechanical stability similar to native bone in vivo for at least two weeks.”* The project consists of designing and fabricating a physical bioreactor to house the synthetic bone graft samples. The bioreactor must maintain physiological conditions (through electronic and software regulation) and sterility over the span of two weeks. For both the bioreactor and bone graft samples, the teams iterate through the design process to design, build and test their hypothesis against their design specification using compressive stress analysis at three time points. See the Appendix for more details on the project scope.

### *Course and Design Project Improvements*

After the first two offerings of BME 201 (as presented previously [4]), for the 2014 semester, significant improvements were made to enhance the course flow and the relationship of the laboratories to a new more multidisciplinary design project (described above). Previously, teams had very little freedom within the various aspects of the project as the laboratories primarily solved the design challenge, though we did not fully define project scope in the course until many of the laboratories were complete. Additionally, throughput was limited during testing due to space and the constraints of the project. Each team is now able to generate a unique hypothesis related to their design choices and test their design independently resulting in variability between the teams. At the end of the semester, groups learn from others’ successes and failures during the final presentations. These project related enhancements were made possible by opening a dedicated Design Studio space for both BME 201 labs and our client-based design projects. We also made additional improvements in 2014 including: changing from peripheral interface controller microcontrollers to Arduino, publishing our laboratory manual in LabArchives instead of print copies, simplifying our learning management platform across design [6] and adding feedback throughout the semester on portions of the team’s paper and the individual’s notebook. Overall, BME 201 has become a platform to introduce new technologies, design-based strategies and for continuous improvement within the curriculum.

### **III. BME Assessment Committee Evaluation, Results and Discussion**

The department’s Assessment Committee annually evaluates ABET Student Outcome performance from the prior year’s spring design course teams (BME 201, 301 and 400-402) using the team’s final report(s) and peer-evaluations. In brief, the Committee first calibrates itself using a randomly selected senior team by discussing any discrepancies in scores and the assessment process itself. Following the calibration exercise, the Committee Chair assigns reviewers to a random sampling of projects. At least two reviewers assess each project’s report(s) and peer evaluations to the expectation of graduating seniors for all levels. In 2010, we established a rubric with performance indicators to more consistently measure student outcomes [7]. This rubric as shown in Table 1, has also evolved through the annual assessment exercise. At the end of the process the Assessment Committees generates a report and recommendations that are generally implemented in the design curriculum the following year.

**Table 1:** Assessment rubric for BME Design and the Assessment Committee for each ABET and *BME Specific* student outcome (left) and the performance indicators for a score of a 5/5 (right).

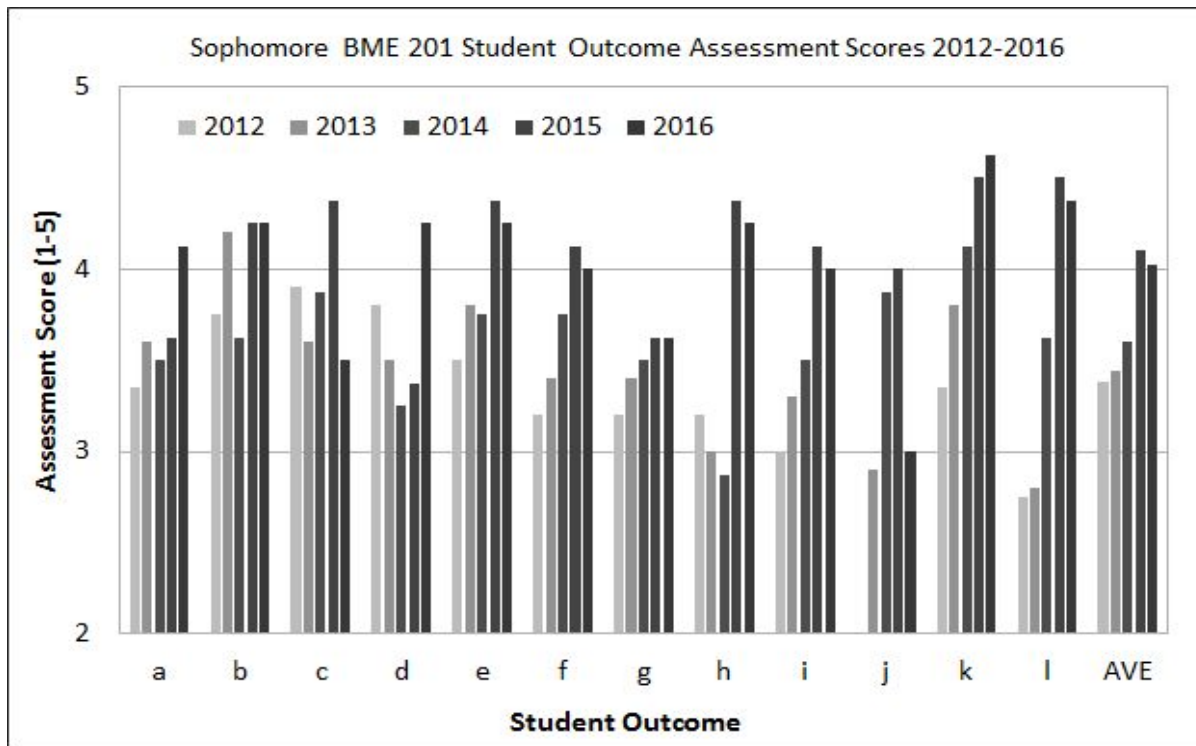
Student Outcomes	Criteria Required for 5/5 Score
(a) Apply knowledge of mathematics (including differential equations and statistics), science, and engineering <i>to solve problems at the interface of engineering and biology</i>	<ul style="list-style-type: none"> <li>• Uses appropriate, advanced mathematics, science and engineering knowledge/skills</li> <li>• Uses appropriate statistical analysis</li> <li>• Calculations predict and are compared to experimental results or are used to optimize final design</li> </ul>
(b) Design and conduct experiments (including making measurements) on, as well as to analyze and interpret data <i>from living systems; addressing the problems associated with the interaction between living and non-living materials and systems.</i>	<ul style="list-style-type: none"> <li>• Experimental approach (hypotheses and protocols) leads to design improvements or new approaches</li> <li>• Data are used to assess all relevant PDS criteria</li> <li>• Sources of error are identified and methods to reduce it are discussed</li> <li>• Clear conclusion stated</li> </ul>
(c) Design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability	<ul style="list-style-type: none"> <li>• Final design meets or exceeds client-specified criteria</li> <li>• The design evaluation considers environmental, ethical, health, safety, regulatory constraints</li> <li>• The design evaluation considers manufacturability, sustainability, social, political, and economic constraints</li> </ul>
(d) Function on multidisciplinary <i>and</i> diverse teams <i>and</i> provide leadership	<ul style="list-style-type: none"> <li>• Positive peer evaluations</li> <li>• Clustered “bonus” scores or consistent ranking</li> <li>• Identifiable individual contributions in team output</li> <li>• Leadership mentioned</li> <li>• No non-contributors</li> </ul>
(e) Identify, formulate, and solve <i>biomedical</i> engineering problems	<ul style="list-style-type: none"> <li>• Final design works as intended</li> <li>• Design alternatives provide evidence of multiple viable approaches</li> <li>• Several criteria are evaluated in a design matrix for each design alternative</li> <li>• Design problems are identified and solutions logically presented</li> <li>• PDS provides mostly quantitative, but some qualitative metrics that can be evaluated</li> </ul>
(f) Understand their professional and ethical responsibility	<ul style="list-style-type: none"> <li>• Current or future ethical considerations are clearly identified and addressed including the safety of user and patient</li> <li>• No research ethics violations</li> <li>• Design concepts credited appropriately</li> <li>• Text references and figures cited appropriately</li> </ul>
(g) Communicate effectively: <i>written and graphic modes</i>	<ul style="list-style-type: none"> <li>• Virtually no errors in spelling or grammar</li> <li>• Layout enhances readability</li> <li>• Problem defined with additional material and motivation</li> <li>• Design matrix categories are justified and scores explained</li> <li>• Experimental methods are clearly described and results reported (methods and results)</li> </ul>

Student Outcomes	Criteria Required for 5/5 Score
(g) Communicate effectively: <i>written and graphic modes</i> (continued)	<ul style="list-style-type: none"> <li>Effectively uses graphics to illustrate key points including meaningful figure captions</li> <li>Appropriate data presentation (e.g., labeled axes, SI units)</li> <li>Proper reference and citation formatting</li> </ul>
(h) Understand the impact of engineering solutions in a global, economic, environmental, and societal context	<ul style="list-style-type: none"> <li>Researches the overall global impact (size/demographic) of the problem and solution and this statement is thorough and clear (including historic and potential impact, effect of solution)</li> <li>Identify beyond the need of the client when appropriate and is in context</li> </ul>
(i) Recognize the need for, and an ability to engage in life-long learning	<ul style="list-style-type: none"> <li>Several references (typ 20+) of multiple types (articles, books, websites, patents, personal communications, etc.)</li> <li>Reference material enhances the paper/presentation</li> <li>Reference material is in context when cited – uses multiple references for key points.</li> <li>Resourcefulness is evident in all of the peer/self-evaluations</li> </ul>
(j) Knowledge of contemporary issues	<ul style="list-style-type: none"> <li>Relates the problem and project to recent events as appropriate (engineering/science based)</li> <li>The big picture</li> </ul>
(k) Use the techniques, skills, and modern engineering tools necessary for engineering practice	<ul style="list-style-type: none"> <li>Employs the appropriate tools especially those available i.e. CAD (CAE software), COE Shop, BME Teaching Labs, etc.</li> <li>Seeks out additional tools</li> </ul>
(l) <i>Understand biology and physiology as related to biomedical engineering needs</i>	<ul style="list-style-type: none"> <li>Clearly communicates all of the relevant biology/physiology</li> <li>Problem description is appropriately motivated by relevant biology/physiology</li> <li>Does not “fill” intro with irrelevant biology/physiology</li> </ul>

The results from the BME Assessment Committee are shown in Figures 3-5. Through the assessment process, the committee was able to observe improvements within BME 201 itself as shown in Figure 3. There is a generally increasing trend in most of the outcomes (with the exception of c, d, h, and j) as improvements have been made each year in BME 201. After the first two offerings the Committee recommended to run BME 201 more similar to the client-based design courses by introducing the design problem, form teams, hold ‘client’ meetings, and provide the best practices guidelines for writing reports and the evaluation forms at the beginning of the semester. Additionally, course evaluations revealed that there were too many disparate content platforms needing greater organization which could have also influenced team dynamic: outcome d, as well as overall performance in the course. Many of the changes described above in 2014 were made to address some of these issues. After the 2014 changes, the Committee noted that the reduction in scores for outcomes a, b, and d were a result of the greater flexibility in the new design project solution, however this decline did not persist. Overall scores in the last two years for sophomores have been high (above four, which is the benchmark expectation for senior performance). A potential major contributing factor beyond the course improvements is consistency – all students in BME 201 have very similar experiences, i.e., same client, same advisor, same project and same resources. The students are allowed to explore and develop their



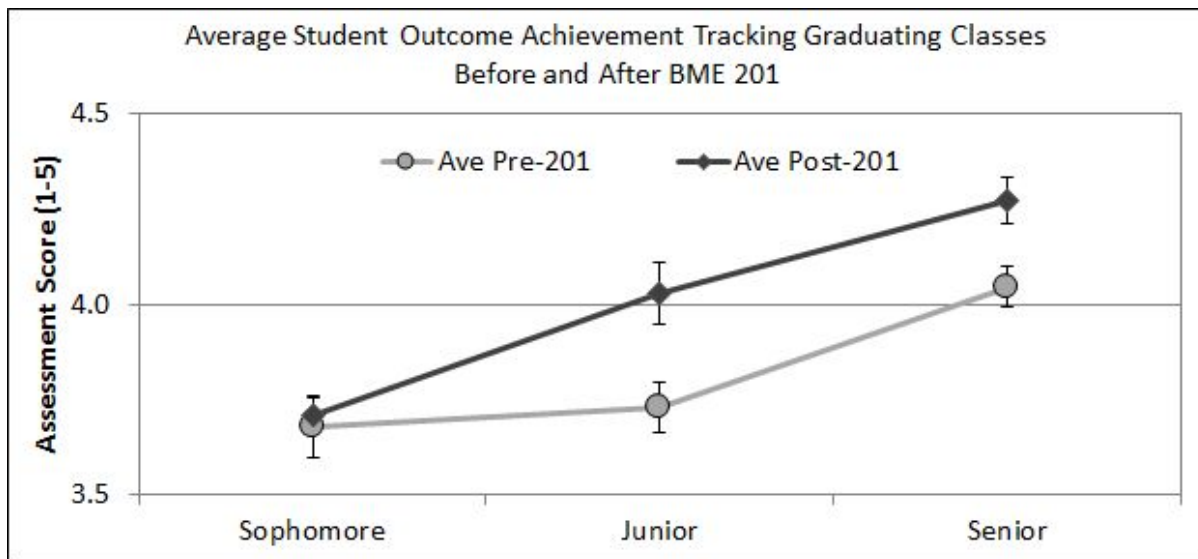
ideas within these confines, thus eliminating any complicating factors or influences on performance due to varying clients and projects.



**Figure 3.** Assessment Committee scores of sophomores in BME 201: Biomedical Engineering Fundamentals and Design showing an increasing trend of student outcome performance (Table 1) and the average of all outcomes over the iterations of BME 201. Major changes in the course structure and design project were implemented in 2014 with continuous improvement efforts each year (n = 5, 5, 4, 4, 4).

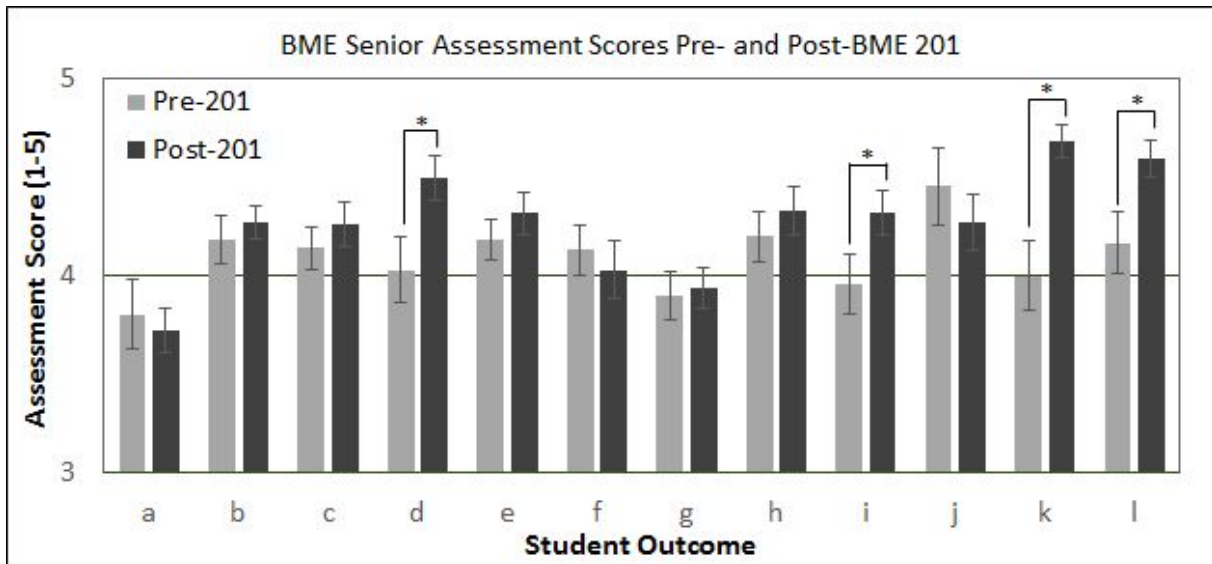
The Assessment Committee also tracks cohorts of students throughout the curriculum. Figure 4 shows these results as the average of all student outcomes for a collection of incoming classes at each level (sophomore, junior, and senior) separated by their sophomore design experience. Students that had the new BME 201: Biomedical Engineering Fundamentals and Design (Post-201, incoming students 2012-2016) performed better ( $p < 0.05$ ) in subsequent design courses (junior and senior design) compared to students who had the open ended client-based design course in their spring sophomore year (Pre-201, incoming students 2008-2011). At the sophomore level, even with the guided nature of BME 201, the students in BME 201 only marginally performed better than those with the open ended project. These results are confounded by the changes made in BME 201 especially in 2014. While the Committee did not see significant change in the sophomores pre-201 compared to the sophomores in the first two offerings of BME 201, there is a significant improvement comparing 2014-16 sophomores in BME 201 against pre-201 sophomores alone and BME 201 sophomores in 2012-13 alone (Figure 3 - average score). Despite the changes in 201 over time, there is still an impact on overall performance later in the curriculum for all groups having the guided-skills based design project in the sophomore year. Again, the consistent nature of course and exposure of all students

sophomore year to the various biomedical engineering technical and professional areas is beneficial as compared to the “as needed” model of the differing client projects. Additionally, as students progress throughout the curriculum, they gain additional valuable experiences and coursework that leads to the increasing trend from sophomore to senior year.



**Figure 4.** Assessment Committee scores of student outcome performance in the spring design courses following each class through the curriculum. Average performance of all student outcomes from students in the real-world, client-based design course as sophomores in 2008-2011 (pre-201 ●; n=11,18,30); Average performance of all student outcomes from students having had BME 201: Biomedical Engineering Fundamentals and Design as sophomores in 2012-2016 (post-201 ◆; n=12,14,27), error bars as standard error.

Finally, using Assessment Committee results, senior performance on each student outcome in Table 1 was analyzed between the groups pre-201 and post-201 (Figure 5). BME 201 has had a significant impact on student outcome ‘d’ - teamwork and leadership, outcome ‘i’ - life-long learning assessed by research ability and resourcefulness, outcome ‘k’ - engineering tools and outcome ‘j’ - understanding of biology and physiology as evidenced by background literature research. The improvements in outcome ‘k’ are a clear result of efforts in BME 201 by providing technical expertise/skills across many platforms. This is supported by commentary from the design instructors as well as our design award judges who have observed an overall jump in utilization of our student shop, prototype quality, graphic design, and other components emphasized in BME 201. Overall, there was also no significant decrease in any outcome. It is also important to note that the department actively pursues continuous improvement strategies across the curriculum and it is difficult to isolate the impact of BME 201 alone, though BME 201 has been the most significant change in the curriculum since 2012. Similarly, changes made in BME 201 are not only seen and experienced by all the sophomore students, but also by the roughly 20 student assistants we hire to help teach the course, thus having an influence across the department.

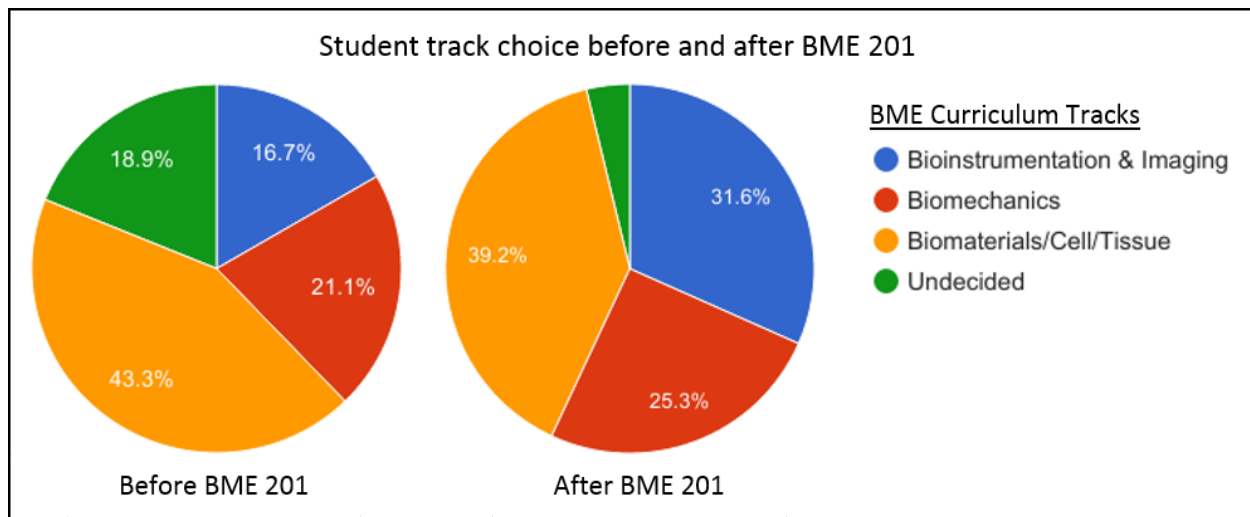


**Figure 5.** Assessment Committee cumulative results of senior performance on each student outcome (■) pre-BME 201 Biomedical Engineering Fundamentals and Design (sophomores during 2008-2011) and (■) post- BME 201 (sophomores in 2012-2016). A statistically significant increase in performance was seen in outcomes ‘d’, ‘i’, ‘k’, and ‘l’ with  $p < 0.05$ , error bars as standard error.

#### IV. BME 201 Student Survey Results and Discussion

In addition to the Assessment Committee’s evaluation, self-reported outcome measures have been collected from students in BME 201 over two-years (2015 and 2016). At the end of the course, students were asked to complete an anonymous survey to evaluate the effectiveness of BME 201 on their design abilities, curriculum subspecialty selection and career outcomes. Out of the 207 students who completed the course in 2015 and 2016, 76% completed the survey.

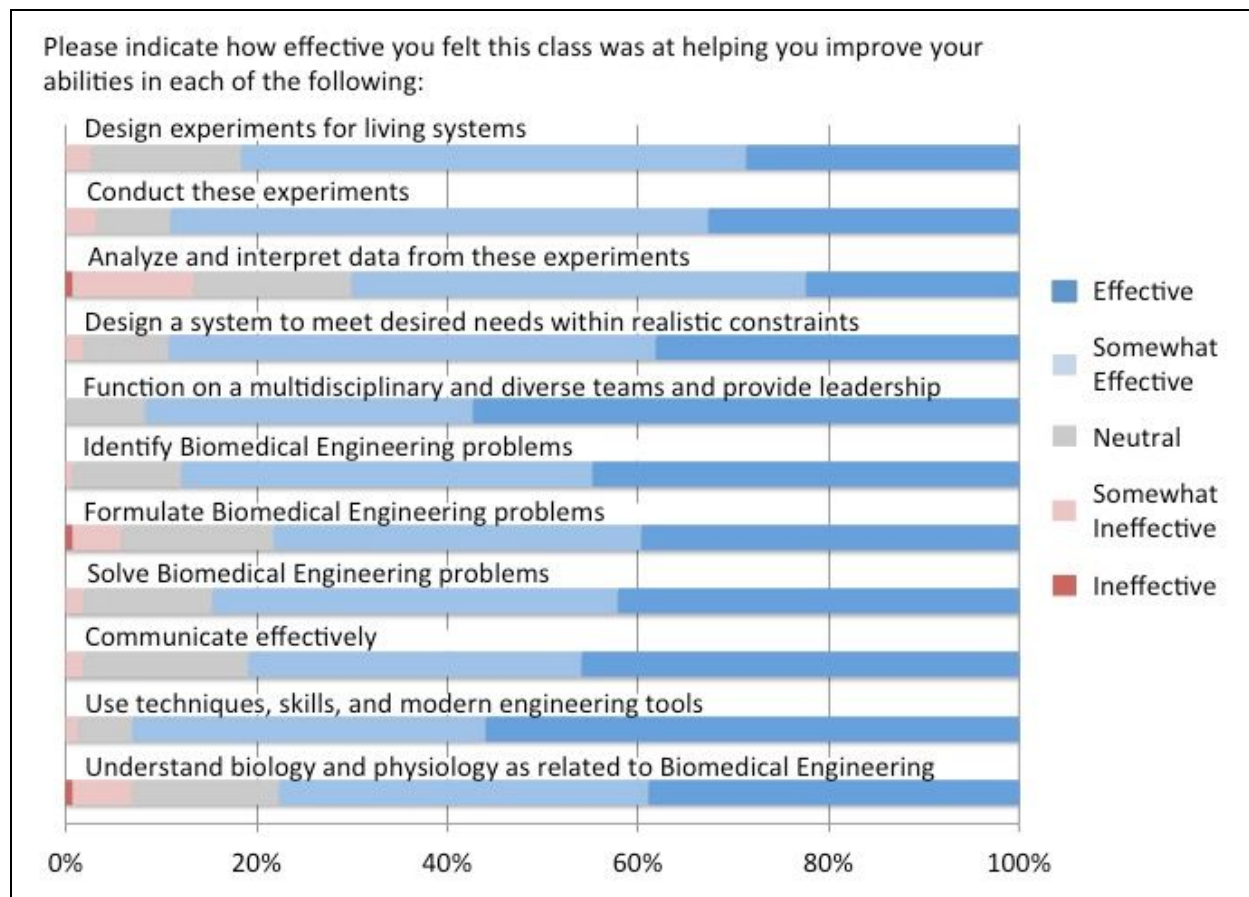
BME 201 had a noticeable effect on assisting students with selection of one of the three main tracks. When surveyed at the start of the semester, almost 19% of students were undecided as shown in Figure 6, left. Through the diverse curricula of BME 201 and the hands-on introduction to the different subspecialties, on average 20.4% of survey respondents felt that the topics addressed in this course played a unique and critical role in the selection of their track. As a result, there was a noticeable decrease in the percentage of students who were undecided in their track selection (3.9%) at the completion of the semester (Figure 6, right). By providing a hands-on introduction to each of the subspecialties within the BME major, students are able to select a track that is more appropriate for them. This will allow them to declare a specialization earlier in their academic career and efficiently develop advanced skills within a focused topic, all the while continuing to maintain breadth from their BME 201 experience. With a more advanced skill set, each individual can provide a greater contribution toward their interdisciplinary design teams later in their academic career, contributing to the overall trend in improvement in the quality of design projects completed after the implementation of BME 201.



**Figure 6.** Student survey results from the Spring 2015 class of BME 201: Design Fundamentals with respect to the student's choice in BME track/area within our curriculum - surveyed before and after the course. Of the students who changed their track, 22.2% reported they did so solely based on their BME 201 experience in 2015. Similar results were seen in 2016 with 18.4% reporting that BME 201 was influential in their decision to change tracks.

In addition to providing guidance for each student's academic path, BME 201 also educates students on the technical and professional skills necessary to be a design engineer. Through the guided design project, students are educated on proper techniques for the design, implementation and analysis of BME experiments. They are expected to complete the project within a narrow window of time and a marginal budget, similar to realistic constraints. Students felt that BME 201 was overwhelmingly effective at improving their abilities to design and conduct experiments, but not as effective in the analysis of these experiments (Figure 7). At the inception of the course, the primary goal was to provide an early introduction related to the technical skills required to successfully complete a design project. Reflecting upon outcomes of the course and student survey responses, it is clear that analysis and interpretation of the information gathered through newly gained skills is an area of improvement. As an integral component of the design process, analysis and interpretation of experimental results is an area of the course that we plan to improve upon in coming years by strengthening the MATLAB module related to data processing and statistical assessment of results.

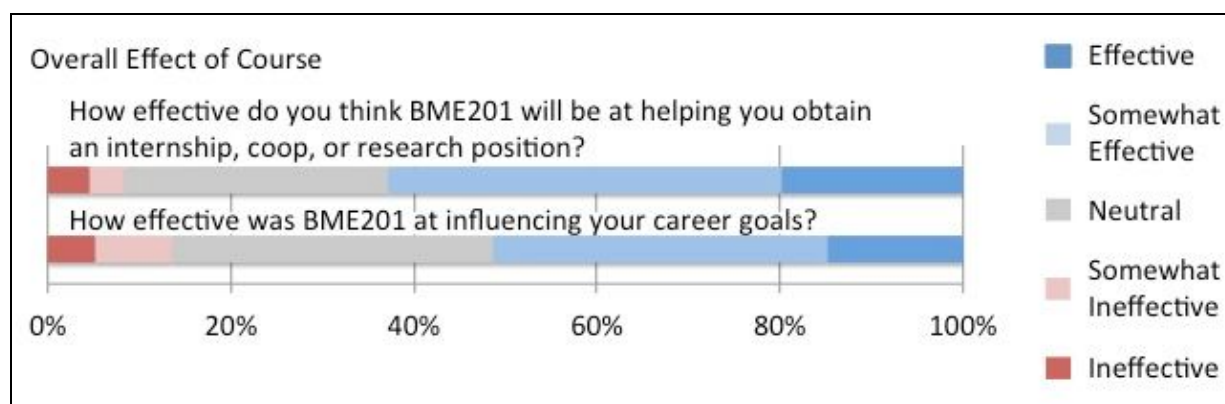
Teams, whether in a classroom project or in an industry setting, consist of individuals with unique backgrounds. We aim to encourage a diverse team in BME 201 by starting the first week with a number of icebreakers, having the students get to know each other and then forming groups that have students from all interest areas and levels of experience (as described previously). We also encourage teams to work cohesively to identify, formulate and solve BME related problems using modern engineering tools. Students again indicated that BME 201 was effective at improving their abilities related to working as a team to appropriately address BME-related problems (Figure 7). Working effectively as a team is a necessary skill essential for the successful completion of design projects at any level, educational or professional.



**Figure 7.** The effectiveness of BME 201 on the development of necessary design skills for biomedical engineers. Students felt BME 201 was effective at improving their abilities to design and conduct experiments within realistic constraints; identify, formulate, and solve BME problems; and function on a diverse team and communicate effectively. Students felt that BME 201 was on average less than Somewhat Effective at assisting with the analysis and interpretation of engineering experiments.

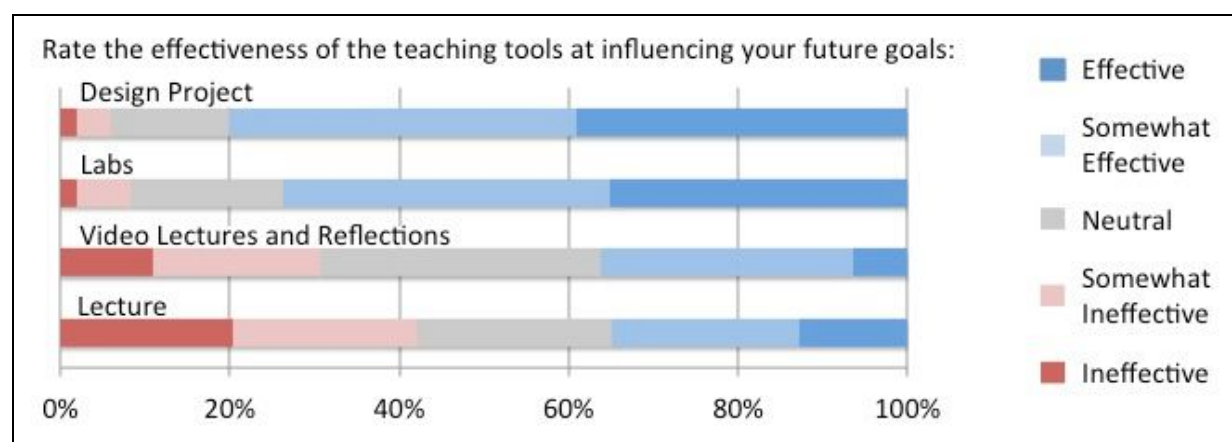
In addition to teaching students about necessary skills required to succeed as a biomedical engineer, this course also has an effect on students to ensure they obtain the proper extra-curricular experiences to succeed. Students felt that BME 201 was effective at helping to obtain an internship, co-op experience or research position. In addition, they also felt that this course had an effect on their overall career goals as shown in Figure 8. With proper exposure to various skills required to succeed as an engineer, students are more qualified to succeed in their future experiences. In addition with a better understanding of their interests, it is likely that they are more prepared to seek out an opportunity that aligns with their subspecialty. With an appropriate introduction to the necessary professional and technical skills and an opportunity that suits their interests, students are likely to be more confident in pursuing additional opportunities therefore setting them up for success in their academic and career aspirations.





**Figure 8.** Survey results indicating the overall effectiveness of BME 201 on helping students to obtain internships, coop experiences or a research position as well as the influence of BME 201 on their overall career goals.

In order to assess all the educational components of the course, we asked students to rate the effectiveness of each element. Students evaluated each teaching tool related to the effectiveness of each aspect in relation to their future goals. They indicated a trend toward an effective response related to the hands-on components: design project and the laboratory sessions, with a neutral response on the video lectures/reflections as well as the lecture sessions (Figure 9). Comments from the course evaluations, however, show that video lectures had a polarizing effect; some students said the videos were “a waste of time” or “busy work” while others said they “enjoyed the video lectures” and another student said “[the video lectures made me] realize that I wanted to change tracks”. Although several of the video lectures have been updated since the implementation of the course, we aim to continually improve these. The lower response to the in-person lecture time as it relates to their future goals is difficult to interpret as the lectures are designed to prepare the students for the following week’s lab. We plan to evaluate this differently in the future and make adjustments accordingly.



**Figure 9.** Survey responses indicating the effectiveness of each teaching tool used in BME 201 related to their future goals: the design project, labs, video lectures and reflections, as well as lectures. Students had a more positive response toward the hands-on components.

When given the opportunity to express open ended comments, survey respondents had overwhelmingly positive comments including “I’ve gained many skills that I will be able to apply to my future career.” Another student felt the course was so influential that it should be offered to other engineering students. “GREAT OVERALL CLASS. Make available to non-BME students. I think this hands on learning [is] so critical to becoming a better engineer and other programs don’t have this.” Constructive criticism for the course commonly included frustrations related to the large time requirement for a two-credit course, “Very stressful overall and lots of work... I just wish I got more credit.” Some did not value all of the skills until they used them “I didn’t appreciate the shop requirement at the time, but now I’m very glad to be more familiar and comfortable with it.” While others wish they could go more in depth in some areas “I would like to have a more challenging module for times that I already have experience.” In addition, with several different methods of instruction students had various opinions related to the effectiveness of each. Overall, the students felt that “this course provided a comprehensive understanding of both the breadth and depth of the field of Biomedical Engineering” and that it allowed them to “make a more informed decision in regard to [what] track [in] BME” they wanted to pursue.

## **V. Conclusion and Future Work**

Despite being in the early years of implementation, BME 201 has had a significant impact on the academic experiences and outcomes related to the design curriculum at the University of Wisconsin-Madison. In the assessment of each graduating class’s student outcomes, a noticeable improvement is observed in the quality of work completed in the upper level design classes from students who had participated in BME 201. Our assessment processes have also shown how effective making changes in BME 201 are at impacting student performance throughout the curriculum. These sentiments have been echoed by our external advisory board who attends our spring design poster session as design judges, noting that they are impressed more and more every year. At an individual level, students self-reported BME 201 was effective in assisting with the selection of their subspecialty with an average of 20% of the students indicating that this course was solely responsible for changing their mind. Furthermore, students responded to end of semester surveys indicating that the course was overwhelmingly effective at improving their abilities related to student outcomes. Areas for future development include: the additional content related to the interpretation of experimental data including statistics (though most students have not had a statistics course yet in the curriculum), furthering the various modes of instruction by improving online video content, and better assessment of the lecture portion of the course. We also hope to develop a suite of projects that will rotate annually. In summary BME 201 has significantly influenced not only the quality of design projects but also the caliber of students (directly from with the course and indirectly through the student assistants learning by teaching) graduating from the University of Wisconsin-Madison by preparing them early in their academic career to succeed as a Biomedical Engineer both in an academic and real-world setting.

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## Appendix

### Project Statement & Scope

BME 201 is all about teaching you design fundamentals toward solving a guided design project, this includes working through the design process of developing a specification through research, evaluating design alternatives, fabricating and testing the final design (using the various laboratories - 3D modeling, basic electronics, programming, machining, writing, brainstorming, and many other skills) and making conclusions.

The problem statement: Your "client" would like you design a synthetic bone graft. The bone graft must maintain mechanical stability similar to native bone in vivo for at least two weeks. You have up to \$100 to design build and test your synthetic bone graft material.

**Scope:** Over the course of the semester you will choose a synthetic replacement for bone and characterize its mechanical properties in a simulated physiological environment for a two week duration. In order to do this you will construct a simple bioreactor and sample container to expose your material samples to “biological” conditions. The bioreactor must be able to automatically maintain a constant temperature using a temperature sensor, heating element, and a microprocessor. You will also record the temperature readings over time.

At three timepoints ( $t=0$ ,  $t=\text{halfway}$ ,  $t=\text{end}$ ) you will do compression testing using the MTS machine to measure mechanical properties of your material samples. The compression test will destroy the sample. For statistical purposes, you will want to test at least three samples at each time point. Time zero samples will never be “cultured” in your bioreactor.

You should generate a hypothesis based on your research, material and testing choices. You will need to analyze the data from your experiments to test your hypothesis and determine Young's Modulus and the ultimate strength at different times, which can be used to create a profile over time (with statistical analysis: standard deviation plotted as error bars and t-test between timepoints).

Materials provided:

- Available to use not counting toward your budget:
  - Your 201 electronics kit (purchased by the students)
  - Computer & software
  - Oscilloscope and power supply
  - Mechanical testing machine
  - Miscellaneous lab equipment in the tissue engineering and design teaching labs
- Counts toward your budget
  - Bioreactor jar
  - Heating mechanism (you will design the circuit and interface to control this)
  - Sample holder raw materials (you will design and fabricate this)
  - Synthetic bone raw material (you will design, research a protocol and fabricate it)
  - Buffer solution (you will make this)
  - Additional electronics

## BME 201 (2017)