Introduction to Biomedical Engineering: an Effective Way to Motivate Prospective High School Students and Engage Freshman to the Biomedical Engineering Program

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Abstract –The Biomedical Engineering (BME) department at the University of Miami developed two courses to introduce BME at either the freshman (BME112) or high school (BME100, summer scholar program) level. BME112 and BME100 are taught in a lecture-laboratory format and share the primary objective to engage students in the BME profession, by providing them with a solid understanding on the main topics relative to the discipline, in addition to exposing them to the diverse professional development options. The following strategy is being used: 1) students interact with BME faculty, covering a broad spectrum of BME topics; 2) students perform a series of hands-on experiments where they make measurements on living systems and interpret data; and 3) teams of students develop a short research project (freshman) or a simple medical device (summer). The courses were observed to be effective in engaging the BME students to the various aspects of the discipline.

INTRODUCTION

The Biomedical Engineering (BME) Department at the University of Miami has 12 primary faculty and 280 undergraduates. The BME undergraduate program has three concentrations: premedical, electrical and mechanical. The program's curriculum is divided into four main areas: (a) mathematics and basic sciences; (b) general education; (c) engineering principles and (d) biomedical engineering. The mathematics and basic science area covers courses in mathematics, physics, chemistry and biology. The general education area includes two courses in English and six electives in humanities and people and society. Engineering principles courses provide basic engineering skills, such as electric circuit theory, probability and statistics, and mechanics, and are normally taught by other engineering departments. Biomedical engineering courses infuse the professional component and are taught by BME faculty. The credit distribution, per semester, in the different areas for the three concentrations is presented in Table 1. The premedical concentration has the highest number of credits in mathematics and basic science (55), corresponding to 41% of the total credit count, while electrical and mechanical concentrations have 42 credits (31%). This credit difference comes from inclusion of additional courses in chemistry and biology in the premedical concentration. All concentrations have 24 credits in general education (18%). The engineering principles area shows the highest credit count for the electrical concentration with 26 credits (19%) followed by mechanical with 22 (16%) and premedical with 19 (14%). The higher count for electrical concentration is explained by the fact that the

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electrical concentration has several electronics courses taught by the electrical and computer engineering department. The BME faculty teaches 37 (27%), 43 (32%) and 47 (35%) credits in biomedical engineering for the premedical, electrical and mechanical concentrations respectively. In general, the credit distribution in each concentration is in excess of the ABET curriculum requirements for a biomedical engineering program.

Table 1. Curriculum Distribution

Sem	Math & Basic Science			General Education			Engineering principles			BME		
	Prem	Elec.	Mec.	Prem	Elec.	Mec.	Prem	Elec.	Mec.	Prem	Elec.	Mec.
1	8	8	8	6	6	6	**3**	**3**	**3**	0	0	0
2	12	12	12	3	3	3	0	0	0	**2**	**2**	2
3	15	15	15	3	0	0	0	3	3	0	0	0
4	10	4	4	0	3	3	6	10	10	0	0	0
5	0	0	3	3	3	3	6	9	6	9	6	6
6	7	3	0	3	3	3	4	1	0	3	10	14
7	3	0	0	3	3	3	0	0	0	12	12	14
8	0	0	0	3	3	3	0	0	0	11	13	11
Tot	**55**	**42**	**42**	**24**	**24**	**24**	**19**	**26**	**22**	**37**	**43**	**47**
%	*41%*	*31%*	*31%*	*18%*	*18%*	*18%*	*14%*	*19%*	*16%*	*27%*	*32%*	*35%*

The analysis of the subject area distribution during different semesters provides information on the diverse learning experience of BME students. The mathematics and basic science requirements are covered during the freshman and sophomore years; general education credits are evenly distributed; the engineering principles credits peak during the second semester of the sophomore year and the first semester of the junior year; and, finally, the BME courses are concentrated in junior and senior years. During the first semester students take a college-wide introduction to engineering course (BME111/ECE111/MAE111/CAE111), which is classified under the Engineering principles column. BME111 uses innovative approaches to enhance the freshman experience similar to the ones adopted in the Citadel 101 freshman initiative [Brannan et al., 2]. It presents the students with general academic success strategies, career planning and general engineering skills and tools. The specific topics related to BME are covered in BME112 Introduction to Engineering II, which is offered during the second semester. BME112 is the first BME course, and the primary formal opportunity the department has to introduce its students to the program and to the BME profession within the first two years. After a curriculum review in 2004, the current approach to teach BME 112 was established. Since then, BME faculty, with diverse professional backgrounds, have taught the course, with revisions over the years to better fit departmental requirements and the student population. Specifically, topics related to good laboratory practices and cellular and tissue engineering, have been enhanced in recent years.

The Summer Scholar Program

The University of Miami offers a summer scholar program for high school students. The objective of this program is to provide a means for students to explore their career possibilities through a college educational experience. Students attend classes from 8:20 am to 4:10 pm, five days a week for three weeks. The university offers 13 programs including: journalism, business, marine science, and engineering. The college of engineering offers four courses in civil, mechanical, electrical and biomedical engineering. Students have the choice between two programs, each one covering two disciplines: A) civil and mechanical engineering; and B) electrical and biomedical engineering.

The BME introductory course (BME100) is designed to expose exemplary high school students interested in STEM disciplines to Biomedical Engineering. The selection process for Summer Scholar is very similar to the selection process for undergraduate admission at the University of Miami. Students are required to submit an application, essay, transcript, and teacher recommendations. At least a B average is required for students to participate, which is typically representative of a GPA of a 2.8 and higher. For engineering, it is recommend that students have been exposed to higher level math such as algebra, trigonometry, and or pre-calculus, as well as physical sciences such as physics. These students should have a curiosity for learning and should want to participate in an academic experience during the summer. The elective process of the application and requirement results in an application pool of high academic caliber. The BME summer program takes many elements from the freshman course (BME112), but with modifications to fit the intense three week schedule. The students are provided with lectures, visits, and hands-on experiences aimed to provide an introductory understanding of the discipline. The course includes topics on optics, medical imaging, biomaterials, rehabilitation, cellular engineering, tissue engineering, bioelectricity, and biomechanics. The course also includes a final design project based on LabView. The BME summer scholar course has been delivered two times during 2009 and 2010.

Objectives of the Introduction to Engineering Course and the Summer Scholar Program

The courses BME112 and BME100 share the same objective: to engage current or prospective BME students in the BME profession and program. Engagement encompasses two aspects: 1) an informational aspect, related to conveying a clear picture of the biomedical engineering profession to the students; and 2) a motivational aspect, related to presenting the students with diverse and attractive professional development options. By providing a solid introduction to the BME discipline, along with its professional development options, we seek to provide a vision and context to the seemingly uncorrelated courses taken during the freshman and sophomore years. Additionally, the personal links established between the students and the BME faculty provides an excellent opportunity to attract undergraduate students to research opportunities, as well as keeping them in contact with the department throughout their four year college experience. For the prospective students enrolled in the summer program, BME100 provides an opportunity for them to make an informed decision about their future enrollment in a BME program, as well as providing a glimpse of their future professional development options.

DESCRIPTION OF THE BME 112 INTRODUCTION TO ENGINEERING II COURSE

The current version of the BME112 in a lecture/laboratory format was established in the curriculum reform of 2005 and has been continuously updated following the evolution of the profession and the BME faculty profile. In the early versions of the course, the students, working in teams, developed a semester long research project that included hands-on experience and the writing of a formal final report and an oral presentation. The students didn't obtain a global vision of the BME profession and the interaction with the faculty was limited. The 2005 reform introduced the sequence of formal lectures and laboratory sessions limiting the research project to the last weeks of the semester. Currently BME112 is delivered once a year, in the spring semester, and uses a format consisting of weekly lectures and bi-weekly laboratory sections. All students (approximately 60) attend the weekly lectures in a large classroom setting. For laboratory sessions, they are split into smaller groups (10 - 12 students), which are further divided into teams (typically 2-3 students). The grade of the course comes from two exams (30%), the laboratory notebook and reports (35%), the final project (25%) and the class participation (10%).

BME112 Lectures

BME112 lectures cover topics designed to highlight the broad BME discipline spectrum and the general aspects related to BME professional practice (see Table 2). In general, BME primary faculty lecture on BME discipline topics closely related to their research activity, while external experts are invited to teach a portion of the professional practice topics such regulatory affairs and intellectual property. Research lectures are designed to highlight challenges and opportunities within the general research field presented. In this context, research topics are presented by leaders in the field on these topics, providing for an intimate and exciting prospective of the various research fields. The BME department gives special importance to an early teaching of the professional practice topics that shape the professional practice of BME graduates. These topics are initially addressed, in a more general mode, during the college wide introduction to engineering course (BME111). In BME112 the coverage is more specific to the BME profession, addressing, for example, topics like the Food and Drug Administration (FDA) regulatory role and the ethical and legal issues related with human subjects and animal experimentation.

Table 2. List of BME Lectures

Lect.	**Lecturer**	**Title/Content**	**Type**
1	Faculty coordinator	**Course introduction**	Informative
2	BME Faculty	Scholarship skills and life-long learning	Professional Practice

3	BME Faculty	Minimally-invasive ablative tumor treatments	BME and Science
4	External Expert	Regulatory affairs	Professional Practice
5	BME Faculty	Advanced microscopy and tissue nanomechanics	BME and Science
6	External Expert in IP	Patents and technology transfer	Professional Practice
7	BME Faculty	Optics of the eye	BME and Science
8	BME Faculty	Biomechanics	BME and Science
9	BME Faculty	Development of a novel bioreactor system for cartilage tissue engineering	BME and Science
10	BME Faculty	Professional responsibility, ethics, animal and human experimentation	Professional Practice
11	BME Faculty	Biomaterials	BME and Science
12	BME Faculty	Neural Engineering	BME and Science
13	BME Faculty	Cell and tissue engineering	BME and Science

BME112 Laboratory Sessions

Students, working in teams of two or three, perform laboratory experiments every other week, under the supervision of 1-2 teaching assistants. Objectives for the laboratory sessions are to: provide hands on experience; introduce proper methods for notebook keeping; provide practice in planning and performing biomedical engineering experiments and collecting and correlating data from the experiments; and provide experience on scientific writing. Laboratory sessions consist of five modules, plus a final project (see Table 3). Students are provided with a Laboratory Rules, Regulations, and Standards guidebook, which outline guidelines for proper experimental preparation, data collection, data analysis, and report writing. Each laboratory team is expected to have a laboratory notebook and follow good laboratory procedures for inputting data. For each laboratory session, a laboratory guideline is posted on Blackboard in advance and the students are required to download and study it, in addition to performing preparatory work in their notebooks. The lab guide contains three main sections: physiological background information; detailed methods of the experiments to be performed; and instructions to write the lab report. All lab reports follow the same general format, with an introduction, theory, and experimental (results, discussion, conclusions) sections. The lab reports seek to provide the opportunity for students to describe their experimental results and to give interpretation of these results in their physiological context. The students must also perform calculations and data analysis, requiring the use of computer tools such as excel or matlab. The laboratory sessions are carried out in either a general BME measurement laboratory or in a research laboratory. For the research laboratory sessions, graduate students working in the respective research laboratories are normally involved and help the regular TAs during the experiments.

Table 3. BME 112 Laboratory Sessions

Session	Laboratory	Location/ Equipment
1	Respiratory measurements and heart rate	Main measurement laboratory/Powerlab Systems
2	Rest and exercise electrocardiogram	Main measurement laboratory/Powerlab System-treadmill
3	Optical transmission measurement	Biomedical Optics Laboratory/Laser system
4	Cellular engineering lab	Stem cell and mechanobiology laboratory/Electrophoresis equipment
5	Tissue biomechanics lab	Tissue biomechanics laboratory/Instron material testing system

BME112 Final Projects

Following completion of the five laboratory modules, student teams conduct an independent final project. The objective of this final project is to introduce skills for performing independent research. BME faculty define the general topics for the projects and provide access to their research facilities to perform the experiments. The projects are purposely defined in an open manner, to encourage students to develop their own working hypotheses. Students are expected to conduct their own research on the topic selected, design and develop an experimental procedure to test their hypothesis, collect and analyze data, and present this project both in a written and oral format. Student teams are assigned mentors, typically graduate students from the faculty host's laboratory, to assist them in background research, hypothesis development, data collection, and analysis. The mentor also ensures that the team has a realistic research experience and helps in limiting the project scope. Students are given 4 weeks to conduct their research and prepare their written and oral reports. Oral reports consist of a 15minute PowerPoint presentation. Written reports are of the same format as for the standard laboratory session, but with greater detail in the Introduction and Theory sections. Table 4 describes selected research projects, performed in previous years.

Table 4. Sample of Final Projects

Laboratory	Subject	Description
Measurement	Effects of exercise on the ECG morphology and Heart rate.	ECG and HR signals of volunteer(s) will be recorded at varying exercise levels and they will identify what components are the more affected.
Measurement	Relation between EMG and force	The students simultaneously record EMG activity and the force applied to a load-cell. They fit a mathematical equation to correlate force and EMG.
Neurosensory Laboratory	Record Visual Evoked Responses	Pattern Reversal Visual Evoked Potentials will be recorded at different stimulation rates
Biomedical Optics and Lasers	Measurement of the attenuation coefficient of a tissue phantom as a function of laser wavelength	Use transmission measurements to determine how the absorption coefficient of Nigrosin ink, a common tissue phantom, varies with wavelength
Tissue Biomechanics	Electrical conductivity of cartilaginous tissues	The electrical conductivity of intervertebral disc tissues will be measured. The effect of water content on conductivity will be investigated.
Tissue Biomechanics	Proteoglycan content measurement	A spectrophotometric technique will be used to measure the proteoglycan content of intervertebral disc tissues.
Diabetes Tissue Engineering Laboratory	Protein release from biomaterials	Evaluating the effect of biomaterials on the release of proteins. Proteins will be measured using electrophoresis and protein assays.
Diabetes Tissue Engineering Laboratory	Oxygen release from biomaterials	Evaluating the effects of biomaterials on controlling the release of oxygen from peroxide based systems.
Stem Cell and Mechanobiology Laboratory	Osteogenic differentiation of dental stem cells	Osteogenic differentiation of dental stem cells will be induced by dexamethasone treatment and the expression of osteogenic markers (i.e., alkaline phosphatase and RUNX2) of the treated cells will be examined using analysis of reverse transcription-polymerase chain reaction.
Hemodynamics Laboratory	Changes in blood flow due to geometric changes in blood vessels	The team will design and produce 2D models. These models will be used to demonstrate the effect that bifurcations and obstacles have on fluid flow and how this relates to diseases such as cardiac arrest and stroke.

Relation Between BME112 and the ABET Requirements and Assessment

The department uses the criteria from the Accreditation Board for Engineering and Technology (ABET) as an effective way to convey the BME profession to the students. ABET defines three basic criteria [ABET, 1]: *"1) An understanding of biology and physiology; 2) The capability to apply advanced mathematics (including differential equations and statistics), science, and engineering to solve the problems at the interface of engineering and biology; and 3) The ability to make measurements on and interpret data from living systems, addressing problems associated with the interaction between living and non-living materials and systems"*. BME112 is used in our accreditation process to support the accomplishment of criteria 1) and 3). Also, a direct assessment of the educational outcome *"g: An ability to communicate effectively"* is performed during the final project presentation and report evaluation. In spring 2010, faculty assessed educational outcome (g), on 46 students, using a set of 11 communication attributes.

Using a grade scale of 0-4 per attribute, 506 (11x46) grades were collected from the student population, 58% of the grades were 4; 38% fell in the range 3-4 and 4% of the grades were in the rage 2 -3. No grades below than 2 were recorded. We think, BME112 has a potential to be used in the early assessment of more educational outcomes like Outcome *"b: An ability to design and conduct experiments, as well as analyze and interpret data"*, for example.

DESCRIPTION OF THE BME100 SUMMER SCHOLAR PROGRAM

The summer scholar program aims to introduce prospective college students to the BME profession and the undergraduate program at the University of Miami. The combined lecture-laboratory approach used in BME112 is replicated in the summer scholar program with a few adaptations to accommodate the three-week intense schedule. During the summer period, it was possible to have the benefit of having the lecture and the laboratory hands-on experience the same day[3, Cavanagh and Richerson]. He summer scholar program students register in two engineering programs. The students take introduction to BME in the morning and an Introduction to Electrical Engineering in the afternoon. As shown in Table 5, in the summer program, the day normally starts with one hour lecture, followed by a hands-on experience on the same topic. The hands-on experience is conducted in the BME measurement laboratory (ECG, LabView), in a BME research lab (Ultrasound, Neurosensory laboratory, Biomechanics lab, Tissue Engineering Laboratory), or in a field trip to research facilities in the medical campus (4.7 Tesla research MRI, PET scan clinical facility, Diabetes Research Institute). Since the number of students in the summer session is typically small (10 students in 2009 and 6 students in 2010), students can have a close personal contact with the BME faculty, research engineers, and research and teaching assistants involved in the program. In lieu of a final research project, the summer scholars develop and test a simple medical device: a thermistor based thermometer. For this project, the instructor provides the students with the physical principles of temperature measurement and gives the characteristic equations of the thermistor to be used. In three sessions, the students use a specially designed sequence of labView programs that enable the students to "assemble" their digital thermometer. The students then quantitatively test their products using a thermal bath along with a laboratory thermometer.

Table 5. Summer Scholar Program Schedule

Day	8:20-9:20am	9:25-10:25	10:30-11:30am
1	Introduction to BME Lecture (professional aspects)	First LabView Laboratory	
2	4.7 Tesla MRI - PET Field Trip (Afternoon)		
3	Medical Imaging lecture		Ultrasound Laboratory
4	Second LabView Laboratory	Scanning Electron Microscope Lecture	Scanning Electron Microscope Laboratory
5	Optics Lecture	Optics Laboratory	
6	Electrocardiography Lecture	ECG Laboratory	
7	Rehabilitation Engineering Lecture	Miami Project Field Trip	
8	Neural Engineering Lecture	Neural Engineering Laboratory	
9	Biomechanics Lecture	Biomechanics Laboratory	
10	Biomaterials Lecture	Third LabView Lecture: Project	
11	Cellular Engineering Lecture	Diabetes Research Institute Visit	
12	Tissue Engineering Lecture	Tissue Engineering Laboratory	
13	Review	Final Exam	

To enhance the informative character of the summer session, this program has more lectures on BME topics (10 lectures) and hands-on activities (7 laboratory sessions, 3 field trips and one design project) than BME112 (8 lectures, 5 lab sessions and one research project). Since it is considered that topics related with professional practice are less relevant during the decision making process of high school students, they have less priority in the summer program. The grades are computed using the laboratory reports (40%), the design project (20%) the participation (10%) and a written final exam (30%). The students get three college credits when they pass the course. If the students are accepted in the BME program, they can request the transfer of these credits to the BME program. The transfer is studied by the BME faculty in case by case basis.

ASSESSMENT

BME112 Assessment

At the end the semester the students are invited to fill out a three part, anonymous evaluation of the course. The first part asks for a quantitative evaluation of the instructor, the second deals with an evaluation of the fairness of the course grades, and in the third part the students are asked to write candid comments about the course content, the instructor, and a general opinion. The candid responses are good indicators of the achievement of our objectives and provide valuable feedback for continuous improvement. Representative student comments are presented in Table 6.

Table 6. Student Candid Responses to Open Questions

Please provide us with any suggestions and comments about the course content
This course was interesting because rather than one professor; each class was a different professor lecturing on a different topic. This was nice because we got to learn about many different topics from knowledgeable professors but some of the topics were not interesting or very hard to comprehend.
The lectures on some of the different topics within biomedical engineering greatly increases interest in the field.
It was very interesting hearing about so many different fields in biomedical engineering. It definitely gave me a feel for what I wanted and didn't want to do.
This course is very broad and is introduces you to all the places and applications BME has in the outside world. It got me really excited for the future and to go more in depth in particular areas and to stay away from ones that I don't like.
The course is helpful, as it allows students to determine somewhat as to what field they are interested in. The guest lecturers that are "boring" are indications of fields not interesting to the students, and so students can narrow down their choice of field, which is the most helpful aspect of this course, as well as gaining lab experiences.
The labs were very interesting and showed a lot of different parts of the field.
The course subject matter is very broad. But Biomedical engineering is a field that is broad within itself. It presented me with a lot of introductory avenues as the course goal was to do just that. Now I want to dive deeper into particular areas that this course has introduced me too like neural engineering and tissue engineering.
If another student were to ask you about taking the same course, how would you summarize your opinion?
This course is mandatory for biomedical engineering students but it was an interesting course because many different topics were covered and gave insight into possible future careers and possible research opportunities.
I think the class made me more interested in the biomedical engineering field. It also helped me realize what I like more within the field.
Take it, it's good. Some lectures are boring but it is good for people who don't know what they want to do with BME
I would say it introduces you to certain fields; it's your idea to pursue them further.
I think the labs made me realize how interesting and diverse biomedical engineering is.
I would tell them that it's a good course, and you actually get to learn hands-on. This course was helpful to me in choosing which field of engineering I wanted to stay in. Also it's not an overwhelming amount of work, and you know what is asked of you every week.
It was a good introductory course. It showed different sections of BME, and allowed you to experiment in labs within specific sections. Every week there would be a new lecturer presenting his/her specific field and research. It was a good way to meet professors and learn about the research going on at UM.
This course was a good way to get introduced on how to keep a laboratory notebook and how to write formal lab reports. Some of the labs were interesting but others were extremely tedious.
It was a good course, you are able to learn about many things you see in class so you get to see what you are interested in

Summer Scholar Assessment

The assessment of the program is done using two tools: student's surveys and the number of students that get enrolled in the program.

At the end the three week program the students are invited to fill out a two part, anonymous evaluation of the course. The first part asks for a quantitative evaluation of many aspects of the course, instructor, grades, etc. The second part contains open questions about the program. Table 7 present the evaluation results related to the course content from summer 2009 and summer 2010.

The evaluation shows an agreement among the students (100% strongly agree or agree) about the program conveying a clear picture of the biomedical engineering profession. Due to the small number of students providing feedback (9), the answer to the open questions the feedback information is more limited than the one supplied by the

BME112 students (46). However, the responses indicate that the strategy lecture-laboratory, field trips, and the close human interaction motivates the students to the BME profession.

Table 7. Summer scholar student evaluation results

I-	**Quantitative question, Please rate the following:**
Q1. I understand more about this academic discipline now that I have taken the course.	
	Strongly agree 78% (n=7); agree 18% (n=2); neutral, diagree or strongly disagree : 0% (n=0)
Q2. *This course has challenged me to think.*	
	Strongly agree 78% (n=7); agree 18%% (n=2); neutral, diagree or strongly disagree : 0% (n=0)
II-	**Open question: What did you enjoy most about the class?**
1.	The field trips to the medical school.
2.	The interaction in the field trips.
3.	Learning about a discipline I never learned about before.
4.	The thing I enjoyed most about the course was the attitude of the instructor. He was very concerned about the class and the material, but he also knew how to make it so that we had fun.
5.	I enjoyed the field trips where I could see what it is like being an engineer for a career
6.	I enjoy the labs that we do after the lectures in order to apply the knowledge we just learned.

Among the ten students that participate in the BME 2009 summer program, 5 applied to the college of engineering; four were accepted; one enrolled in electrical engineering and three enrolled in the BME program. Even if this figure is not statistically significant, it is very encouraging to have these three new exemplary students enrolled in the BME program.

DISCUSSION

The BME department effectively capitalizes on the critical window during the first year in college to establish a connection between students and their home department, as well as to introduce the BME profession. There is an excellent correlation between the course objectives, information and motivation, and the student candid evaluation of the course. BME112 thoroughly presents the many academic and professional development opportunities and establishes the foundation for professional responsibilities. Students are also introduced to good engineering laboratory practices, ie data collection, data analysis, laboratory notebook keeping. Using the concepts learned in the lectures and laboratory sessions (for example the scholarship skills and life-long learning lecture addresses literature search), students have their first (guided) research experience involving literature search, experimental design, scientific writing, and presentation experiences. The students receive a preview of what lies ahead in the next three years of their education and in their future engineering practice.

We explain the good achievement level of our course objectives as: 1) the whole BME faculty body gets involved in the course and, as a team, is able to convey a clear picture of the profession; 2) the lecture-hands on approach motivates and prepare the students for a profession rich in experimental work at the interface of engineering and biology; 3) close contact with faculty and RAs working in the research labs during the overall course educational experience, particularly the final research project provides the students with the opportunity to develop a bond and connection with the department. The BME research laboratories welcome undergraduate students to work as volunteers. In 2010, the BME department formalized the recruitment of undergraduate students in the research laboratories and is keeping a database of undergraduate students doing research. Currently 11 sophomores and juniors (around 10% of the total) work in different research laboratories, illustrating the further impact of BME112 in achieving life-long learning.

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