BIOEN 402 SYLLABUS FOR 2018-19

Course Title: BIOEN 402 – Bioengineering Capstone Design Project

Instructors: C. M. Neils, A. C. Taylor, and Bioengineering faculty. Each student registers with an individual Bioengineering faculty advisor. Instructors supervise writing progress, student presentations, and individual issues that may arise.

Credits: 9 total, divided among 2-4 consecutive quarters, with 2-6 credits per quarter.

UW General Catalog Course Description: Independent senior design project. Prerequisite: BIOEN 401.

Course Description:
BIOEN 402 places seniors in Bioengineering faculty laboratories to conduct individual design projects related to real medical problems. Students may initiate projects or choose projects suggested by the faculty host. A senior project may be part of a larger project, but it must have definable design goals and be sufficiently novel that its successful completion would merit publication in a science or engineering journal. The design content should be consistent with the ASEE white paper, *Design versus Research: ABET Requirements for Design*.[1]

During the project, seniors are members of a laboratory group, attending group meetings and sharing lab maintenance duties in addition to planning and executing the senior project. In larger lab groups, seniors are typically assigned a graduate student or post-doctoral fellow as mentor.

Students register for 9 credits, divided among 2-4 sequential quarters with 2-6 credits per quarter. Autumn quarter typically includes planning, equipment acquisition, and training, winter quarter includes fabrication and/or experimentation, and spring quarter emphasizes analysis and reporting. This schedule is flexible to accommodate students' progress and graduation plans. The grade for all quarters of BIOEN 402 is determined upon completion of the course, the project, and a formal report. Details of capstone grading are provided in the appendix.

Each student will choose a host lab before starting BIOEN 401 in spring of the junior year, and must select a project topic early in BIOEN 401. The BIOEN 402 project proposal is developed during BIOEN 401, and the nature of the project and plan to fulfill the design requirements are examined by the BIOEN 401 teaching team and faculty advisor. Review in BIOEN 401 confirms that each project will be a culminating Bioengineering design experience, recommending changes as necessary.

Additional details about the capstone procedures may be found in the capstone help file: http://depts.washington.edu/bioe/academic-programs/undergraduate/capstone-help-file/

Prerequisites by Topic: Bioengineering Capstone Proposal (BIOEN 401), biology, chemistry/biochemistry, probability and statistics for scientists and engineers.

Textbooks: None

Course Objectives:

Allow students to observe and practice the detailed tasks needed to plan and conduct Bioengineering projects and to maintain an R & D lab. Provide independent bioengineering design experience with educational support and advice. Promote the transition from student to engineer by assigning professional responsibilities. Provide experience working in a group. Provide practice writing and revising a thesis.

Topics Covered (mainly by experience in your lab groups):

Design of experiments, tools, and devices. Engineering and experimental standards. Statistical basis for the design and analysis of experiments. Composition of design project reports. Podium and poster presentations. Specialized topics and techniques as appropriate. Intellectual property, regulatory issues, and R & D funding.

Class Schedule:

Students work in lab on a schedule agreed between each advisor and student (8-24 hours/week). All students convene one hour per week to discuss their progress and course requirements.

Course Outcomes and Assessment:

Students' success in BIOEN 402 depends on their ability to perform the tasks described below, and to synthesize these tasks into a coherent effort. Individual students are assessed by their senior project advisor(s), with contributions from the course instructors; details are provided in the "Grading summary" section below. In addition, the course itself is reviewed annually by a committee of faculty who review the outcomes data from advisors.

All BIOEN 402 students are expected to complete various assignments designed to keep students on track with their projects, including draft Capstone reports, literature review assignments, and mandatory advisor check-ins.

All BIOEN 402 students are encouraged to give a public presentation, i.e. one to which the university community is invited. The Mary Gates Symposium is a good opportunity, and participation in the annual Bioengineering Capstone Design Symposium is expected. Students are also encouraged to prepare a poster for review and feedback from the advisor and instructors.

Students are graded on their ability to engage in the following eight activities, as demonstrated by their final report and their performance in lab and quantified in the attached grading rubrics.

ABET student learning outcomes, which apply to all students and projects:

A1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

A2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors

A3. an ability to communicate effectively with a range of audiences

A4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts

A5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
A6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
A7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

BioE-specific program criteria: All Capstone projects address criteria W and Y. Given the real-world relevance and wide variety of project topics, any given Capstone project will emphasize some subset of the topics listed below.

W. apply principles of engineering, biology, human physiology, chemistry, calculus-based physics, mathematics (through differential equations), and statistics
X. Solve bio/biomedical engineering problems, including those associated with the interaction between living and non-living systems
Y. Analyze, model, design, and realize bio/biomedical engineering devices, systems, components, or processes
Z. Make measurements on and interpret data from living systems

Relationship of course to Departmental Objectives:

This course allows students to apply the Bioengineering fundamentals they have learned, and to learn advanced topics and techniques, in a manner consistent with graduate and professional training in medicine and biology. The student projects are typically part of externally funded programs, and therefore address immediate or long-term issues that are of considerable importance to human health. Students may encounter problems that require knowledge from any or all of their prior courses and that may require them to master concepts and techniques that they have not previously explored. Students must communicate their progress to their advisors, collaborators, and peers, who may encompass a broad range of academic and professional backgrounds.

The Department of Bioengineering has a goal of preparing our undergraduates to achieve a specific set of career objectives, which are listed below. Although not all of our students will pursue all of these objectives, every student should gain the educational foundation to do so. BIOEN 402 contributes to this foundation by requiring students to manage a real-world research and design project independently, while working as part of a larger group in a workplace setting. They develop lab citizenship skills, technical expertise, and engineering design knowledge. They build upon the technical knowledge and analytical skills developed in prior coursework, and communication and team-working skills developed in previous class projects. Together, this experience in project management, working in a team in a lab setting, and communicating their ideas to their peers and supervisors prepares them for long-term leadership roles. Students also gain key professional and research skills that they will need to obtain near-term employment in bioengineering-related fields. Students help develop new knowledge for their lab and, in many cases, use this knowledge in grant applications, publications, patents, etc. As such, the BIOEN 402 capstone experience gives students many tools needed to reach the program educational objectives of the Bioengineering undergraduate program:

• Earn advanced degrees and/or obtain employment in bioengineering-related fields, such as medicine, device development, or biotechnology.

• Advance their careers by obtaining appropriate educational and professional qualifications.

• Serve their profession and community.

• Contribute to responsible development of new technical knowledge.

• Take leadership roles as individuals or in teams to address domestic or global bioengineering-related issues.

References:

(1) Gassert, J., Enderle, J.D., Lerner, A., Richerson, S. and Katona, P., Design versus Research; ABET Requirements for Design and Why Research Cannot Substitute for Design, *Proceedings of the ASEE Annual Conference and Exposition,* June 18-21, 2006, Chicago, Illinois, Session 2006-1139.
Accessed September 14, 2009, http://soa.asee.org/paper/conference/paper-view.cfm?id=1341
Also available via http://depts.washington.edu/bioe/about/about_accreditation.html#design.

Grading Summary

BIOEN 402 is a hyphenated course, meaning that no letter/number grade is assigned until the last course of the sequence is complete. Earlier quarters receive an N grade, which are back-filled upon assignment of the final numerical grade.

BIOEN 402 is graded on the following items:

- Quality and quantity of work in lab 40%
- In-class contributions and assignments 10%
- Final project report 50%

Progress Reports

At the end of each of the first two quarters, the primary adviser should meet with the student to provide a performance review and hypothetical numerical grade for the "Quality and quantity" portion of the course evaluation. When the numerical grade is calculated for the final quarter, the "Quality and quantity" portion should be consistent with the performance reviews reports from the previous quarters. This policy is intended to increase students' motivation to improve when necessary, and to give them a more accurate prediction of their final capstone grade.

In-class contribution and assignments – 10%

BIOEN 402 students are required to submit drafts of their capstone reports during each of the first two quarters of the project. Students are expected to participate in the classroom meetings and complete various assignments throughout the year designed to facilitate the drafting and improvement of report drafts. In addition, students should meet with their advisors at least quarterly to solicit feedback on their performance, and the results of those check-ins must be reported to the BIOEN 402 classroom instructors. The classroom instructors will report a score for in-class contribution to the capstone advisors for inclusion in the overall course grade.

Quality and quantity of work in lab – 40%

The capstone advisor(s) have the flexibility to judge – as objectively as possible – the performance of the student on a day-to-day basis. This judgment should consider progress on the project itself, as well as the student's ability to function effectively as a member of a research lab group. Specific items to be considered include planning tasks, record keeping, adherence to safety guidelines, following experimental procedures and good lab practice, communication with advisors and group members, follow-through on agreements, and time spent on the project or in lab.

Table 1 provides a rubric for evaluating a student's performance on the practical aspects of conducting the design project.

Table 1. Each BS BIOE graduate will conduct a design **project** that shows his/her ability to…

ABET Outcome	Ability	4 Exemplary	3 Proficient	2 Apprentice	1 Novice	Score
A1	**Identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics:** Recognize need in medical or bioscience community; evaluate its relative and absolute importance; cast need as engineering challenge; demonstrate device or process that addresses the problem.	Medical or scientific need is clearly understood as student tells mentors how results and next steps related to scientific or medical need; current costs (health, economic, social, etc.) were used to justify project; device or process was shown to be an effective solution, or student clearly understood the outcome of efficacy testing.	Medical or scientific need is understood; current costs (health, economic, social, etc.) were considered; problem was cast as engineering challenge; device or process was shown to be an effective solution, or student at least understood the effectiveness of the attempted solutions.	Student understands how results and next steps relate to medical or scientific need only when told; current costs were considered; engineering design may be inappropriate for challenge; demonstrated some understanding of the effectiveness (or lack thereof) of attempted solution.	Student did not show understanding of need for project, problem was not addressable by engineering solutions, and/or the student did not understand clearly why the attempted solution did not satisfy the stated needs.	
A2	**Apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors:** Apply design plans developed in BIOEN 401 while considering multiple design options and realistic constraints (such as cultural, social, economic, and engineering standards); modify and improve the design based on experimental results to meet specified needs (iterate on design); consider risks and trade-offs during design process.	Realistic design constraints, including appropriate engineering and experimental standards, were considered thoroughly during the design process. Student completely considered public health, safety, and welfare, global, cultural, social, environmental and economic factors and thoughtfully incorporated the relevant factors into design decisions. Risks were considered and thoughtful trade-offs were made during design process. Design adaptations based on acquired results were considered to better adapt the design to the desired needs. More than one option was considered and tested and the best option was utilized.	Multiple realistic constraints (including any relevant engineering standards) were identified and incorporated into the design process. Student considered public health, safety, and welfare, global, cultural, social, environmental and economic factors and incorporated the relevant factors into design decisions. Satisfactory consideration of risk throughout design process. Design adaptations based on acquired results were considered to better adapt the design to the desired needs. At least one design adaptation (based on acquired results) was considered and tested.	Realistic constraints were integrated into the design process but some obvious ones may be missing. Student considered and incorporated public health, safety, and welfare, and global, cultural, social, environmental and economic factors only to a marginal degree. Some risks relevant to the project were considered and addressed, but this may be incomplete. One design adaptation based on acquired results was considered but not tested.	Failure to identify and/or incorporate relevant realistic constraints into design process. Student did not consider public health, safety, and welfare, nor global, cultural, social, environmental and economic factors and/or failed to incorporate those relevant factors into design decisions. Student does not display consideration of risk during design project. Original design followed without considering modifications.	

A3	**Communicate effectively with a range of audiences:** Maintain active, effective communication with lab members and advisors. Scheduling and form of communication depends on the lab group and agreements with the advisor.	Student maintained frequent, productive communication with lab members and advisor. Provided high-quality written reports, symposia presentations, or lab group presentations. Could be counted on to communicate professionally with outside collaborators.	Student maintained adequate, communication with lab members and advisor. Provided written reports on time and was prepared for group meetings. Could be counted on to communicate effectively with outside collaborators and deliver clear, effective presentations.	Student maintained intermittent, communication when required. Written reports were submitted eventually, and participation in group meetings was minimal. Advisor needs to oversee communication with collaborators. Clarity of oral presentations may be lacking.	Student seldom responds to email, Attendance at group meetings was minimal. Advisor reluctant to let student communicate with collaborators. Oral presentations need work.	
A4	**Recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts:** Display knowledge of ethical and professional responsibilities surrounding the design, such as regulatory matters including standards, and environmental, social, legal, ethical, geopolitical consequences. Describe impact of solution in global, economic, environmental, and societal contexts.	Displays knowledge of ethical and professional responsibilities surrounding the design, such as regulatory matters including standards, and environmental, social, legal, ethical, geopolitical consequences and uses that knowledge to make informed judgements during the design process. Can describe impact of solution in global, economic, environmental, and societal contexts.	Identifies a number of important global, economic, environmental, and societal considerations relevant to project and utilizes knowledge to make informed design judgements; identifies regulatory matters including current relevant standards; may include limited discussion of each category, including present ramifications.	Identifies only a few of the obvious global, economic, environmental, and societal considerations surrounding the engineering design solution, with shallow discussion of the ramifications.	Identifies only a few of the obvious global, economic, environmental, and societal considerations surrounding the engineering design solution, with no discussion of the ramifications.	
A5	**Function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives:** Function effectively as a member of a research team as defined by the PI, through behaviors such as integrating lab resources, objectives, and expectations into project planning and execution. Solicit and integrate feedback from mentors.	Student actively and obviously worked to understand and execute the team-working and leadership expectations set by the PI. Student was effective at working with their team to establish project goals, plan tasks, and meet objectives. Student was proactive about soliciting feedback from mentors and always followed through in incorporating that feedback. Student consistently contributed to a collaborative and inclusive research environment.	Student worked to understand and execute the team-working and leadership expectations set by the PI. Student was effective at working with their team to establish project goals, plan tasks, and meet objectives. Student solicited feedback from mentors and usually followed through in incorporating that feedback. Student usually contributed to a collaborative and inclusive research environment.	Student exhibited developing team-working abilities and may have not met the expectations set by the PI. Student was somewhat effective at working with their team to establish project goals, plan tasks, and meet objectives but may have needed more guidance and prompting than expected. Student did not solicit feedback from mentors during the Capstone process, and/or failed to incorporate that feedback. Student did not usually contribute to a collaborative and inclusive environment.	Student's team-working abilities were not effective. Student did not exhibit behaviors set by lab norms. Student did not ask for feedback and did not work effectively with research team to establish project goals, plan tasks, and/or meet objectives. Student may have been incommunicative or inaccessible, and did not contribute to a collaborative and inclusive environment.	

A6	**Develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions**: Utilize BioE skills to test experimental hypotheses or prototypes from design plans developed in BIOEN 401; correctly analyze results; compile/interpret results in a permanent record such as lab notebook or written reports.	Appropriate analytical methods were selected and correctly implemented and interpreted. Quality laboratory conduct was followed including: results compiled in a professional manner in lab notebook or written reports. Exhibits independence in selecting next steps.	Analytical methods were appropriately designed and correctly implemented and interpreted. Basic laboratory conduct was followed including lab notebook, detailed notes or written reports.	Analytical methods were appropriate, but implementation and/or interpretation may be questionable. Basic laboratory conduct was followed including lab notebook or detailed notes and reports.	Analytical tools applied were inappropriate and/or not implemented correctly. Basic laboratory conduct was only partially followed (inadequate details in lab notebook or infrequent reports).	
A7	**Acquire and apply new knowledge as needed, using appropriate learning strategies:** Shows an ability to keep up with continuous progress in the field during project. See note (1) below.	Current literature is monitored. Key advances relevant to the project are identified and considered as motivation for changes in the project. Student welcomes opportunities to attend conferences, if available.	Literature is monitored, and key advances relevant to the project are identified but impact on project may not be recognized.	Student reads relevant current literature when its existence is pointed out by mentors. Student is not interested in interpersonal communication as means to advance knowledge.	Either ability or motivation to engage with current literature is lacking. Never discusses literature with mentors.	
Apply math (Program Criterion W)	**Apply mathematics (including statistics) and engineering to solve bio/biomedical engineering problems.** Preparation on this topic via Capstone should emphasize statistical analysis when appropriate to support conclusions.	Masters appropriate mathematical techniques or extended math capabilities appropriate for undergraduate curriculum; addresses each hypothesis posed in experimental design; performs statistical analysis using appropriate methods, large sample sizes and thorough control experiments.	Correctly applies undergraduate-level engineering mathematics in theoretical analysis; addresses hypotheses posed in experimental design; performs statistical analysis to assess statistical significance of conclusions, with appropriate methods, adequate sample sizes and some control experiments.	Applies basic mathematics to theoretical analysis; performs statistical analysis to assess statistical significance of conclusions, but may use inappropriate methods, analysis may be insufficient or has errors	Incorrectly applies engineering mathematics; does not quantitatively address hypotheses posed in experimental design.	

(1) Assessing the ability to **acquire and apply new knowledge as needed, using appropriate learning strategies**: Students should be able to relate: A brief history of their technical field, starting from a point that predates their advisors' entry into the field; Recent and ongoing advances in the field, especially those that change the goals, methods, and analysis of their projects; A set of new skills or knowledge that must be learned before the next major step in this project or research can be taken. Suggested criteria for assessing a student's ability to acquire and apply new knowledge, using appropriate learning strategies are: An ability to gain access to available academic resources and to navigate them to obtain information needed for the project – including texts, specialized periodicals, and technical databases; An ability to seek out and communicate with persons who possess knowledge that cannot be learned effectively from impersonal means; An ability to assimilate newly acquired knowledge into one's existing understanding of technology; An ability to assess which endeavors are worthy of pursuit, in order to apply time and energy effectively.

BIOEN 402 Project Report – 50%

The final report should be a polished narrative that includes all the content listed in the bullet points below. We recommend organizing the content into the sections listed below. If you advisor has specific instructions for the formatting, you may modify our suggested format, as long as the *content* is still included in the report*.

Recommended format is 11-point Cambria or similar font, single line spaced, with 1-inch margins. The page number guidelines below are not meant to be prescriptive, only a rough estimate. All writing is to be in formal technical English, using EndNote or equivalent for references (with appropriate in-text citations).

1. Title Page (1 page)

- Student Name
- Advisor Info
- Date
- Abstract (~250 words)

2. Introduction (Motivation for the project, based on in-depth literature analysis; 2 to 5 pages)

- Significance of the biomedical need
- Scientific and medical knowledge relevant to the design solution
- Current technology used to solve the problem, including relevant unpublished work in the advisor's laboratory if appropriate.
- Shortcomings of the current technology
- Description of any scientific knowledge gaps that would have to be closed to design an effective solution
- The narrative should highlight the most important considerations addressed in the "Development of Design Specifications" section
- Overview of design solution (1 paragraph)

3. Development of Design Specifications (Analysis of needs and constraints that design should meet; 3 to 4 pages)

- Analysis of desired needs and technical functionality
- Analysis of constraints imposed by technology to be used or developed for the design solutions
- Analysis of constraints imposed by engineering standards related to design project.
- Analysis of which of the following considerations are relevant to the project: public health, safety, and welfare, global, cultural, social, environmental, and economic factors. *Report must address each of these.*
- Analysis of any additional realistic constraints (such as those imposed by accessibility, aesthetics, codes, constructability, cost, ergonomics, extensibility, functionality, interoperability, legal considerations, maintainability, manufacturability, marketability, policy, regulations, schedule, standards, sustainability, or usability) considered during engineering design process *Report may include only those which are relevant to project*
- Table of design specifications based on the analysis in this section.

4. Materials and Methods (Used to develop, test, or apply the design; 1 to 5 pages)

- Statistical basis for design of experiments
- Theoretical, Computational or Experimental methods used to test design iterations
- Methods and materials used to acquire scientific data associated with the project

5. Results (Documentation of engineering design process, including any tests that show the use of the final design; 5 to 15 pages)

- For *each* iteration of design components or overall prototypes:
    - Describe the design and implementation
    - Describe the theoretical, experimental and/or testing data that informed subsequent iterations
    - Design analysis leading to the next iteration
- Include figures with complete captions to illustrate designs or testing data
- Discuss what risks were considered during the design process, and trade-offs made
- Discuss any novel scientific knowledge that you discovered during the work in the laboratory

6. Discussion (Analysis of achievement of outcomes; 2 to 3 pages)

- Explain the significance of scientific knowledge acquired during the project
- Analyze the final design in relationship to all of the identified design specifications
- Relate significance of final design to the biomedical need
- Describe impact of engineering solution in global, economic, environmental, and societal contexts
- Suggestions for future work

7. Acknowledgements

- Recognition of all others who gave significant guidance, technical assistance or financial support in the performance of the project, and of those personnel whose work immediately preceded your own in your laboratory.

8. References

- All factual statements that cannot be found in an undergraduate textbook and are not your own work should be properly cited.
- References on work most related to your own, whether from other laboratories or your own, should be addressed in the report and therefore cited.

9. Appendices (optional)

Data, programs, CAD files, etc., in electronic form made available on a web site, or supplemental materials such as additional figures.

*For example, if a research advisor requests that your report be in the format of a journal article: this format is intended to meet this requirement if you move section 3 (“Development of Design Specifications”) and some or all of the unsuccessful iterations in section 5 (“Results”) to appendices.

Final Report Submission

The report is to be submitted to the primary advisor and any co-advisor(s) in whichever form (paper or electronic) the adviser requests. The official due date is the last day of classes during the quarter in which the 9th credit of BIOEN 402 is taken. The report should also be submitted to the academic counselor and Capstone instructors as a PDF or Word document, via Canvas.

Final Report Grading

The final report is to be graded by the primary advisor. Grading of the report should be based on the criteria in Table 2. The grade should be submitted by the advisor with whom the student is officially registered, who might not be the primary advisor in cases where the primary advisor is not core or adjunct BioE faculty.

Table 2. **Report** grading rubric

ABET Outcome	Ability	4 Exemplary	3 Proficient	2 Apprentice	1 Novice	Score
A1	**Identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics:** Identify and formulate a problem in the medical or bioscience community; evaluate its relative and absolute importance; cast need as engineering challenge; demonstrate device or process that addresses the problem.	Medical or scientific need is clearly explained; current costs (health, economic, social, etc.) are used to justify project; problem is cast as engineering challenge; device or process is shown to be an effective solution to the need.	Medical or scientific need is stated; current costs (health, economic, social, etc.) are mentioned but may not be fully explained; problem is cast as engineering challenge; device or process is shown to meet project goals but may not be related to original need.	Medical or scientific need is stated; some current costs are mentioned; engineering design may be inappropriate for challenge; device or process is implemented but is only partially effective or is not related to project goals.	Need is not clear, problem is not addressable by engineering solutions, and/or the project does not satisfy the stated needs.	
A2	**Apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors:** Apply design plans developed in BIOEN 401 while considering multiple design options and realistic constraints (such as cultural, social, economic, and engineering standards); modify and improve the design based on experimental results to meet specified needs (iterate on design); consider risks and trade-offs during design process	Report describes how the design incorporated multiple realistic constraints and was adapted to meet desired outcome, based on acquired results. Report discusses engineering standards relevant to project and when applicable, describes how the relevant engineering standards were incorporated into design decisions. Report thoroughly analyzes public health, safety, and welfare, global, cultural, social, environmental and economic factors and includes the relevant factors in design specifications. Describes multiple options, test results, and choice of final option. Report thoroughly describes risks considered and trade-offs made during design process.	Report describes how the design incorporated multiple realistic constraints, including appropriate engineering standards, and how the design was adapted to meet the desired outcome, based on acquired results. Report satisfactorily analyzes public health, safety, and welfare, global, cultural, social, environmental and economic factors and includes the relevant factors in design specifications. Describes at least one option, test results, and choice of final option. Risks and trade-offs were made but could be more thoroughly discussed.	Report describes how the design incorporated some realistic constraints but other relevant constraints were not considered. Report analyzes public health, safety, and welfare, global, cultural, social, environmental and economic factors and includes some relevant factors in design specifications, but analysis and incorporation of relevant factors may be incomplete. Report describes how the design was adapted to meet desired outcome. One option is considered but not tested. Obvious risks involved in the design may not be described.	Report does not describe the consideration of realistic constraints during the design process or risks and trade-offs involved in the design process. Report does not discuss any consideration of design modifications. Report does not identify relevant engineering standards. Report does not include analysis of public health, safety, and welfare, global, cultural, social, environmental and economic factors related to the project, and does not include the relevant factors in design specifications.	

A3	**Communicate effectively:** Prepare detailed written report that addresses engineering design, economic, and societal issues as shown in report outline.	Written report is well-written and concise, virtually error-free, and logically presents project. Report is well-organized and easy to understand, and contains high quality data/graphics.	Report is overall logically presented, well-organized, contains high quality data & graphics, with few minor grammatical or rhetorical errors. Everything is understandable, but may require extra time and effort to read because text or figures are not concise or lack summarizing text.	Report is acceptably written but contains grammatical, rhetorical and/or organizational errors; project is not well explained and not fully discussed. Report may be hard to follow.	Does not present project clearly, is poorly organized and/or contains major grammatical and/or rhetorical errors. One or more key points of the report cannot be understood.	
A4	**Recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts:** Display knowledge of ethical and professional responsibilities surrounding the design, such as regulatory matters including standards, and environmental, social, legal, ethical, and public health, safety, and welfare considerations. Describe impact of solution in global, economic, environmental, and societal contexts.	Report thoroughly identifies ethical and professional responsibilities surrounding the design, such as regulatory matters including standards, and environmental, social, legal, ethical, and public health, safety, and welfare considerations. Analysis of these factors was used to make informed judgements during the design process (i.e. generation of design specifications). Thoughtfully and completely describes impact of engineering solution in global, economic, environmental, and societal contexts.	Report identifies a satisfactory number of ethical and professional responsibilities surrounding the design, such as regulatory matters including standards, and environmental, social, legal, ethical, and public health, safety, and welfare considerations. Analysis of these factors was used to make informed judgements during the design process (i.e. generation of design specifications). Describes impact of engineering solution in each of the following contexts: global, economic, environmental, and societal.	Report identifies only a few of ethical and professional responsibilities surrounding the design, such as regulatory matters including standards, and environmental, social, legal, ethical, and public health, safety, and welfare considerations. Report is unclear as to how analysis of these factors was used to make informed judgements during the design process (i.e. generation of design specifications). Incomplete description of the impact of engineering solution in global, economic, environmental, and societal contexts.	Report identifies only a few of the most obvious ethical and professional responsibilities surrounding the design, such as regulatory matters including standards, and environmental, social, legal, ethical, and public health, safety, and welfare considerations. Report is unclear as to how analysis of these factors was used to make informed judgements during the design process (i.e. generation of design specifications). Description of the impact of engineering solution in global, economic, environmental, and societal contexts is cursory or missing completely.	
A6	**Develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions**: Utilize BioE skills to test experimental hypotheses or prototypes from design plans developed in BIOEN 401; correctly analyze results; provide compilation and interpretation of results in written report.	Analysis is complete, correct and conclusions are consistent with results. Appropriate analytical methods are selected and correctly implemented. Report logically explains motivation for well-designed experiments, and how the results address hypotheses and designs.	Analysis is complete but contains 1 or 2 minor errors. Analytical methods are appropriate and correctly implemented. Logically explains motivation for experiments, and how the results address hypotheses and designs, but with some logical flaws.	Analysis is overall satisfactory, but contains 1 or more conceptual and/or procedural errors. Experiments are appropriate to the problem, but may not be correctly designed, implemented, or interpreted.	Analysis contains major conceptual and/or procedural errors. Experiments are inappropriately selected and/or not designed and implemented correctly. Conclusions not supported by appropriate experimentation or interpretation of data.	

A7	**Acquire and apply new knowledge as needed, using appropriate learning strategies**: Show/describe the continuous progress in the field prior to and during Capstone project via literature search and analysis.	Current and seminal literature is discussed and interpreted in relation to the significance and novelty of the project; key advances relevant to the project are identified. Proper referencing shows that the literature was thoroughly searched and analyzed.	The number and quality of citations indicates a thorough literature search. Literature is discussed in relation to the project but interpretation may not be sufficiently logical or may not completely address significance and novelty of project. Sources are cited throughout paper where needed.	The current literature is mentioned/listed, indicating an adequate literature search but key literature is missing. Information sources are cited throughout paper where required.	Number and brevity of citations indicates only a minimal literature search. Statements are made without citing information source.	
Apply Math (Program Criterion W)	**Apply mathematics (including statistics) and engineering to solve bio/biomedical engineering problems.** Preparation on this topic via Capstone should emphasize statistical analysis when appropriate to support conclusions.	Masters appropriate mathematical techniques during quantitative analysis and planning of work; addresses each hypothesis posed in experimental design; performs statistical analysis using appropriate methods and describes why the methods are appropriate for the problem, includes adequate sample sizes and thorough control experiments.	Correctly applies undergraduate-level engineering mathematics in analysis and planning of work; addresses hypotheses posed in experimental design; performs statistical analysis to assess statistical significance of conclusions, with appropriate methods, adequate sample sizes and some control experiments.	Applies basic mathematics to theoretical analysis; performs statistical analysis to assess statistical significance of conclusions, but may use inappropriate methods, analysis may be insufficient or has errors	Incorrectly applies engineering mathematics; does not quantitatively address hypotheses posed in experimental design.	