AC 2012-5475: DEVELOPMENT OF AN INTEGRATIVE BIOMECHANICS COURSE FOR STEM MAJORS

Dr. Yogendra M. Panta, Youngstown State University

Yogen Panta is an Assistant Professor of mechanical rngineering at Youngstown State University, Ohio. He has been teaching and developing courses and research projects in the fluid thermal area. He is currently conducting applied research in thermo-fluids and computational fluid dynamics with local industries and federal agencies. Panta received a B.E. degree from Tribhuvan University, an M.S. degree from Youngstown State University, and a Ph.D. degree from the University of Nevada Las Vegas. Panta's research interests are in fluid dynamics, computational fluid dynamics (CFD), microfluidics/lab-on-chip, and energy research.

Dr. Michael T. Butcher, Youngstown State University

Michael Butcher is an Assistant Professor in biological sciences in the College of STEM at Youngstown State University. Butcher received his Ph.D. in zoology with a specialization in muscle biomechanics from the University of Calgary in Alberta, Canada. Butcher runs and active laboratory at YSU where he focuses on thee areas of comparative biomechanical research: evolution of bone loading and integrated hindlimb muscle-bone function, muscle architectural properties and function is digging lineages, and myosin heavy chain isoform expression and caudal muscle function in the prehensile tails of didelphid marsupials.

Development of an Integrative Biomechanics Course for STEM Majors

Abstract

Initiatives aimed at creating and offering specialized courses for STEM (Science, technology, Engineering and Mathematics) majors are generally not supported at Predominately Undergraduate Institutions (PUI). However, it is imperative that our future scientists have opportunities to experience a broad and integrative scientific education. In the growing STEM environment at various universities around the globe, an interdisciplinary course attracts students from a number of STEM disciplines, offers cross-disciplinary innovative features, and provides training to prepare students for the demands of modern science and biomaterials technology. This paper details about developing and implementing an integrative biomechanics course for STEM majors. The aim of the proposed course is to provide students with an understanding of basic structure/function relationships of biological tissues and systems, mechanical principles governing animal locomotion, and mechanics of biofluids by engaging students with hands-on experiences in computational, demonstrational, and experimental laboratories. This innovative and interdisciplinary course is expected to broaden the experience of our STEM majors towards successful careers in STEM related fields. STEM students can also be engaged in peer mentoring and learning from each other. For example, engineering students may facilitate biological sciences students learning about mechanical principles of solids and fluids, while biological sciences students may facilitate engineering students learning about anatomical features of animal tissues and systems. Integrative courses broaden the educational experiences of STEM majors, and may serve as a general model for developing interdisciplinary STEM curricula at PUIs. Assessment for the course at instructor, institutional and external levels is to be conducted with respect to student learning objectives (SLO) through both formative and summative evaluations.

1. Introduction

A general model of interdisciplinary Science, Technology, Engineering, and Mathematics (STEM) education is proposed by involving engineering and biological sciences students and faculty in collaborative teaching and research. This objective will be accomplished primarily by developing an integrative course in “Biomechanics and Biotransport” that incorporates computational, demonstrational, and experimental laboratories and secondarily, by involving students in sustained semester research projects. Students will first study the fundamental principles of Biomaterials involved in biological systems through a prerequisite introductory course, “Mechanical Properties of Biological Tissues”. Next in a sequence the proposed “Integrative Biomechanics and Biotransport” course comprises (i) biomechanics of solids that includes static and dynamic force and moment analyses as applied to the musculoskeletal system during locomotion, (ii) mechanics of deformable bodies as applied to biological tissues, and (iii) biofluids encompassing kinematics of fluid flow and its application to blood flow in the body, including analyses of low Reynolds number flows *in vivo* and microsystems applications. Students will then conduct a research project during the semester and finally prepare their results for presentations at university sponsored scientific meetings.

2. Goals of the Proposed Course

Specific goals for the proposed *Integrative Biomechanics and Biotransport* course are to:

1. *Provide a* ***general model for interdisciplinary STEM education*** by:
   - creating a peer-mentoring program between faculty and students in different STEM disciplines.
   - implementing rigorous assessment and survey tools to evaluate the success of the course during and after course activities.
2. *Enhance* ***knowledge of Biomechanics and Biotransport*** for faculty by:
   - preparation of lectures, laboratories and student research presentations.
   - modifying existing STEM curriculum based on the need of the course.
3. *Develop and* ***implement a course and curriculum changes*** *to encourage Biomaterials as a minor program of study* by:
   - developing a specialized course, *Integrative Biomechanics and Biotransport* course.
   - developing strong communication between faculty and students.
4. *Engage students in* ***scientific research*** *and build* ***interdisciplinary collaborations*** *in the STEM College* by:
   - selecting and teaming STEM majors on a semester research project that will involve organizing regular discussion and problem solving sessions.
   - creating semester research projects to provide an understanding of technologies used for conducting research that may lead to presentations at scientific conferences and manuscript preparation.

3. Overview of the Proposed Course

Teaching and recruiting students for interdisciplinary science courses can be challenging. Knowledge and skills involved with integrative disciplines such as “Biomechanics and Biotransport” is achieved only from experience gained through sustained effort and improved understanding. We propose to train STEM majors for scientific careers by an offering of an interdisciplinary course in “Biomechanics and Biotransport”, and envision this course as a means to recruit high caliber STEM students. An introductory course, *Mechanical Properties of Biological Tissues,* or similar course may serve as a prerequisite course to provide STEM students with knowledge of the fundamental principles of Biomaterials. Upon successful completion of the introductory course will prepare students for a course in “Biomechanics and Biotransport”.

Integrative Biomechanics and Biotransport. This course outlines structure/function of vertebrate musculoskeletal systems, mechanical principles that govern movement, and fundamental principles of fluid mechanics with applications to physiology (e.g., blood flow) and locomotion (e.g., flying, swimming). The laboratory portion of the course will involve demonstration of basic principles and technologies, along with experimental and modeling techniques commonly used in biomechanical research. These will include but are not limited to: muscle properties (i.e., architecture and fiber type), kinetics and kinematics of animal locomotion, *in vivo* bone strain, muscle activation and recruitment (electromyography: EMG), modeling of fluid flow in biological systems, fluid forces in aquatic locomotion, and properties of flow pertaining to the human body (e.g., blood flow velocity profiles, blood vessel geometries). Semester research projects designed by students groups will be a major requirement of the course outlined in the syllabus. Groups will work closely with faculty to outline their research projects, test hypotheses and interpret results. Students will make presentations of their original research at the end of the semester in the form of a scientific poster. Students will also be expected to give presentations of their research projects at a regional scientific conference organized by the scientific communities between universities. Student projects may also be presented at the annual meeting of reputable scientific societies including: Biomedical Engineering Society (BMES), American Society of Engineering Education (ASEE), American Society of Mechanical Engineers (ASME), Society of Biomaterials (SBM), American Society of Biomechanics (ASB), and the Society for Integrative and Comparative Biological Sciences (SICB).

Student Recruitment. Any STEM major who has completed the prerequisite courses is eligible to take the course. Since 1999, national Biomedical Engineering graduate rates have increased by 187%, and this statistic includes graduation of the highest percentage of females at 40.7% compared with all other engineering fields (< 20%) [1,2]. In addition, successful STEM programs diversify their graduates by engaging them in peer mentoring and integrative research experiences [3, 4].

Interdisciplinary Education in a growing STEM College. One of the major expectations of the College of STEM is to promote innovative collaborations between faculty and students in the natural sciences and applied sciences. The desired goal is the creation of a new synergistic environment leading to more integrative curricula and academic activities that will keep pace with an ever-changing world. As a PUI, interdisciplinary initiatives such as one aimed at developing interdisciplinary courses for STEM majors have not historically been supported because of limited resources, and lack of laboratory facilities and faculty. At such institutions, biological sciences majors are limited to interdisciplinary study within the natural sciences. Similarly, engineering majors are limited to interdisciplinary study within only engineering disciplines. However, it is imperative that our future scientists experience a broad and integrative scientific education. In the STEM environment, collaborative courses that draw students from a number of STEM disciplines, are innovative and provide training to prepare students for the demands of modern science and technology. Moreover, the proposed *Integrative Biomechanics and Biotransport* course may serve as a simple model for developing an interdisciplinary curriculum among STEM disciplines, and more specifically at any PUI that has limited resources, but a strong commitment from faculty.

Interdisciplinary Education for the Student. The need for innovative approaches in the education of scientists in training has been the focus of numerous studies by federal, state and private agencies and institutions. One of the ideas that emerged is the recognition that all advancing science and technological fields are becoming more interdependent on one another[5]. In describing new types of curricula for undergraduate Biological Sciences programs, the National Academies of Science refers to the need for biological sciences majors to be exposed to engineering (mechanical) concepts and their application to biological systems[6]. It is imperative then to develop and implement interdisciplinary courses, programs and experiences for all majors in the STEM disciplines. As an example, the National Council of Examiners for Engineering and Surveying has recently added a new section - Biological Sciences - to the general engineering section of the Fundamentals of Engineering (FE) exam. This was prompted by the fact that virtually all engineering disciplines now encompass a biological component. Productive interaction between both groups takes time to develop and involves the assimilation of different intellectual cultures. Students that are integrated with students from other science fields early in their careers will have the advantage of already starting the process of assimilation[7].

4. Description of the Proposed Course

Course Design. The course is developed for the second semester junior/first or second semester senior level student. The prerequisite for the proposed course is *Mechanical Properties of Biological Tissues*. The course is structured in a traditional way, but with several novelties. It will entail three 1-hour lectures, and one 3-hour lab per week that presents the concepts and applications of integrative biomechanics and biotransport. There will be three sections to the lecture; first will review applied kinetics and kinematics, the second will study the functional anatomy of animal systems and terrestrial locomotor mechanics, and the third will review fundamentals of fluid mechanics as applied to diverse modes of locomotion such as swimming and flying, and human physiological systems. The laboratory exercises will be closely matched to weekly lecture material and will engage students by teaching students how the concepts learned in lecture and laboratory are applied in biomechanical research (***Exhibit A*** *for course syllabus*). Demonstrational, experimental and computational laboratories will be available to the students, and student groups will complete semester research projects.

The course will be ideally team taught by a functional biologist and a bioengineer. By this method, students will obtain a broad understanding of structure-function relationships of animal systems. The lab will be intently focused on demonstrating biomechanical research methodologies and technologies, involving students in experimental data collection exercises and numerical simulation and experimental visualization of biological fluid flows. Moreover, a novel laboratory experience involving testing of a Lab-on-a-Chip device (LOC) is planned to study several aspects of fluid flow phenomena [8]. Laboratory exercises will culminate in semester research projects. The students will conduct small research studies in groups, ideally with students from diverse STEM disciplines working together as a team. The primary objective of this design is that students from different STEM disciplines act as **peer mentors**. For example, projects involving velocity profiles and pressure profiles of fluid flow systems may be easier to conceptualize by the engineering students, and these students can provide mentoring to biological sciences students. Similarly, information on animal anatomy and physiology may be easier to conceptualize by the biological sciences students, and these students can provide mentoring to engineering students. Both in lecture and lab, students will be combined in small group student discussions and problem solving exercises. Faculty instructors will monitor the student interactions to aid in the effectiveness of the desired peer mentorship and group learning, especially when helping groups complete semester research projects. Faculty will work with students from the conception phase of their research projects through experimentation, data analysis and results interpretation using a proven strategy of Problem Based Learning (PBL) [9]. Groups will present their research findings as a poster in a format similar to that presented at a national scientific meeting. Posters and the accompanying presentations at the end of the semester will be evaluated by involved faculty.

***Interdisciplinary coursework for STEM majors*.** This course seeks to bring together students and faculty in an environment that promotes a broad STEM education. The aim of the course curriculum is to provide students with an understanding of basic structure/function relationships of biological tissues and systems, mechanical principles governing animal locomotion, and mechanics of biofluids by engaging students with hands-on experiences in computational, demonstrational, and experimental laboratories. Students entering the course will have completed at least two semesters of both general chemistry and general biology, and general physics and calculus.

***Technical Synopsis of the Course Emphasis*.** This course aims to provide a strong foundation for biomechanics and biofluids. Topics covered include Newton's Laws for forces and moments, free body diagram analyses, transfer of linear and angular momentum possessed by mass and contributed by forces, rigid body and fluid statics to perform applied analyses on animal systems. Lecture classes may include static and dynamic state problems, concepts of mechanical energy and transference of mechanical energy in locomotor systems, and Bernoulli equations and life at variable Reynolds Numbers. Laboratory exercises and semester projects may be given from following which reflect the expertise of the STEM faculty instructors:

- biomechanics of locomotor systems encompassing dynamic force and moment analyses applied to the musculoskeletal system, and locomotor energetics and physiological constraints.
- biofluids of flow systems encompassing kinematics of fluid flow and its application to blood circulation in the body.

Each of these two main technical topics offers lecture, demonstration, laboratory exercises and semester projects as explained below:

4.1 Biomechanics of Locomotor Systems

It is well understood that structure and function are interdependent for species fitness and survival. An understanding of material and mechanical properties of biological tissues is critical to the interpretation of their function. In turn, an understanding of musculoskeletal structure is critical to interpretation of locomotor function (i.e., mechanics and energetics). Finally, an understanding of mechanics and energetics allows for assessment of complex motions and locomotor modes in a variety of environments. A main objective in the proposed course is to integrate musculoskeletal anatomy with mechanical concepts to explain animal function. Certain laboratory exercises will challenge students to apply concepts learned in lecture to animal movement and locomotion. The course laboratory exercises will also challenge students to predict experimental outcomes from their understanding of fundamental mechanics of moving and fluid systems (See ***Exhibit A*** Proposed Course Syllabus).

The laboratories will be relatively simple, yet sophisticated, and adequate for comprehension by juniors, seniors and graduate students. The following are three examples of laboratories exercises focused on terrestrial locomotion and energetics that are rather innovative and involve participation by the entire class. *Example 1*: this laboratory exercise teaches students about Newton's Laws of Motion through a creative applied circumstance of performing a standing long jump while carrying hand-held weights or 'halteres'[10]. The outcome of improved jump distance initially seems counterintuitive to students, however, only through direct performance of the jumps and analysis of the results, students improve their understanding of mechanical principles involved. *Example 2*: this laboratory exercise explores the physiology of locomotor energetics by manipulations to the human walking gait. In this simple laboratory exercise, the variables speed, step frequency and step length of the human walking gait are constrained and measured to indicate the combination that 'optimizes' walking efficiency or metabolic economy.[11] *Example 3*: this laboratory exercise demonstrates ground reaction forces (GRF) during walking and running using force platform technology. The study of GRF is simple in application but complex in analysis, yet GRF is a topic of study that highly interests students. The class will evaluate patterns of GRF as students volunteer to walk and run across a human force platform. The study of GRF may be expanded by challenging students evaluate forces of locomotion in complex 3-D environments such as tree branches vs. over ground situations. This novel laboratory experience will involve evaluating locomotor mechanics of non-human primates (e.g. squirrel monkeys) walking and running across custom-made beam force transducers.

4.2 Biomechanics of Fluid Flow Applied to Physiological Systems

Another novelty of the proposed *Integrative Biomechanics and Biotransport* course is the emphasis on fluid mechanics and simple, yet sophisticated, experimental techniques used in fluid mechanics research. General fluid mechanics and mass transport applied to physiological systems included in the course are detailed below (See ***Exhibit A*** Proposed Course Syllabus):

Fluid mechanics: Viscosity, hydrostatics, application of control volumes for describing mass and momentum conservation in flowing fluids, interpretation of the terms in Navier-Stokes equation, Bernoulli's equation, flow in straight tubes, Windkessel model for blood vessels, wave propagation in blood vessels.

Mass transport: Fick's first and second law of diffusion, diffusion with advection, mass transfer from flow channels, chemical reaction kinetics for first and second order systems, effects of enzymes and inhibitors, oxygen-hemoglobin binding, interstitial gas transport and Krogh's cylinder.

Innovative technologies such as Lab-On-Chip (LOC) and Magnetohydrodynamics, will be available to the students for ultrasensitive measurement and prediction of biological fluid flow phenomena. In addition to locomotor function in swimming and flying lineages, it is becoming increasingly clear that principles of fluid mechanics are critical to regulation of homeostasis in all animals. Modeling biological flow systems experimentally and numerically is important to both prediction and prevention of vascular disease in humans for example. By using Particle Image Velocimetry (PIV) and finite element analysis we gain a better understanding of the dynamics of flow-induced parameters in various blood vessel geometries. Fluid mechanics laboratory exercises designed for the proposed course can be broadly classified in the areas of computational biofluids for the modeling of animal systems.

Two exemplar projects are (1) numerical studies of aortic flow fields and (2) investigation of fluid mechanical disturbance induced by intravascular stents. In the first laboratory exercise, computational fluid dynamic models of arterial geometries will be simulated to understand the physics of blood flow within the aorta and its major branches. This will demonstrate how flow patterns within the aorta are elaborately sensitive to minor changes in aortic geometry [12,13,14,15].

5. Assessment Plan of the Proposed Course

Assessment Plan. The assessment plan addresses the classical issues associated with course evaluation [16] and implements more recent advances in assessment methodology [17].

The assessment plan includes assessment during and following the course offerings, and is comprised of **three levels** detailed in the Assessment Flow Chart (see **Figure 1**). Each level of assessment systematically progresses from Level 1 to Level 3 and is designed to have a reciprocal feedback system among all levels.

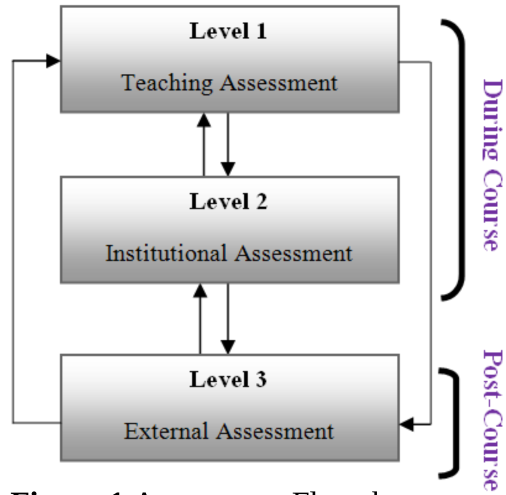

Figure 1 Assessment Flowchart

5.1 Level 1 Assessment (during course offering):

Instructor Assessment. Information will be collected by the instructors during the course. A feedback loop will be established between the course instructors, senior personnel, and external assessment specialist. Details of levels 1 & 2 of the assessment flow chart are shown in **Figure 1**. Clear communication from the instructors as to what is expected of both the mentors and the mentored groups is also important. The effectiveness of faculty instruction, laboratory exercises and peer mentoring can accurately be assessed, using both direct and indirect methods. The indirect assessment will be conducted by the instructor using observation of the class dynamics and course questionnaires. The direct assessment will be conducted using objective course concepts questions asked to both groups regarding material explained by faculty and mentors.

Details of specific measures and information used are further outlined in an Assessment Matrix (see **Table 1**).

(a) Indirect Assessment-Group Discussion

A portion of the lab each week will be dedicated to meeting with the mentor and mentored groups separately. The meeting will be a group discussion format in which there will be a time to discuss aspects that are working well and problems that have emerged. The group will take time to brainstorm how the challenges can be overcome, when necessary. This information will be given back to other groups when appropriate, such that a closed-loop feedback system is established.

(b) Indirect Assessment-Subjective Questionnaires

Questionnaires specific to the mentor/mentored group will be developed. The questionnaire will address student perception of the peer mentoring effectiveness such that anonymous feedback can be gathered. Comments on the questionnaires will be addressed to the class as necessary, however, the data will mainly be used to educate the mentor/mentored groups for greater lecture and laboratory teaching effectiveness.

(c) Direct Assessment-Objective Concept Questions/Quizzes

- A student response system will be used within the classroom to assess student learning both before and after peer mentoring activities. In addition to an assessment tool, the response system will provide the students in both mentor/mentored groups with immediate feedback as to their understanding or lack of understanding of the material.
- Concept quizzes will be developed to be given to all the students periodically. The content of these quizzes will be on concepts that the mentor group was instructed to focus on and ensure that the mentored group understood. Thus, the instructors will be able to employ a rubric to compare the depth of understanding by the mentor group to that of the mentored group. This data will be used during the separate group discussions to help the mentor group become more effective in the transfer of information, as well as to track the improvement of the students' understanding as the semester progresses.

5.2 Level 2 Assessment (during course offering):

Institutional Assessment. The Office of Assessment at a university is resourceful in analyzing course assessment data and will be instrumental in disseminating institutional assessment results in university publications. This evaluation will determine the effectiveness of the proposed course and the value of interdisciplinary models of education in STEM disciplines. This assessment will also give a benchmark from which improvements can be made.

5.3 Level 3 Assessment (post-course offering):

External Assessment. Assessment data collected in Levels 1 and 2 will be evaluated by an external assessment specialist. This individual will conduct a thorough analysis of course assessment data with the main goal of determining if the course met the **Student Learning Objectives**. This level of assessment will be invaluable to assist the involved faculty with refinement of course instruction, laboratory exercises, interactions between peer mentor groups, and overall, the interdisciplinary course experience. Moreover, this level of assessment is paramount to evaluating how the proposed *Integrative Biomechanics and Biotransport* compares with other interdisciplinary proposals at other PUIs.

The most important aspect of assessment is to verify if the course objectives are consistent with institutional education objectives. Course assessment data will be shared by panel discussions with a STEM assessment committee for developing other interdisciplinary courses. Similarly, semester research project representations at the university meeting or similar regional scientific meetings will be shared among the faculty and students of STEM disciplines.

In addition, a questionnaire set will be used to measure and improve the effectiveness of the program (***Exhibit B****).*

Table 1 Assessment Matrix.

Measures: / Goals:	Engage in Research	Enhance Knowledge	Immersion & Cohort building	Interdisciplinary	Use of the Information:
Semi-Weekly Project Oral Presentations (D)	X		X	X	Shared with all mentors and student researchers. Action taken
Project Final Oral & Written Reports (D)		X	X	X	Results shared with Dept. and STEM Assessment.
Student Pre/Post Survey & Tracking Info (I)	X	X			Survey data annually reviewed for action as needed, tracking data aggregated for course and STEM
Student Publications & Presentations	X	X	X	X	Aggregated data are part of course review.
Relationship with other relevant courses					Analyzed and aggregated data for course and STEM program

Direct measure (D), Indirect measure (I)

6. Concluding remarks

In the rapidly growing STEM education at various universities in the US and around the globe, integrative biomechanics course as an interdisciplinary course can attract students from a number of STEM disciplines. This course is expected to offer cross-disciplinary innovative features, and provides special interdisciplinary education to prepare students for the demands of modern biofluids and biomechanics. This paper details about an integrative biomechanics course for STEM majors that includes basic structure/function relationships of biological tissues and systems, mechanical principles governing animal locomotion, and mechanics of biofluids. The course structure details plans to engage students with hands-on experiences in computational, demonstrational, and experimental laboratories. It has been proposed that STEM students can also be engaged in peer mentoring and learn from each other. Integrative courses broaden the educational experiences of STEM majors, and may serve as a general model for developing interdisciplinary STEM curricula at PUIs. Assessment plan to measure students understanding and knowledge is clearly laid out viewing on student learning objectives (SLO) through both formative and summative evaluations.

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Exhibit A Syllabus for STEM 4000 Integrative Biomechanics and Biotransport

Prerequisites: STEM Mechanical Properties of Biological Tissues***, Calculus, Physiology***
Credit hrs: 3 s.h. lectures and 1 s.h. for lab
Instructors:
E-Mail:

Course Meeting Times:

Lecture
Lab

Recommended Textbooks:

Vogel, S. *Comparative Biomechanics*. Princeton, 2003.
Waite, L and Fine, J. *Applied Biofluid Mechanics*. McGraw Hill, 2007.

Course Objectives and Outcomes:

The objective of this course is to apply engineering principles to structure/function relationships in physiological systems. This course aims to provide students with a strong foundation for biomechanics and biofluids. Topics covered include Newton's Laws for forces and moments, free body diagram analyses, transfer of linear and angular momentum possessed by mass and contributed by forces, rigid body and fluid statics to perform simple analysis on animal systems. To demonstrate satisfactory competence at the completion of this course, the student will learn how to:

- Employ correct anatomical and mechanical terminology
- Describe and interpret material/mechanical properties of biomaterials
- Discuss fundamental Newtonian mechanics that underlie all forms of animal locomotion
- Integrate anatomy and mechanics of musculoskeletal system elements in locomotion
- Use technologies common in modern biomechanics research
- Discuss fundamental fluid mechanics involved with locomotor and physiological systems
- Understand physics governing fluid mechanics pertaining to human body fluid flows.
- Apply computational modeling tools (CFD) for use in course projects
- Solve problems using peer mentoring group dynamics
- Conduct a research project and present results in poster format for peer evaluation

Laboratory and Research Projects:

Labs will involve demonstrations of techniques and technologies used in biomechanical and biofluids research, and will engage students by experimental and computational exercises. Performance in lab will be evaluated by the following:

1. Attendance is required for all students during your assigned Laboratory Section. Absences will affect any **bonus points** earned for participation in laboratory demonstrations.

2. Quizzes will be given at the beginning of lab. Quizzes may NOT be retaken for the purpose of changing or improving your grade. Quizzes may contain the following:
   - Material in the course textbook
   - Material covered in lecture
   - Material covered in the laboratory exercises
   - Problems assigned to peer mentor groups

3. If a student has prior knowledge that he/she will miss lab, that student should meet with the course instructor at least one week prior to make alternative arrangements to complete the necessary work in advance of the scheduled date.

4. Semester research projects will consist of small groups of 3-4 students working together on a study adapted from a biomechanical or biofluids research techniques demonstrated in lab. Students will actively participate in the lab demonstrations and formulate testable hypotheses for data analyses exercises. Groups will have approximately 5 weeks to complete their research study and prepare the posters for presentation. Projects will be evaluated according to these criteria:
   - Initial understanding of research inquiry and formulation of a testable hypothesis
   - Efforts in planning, organization and execution of the research project (data collection)
   - Interpretation of the results and representation of the scientific findings (data analysis)
   - Overall visual quality of the poster presentation and the conclusions

Grading Policy:

The final course grade will be based a straight percentage scale for each item:

	% Grade
Quizzes	15%
Problem Sets/assignments	15%
Lecture Exams	30%
Research Project	30%
Participation	10%

Peer-reviewed Journals of Interest:

Journal of Fluid Mechanics, Journal of Experimental Biology, Journal of Biomechanics, Journal of Morphology, Biomedical Engineering, ASME Journal of Biomechanical Engineering, IEEE Transactions

Exhibit B Sample Evaluation Questions and Measures for the course & program assessment

Evaluation Questions	**Evaluation Measures**
What is the effectiveness and reliability of interdisciplinary courses and labs which make critical links between biological problems and engineering solving techniques?	▪ Expert curriculum review ▪ Student effectiveness surveys ▪ Student focus groups ▪ Faculty focus groups ▪ Document review ▪ expert review of student work samples ▪ student activity logs (Laboratory)
What is the effectiveness and reliability interdisciplinary, high motivation problem based teaching learning strategies (PBT/PBL)?	▪ Critical incidence classroom and lab observations ▪ Faculty interviews ▪ Faculty/student artifacts ▪ Pre/Post measure of students' conceptual understanding of course/program concepts ▪ expert review of student work samples ▪ student activity logs (Laboratory)
What changes in faculty's education and research expertise in the intersection of biology and engineering disciplines can be documented?	▪ Faculty focus group interviews ▪ Faculty surveys ▪ Critical incidence classroom and lab observations
What changes in student motivation to pursue undergraduate and graduate studies in these areas can be documented?	▪ Student Survey ▪ Student focus group interviews ▪ student activity logs (Laboratory)
What are the documented increases in the number of students planning to pursue careers in these fields?	▪ Student Survey ▪ Student focus group interviews
Has the project helped to create a common platform to bring together different STEM disciplines and promote interdisciplinary education, research and knowledge sharing?	▪ Student focus groups ▪ Document review
How have the participation rates of female and minorities in the proposed course "Integrative Biomechanics and Biotransport" improved?	▪ Student focus groups ▪ Student Surveys ▪ Faculty focus groups