The best of both worlds: an integrated online/on-site Master's program in biomedical engineering

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Abstract

A high quality graduate education should combine the development of advanced analytical skills together with the practical application gained through collaboration between faculty and other students in a practical hands-on environment. We recently developed a new online Master's program in biomedical engineering at the Johns Hopkins University (JHU), which integrates hands-on laboratory experience in collaboration with classmates and faculty with the convenience of online coursework for working professionals. The cornerstone of the program is a summer residency course, Biomedical Engineering Practice and Innovation ("BEPI").

BEPI was designed to build upon foundational coursework by providing experiential learning opportunities in all program focus areas: Imaging, Instrumentation, and Translational Tissue Engineering. BEPI combines seven weeks of online coursework with two three-day weekends in residency at the main campus and hospital in Baltimore, for a total of twelve sessions taught by multiple engineering and clinical faculty, each experts in their respective fields. Each of the three-day weekends is composed of on-site labs and workshops that demonstrate the practical aspects of the online coursework. Many of our applicants have cited the required residency course and the opportunity to directly interact with their fellow classmates and the world class faculty at the Johns Hopkins University campus and hospital as the primary reason they chose to enroll in the program.

After completing the residency, students are required to specialize in one of three focus areas. Interaction with the faculty during the residency encourages a more personal relationship during subsequent online courses. Many of our students gain additional hands-on skills through an independent study. The onsite training additionally builds a trusted peer environment across the program.

Future plans for BEPI include adding more options to the weekends for students who have already selected a focus area. We are also currently developing advanced residency courses, which offer students the opportunity to learn the state-of-the art in a specific field taught by leading scientists and working biomedical engineers.

Background

The Bureau of Labor Statistics reports that biomedical engineering is expected to be one of the fastest growing occupations from 2014-2024[1]. With a 2015 median pay of almost $90,000 per

year and an expected job growth rate of 23% over the next decade, biomedical engineering careers will enjoy a growth rate well above the expected level of 7% for all occupations [2]. The data are summarized in Figure 1 and Table 1.

Figure 1: Projected ten-year job growth

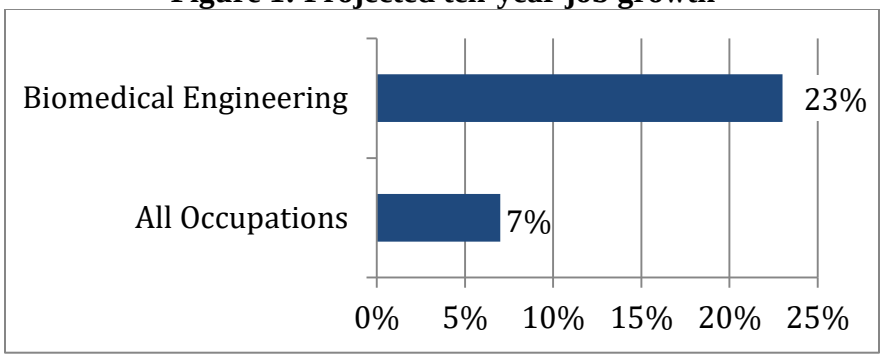

Figure 1: Data from the Bureau of Labor and Statistics indicate that projected ten-year job growth in biomedical engineering (23%) over a ten year period from 2014-2024 is significantly higher than the expected job growth for all occupations (7%)

Table 1: Quick Facts: Biomedical Engineers	
2015 Median Pay	$86,220 per year; $41.45 per hour
Typical Entry-Level Education	Bachelor's degree
Number of Jobs, 2014	22,100
Job Outlook, 2014-24	23% (Much faster than average)
Employment Change, 2014-24	5,100

Johns Hopkins University has been offering part-time master's degree programs for working professionals for over 50 years, and in biomedical engineering for almost 25 years. Our goal is to prepare professional engineers for careers in biomedical engineering by supplementing their undergraduate education with the necessary molecular, cellular, and systems physiology, as well as analytical problem solving to tackle today's health care challenges. Since many of our students are interested in changing their occupation, it is critical to provide them with the hands-on skills needed to enhance their career prospects. The industries that have recently employed the most biomedical engineers are listed in Table 2[1].

Table 2: The industries that employed the most biomedical engineers in 2014	
Medical equipment and supplies manufacturing	23%
Scientific research and development services	16%
Pharmaceutical and medicine manufacturing	12%
Colleges, universities, and professional schools; state, local, and private	8%
General medical and surgical hospitals; state, local, and private	8%

The JHU Applied Biomedical Engineering (ABE) Master's program is designed to equip our students with the knowledge and expertise they need while accommodating demanding work and family obligations. Initially, the program was taught entirely through face-to-face courses at multiple locations throughout Maryland. In 2011 the program was enhanced to require a hands-on lab or design experience. This requirement could be filled by attending evening lab sessions offered to the full-time students on the main campus, or by completing an independent study. The faculty include full time engineering faculty from the undergraduate program as well as working engineers from industry and government. All of our faculty have PhDs and extensive teaching experience, and many teach in our ABET accredited undergraduate program. Based on graduating student surveys, many felt that this hands-on requirement was the most rewarding component of the program.

Biomedical engineering education combines engineering and medical courses, and both these fields have demonstrated the value of carefully designed online modules [3], [4]. The EP ABE program blends online and on-site learning to optimize our students' education. A common theme in many of our courses is the integration of theory with practice. Students learn the structure and function of sensors, devices, cells, and organs through online coursework and then learn how to apply this knowledge to develop data acquisition systems, medical devices, and therapeutics in a clinical setting.

JHU offers two distinct full time Master's of Science and Engineering (MSE) programs in biomedical engineering, both designed to be completed within one-year. One program is offered through the Center for Bioengineering Innovation and Design and provides full immersion in the design aspect of biomedical engineering (MSE CBID). The second full-time program prepares students to pursue careers in research and development, or as a step toward the PhD or MD / PhD and has an optional thesis track. These full time programs are highly competitive, non-funded programs each enrolling 20 to 25students each year, a small fraction of the qualified applicants. The ABE program, however, can accept all qualified students, with a current enrollment of 175 students. Students in this part-time program must complete ten courses within five years.

Within the last few years, the JHU Engineering for Professionals (EP) program's online courses have grown in popularity and now represent the learning method of choice. Seventy-seven percent of all part-time engineering Master's students have enrolled in at least one online course, with many EP students completing all ten courses online. Simultaneously, enrollment in traditional face-to-face courses decreased for all EP Master's programs, and face-to-face courses are now only offered at one site in Maryland. Working professionals prefer the flexibility of online courses, even if they live within commuting distance of the university. Consequently, the ABE faculty made a concerted effort to move courses online. Starting in 2013, JHU was one of the first programs in the country to enroll students in online biomedical engineering courses at the master's degree level. Since then, the JHU online Master's program has been approved by the Maryland Higher Education Committee to offer a fully online master's degree program in Applied Biomedical Engineering.

Summer Residency Course: BEPI

Simultaneous with the development of online courses, we created the summer residency course, Biomedical Engineering Practice and Innovation ("BEPI") as a mandatory core component of the degree program. In fact, the entire program in Applied Biomedical Engineering was re-designed with the residency program as the cornerstone. BEPI ensures that our online students develop essential hands-on biomedical engineering research and design skills through experiences with both the engineering and medical campus faculty. This intensive course provides our working engineering students an opportunity to study living tissue and cells, observe patients in a clinical setting, develop instrumentation to measure physiological signals, image and analyze blood flow, and brainstorm on a design project.

The residency exposes students to all three ABE focus areas and gives students an opportunity to meet the faculty in each discipline, as summarized in Figure 2.

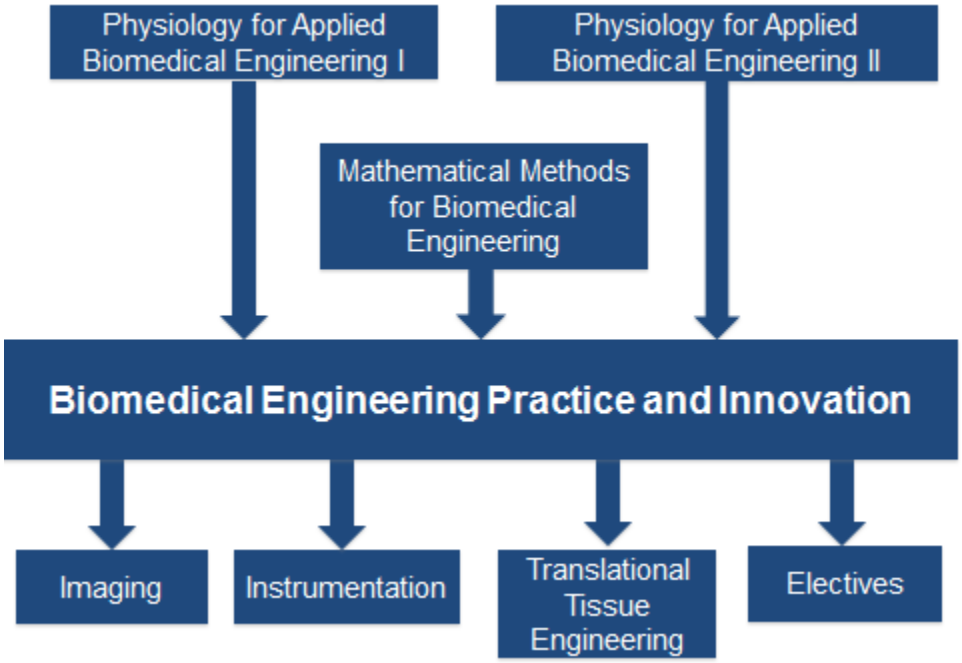

Figure 2: Applied Biomedical Engineering Master's Degree Program. Students need to complete ten courses over a five year period. "Math Methods" and the two-semester "Applied Physiology I & II" sequences are required pre-requisites for the summer residency course "Biomedical Engineering Practice and Innovation". Students take focus area courses in Imaging, Instrumentation, and/or Translation Tissue Engineering along with electives to finish the ten courses required for the degree.

The BEPI course has modules distributed over seven weeks of online learning. Prior to the start of the course, students complete a preparatory module ("Module 0"), which includes online lab safety training, HIPAA, Animal Care and Use, and Bloodborne Pathogen courses and a Matlab programming assignment. Each subsequent module prepares students for two of the labs/workshops. After Modules three and six, students come to the JHU campus for a three day

weekend, during which they have six labs/workshops. The overall course schedule is shown in Table 3. The more detailed, hour-by-hour residency weekend schedules are depicted in Table 4.

When students arrive on campus they receive a "Welcome Package" which includes a thumb drive with all of the handouts and worksheets for each of the labs and workshops. They also receive a campus map, and a JHU Biomedical Engineering tee shirt.

Table 3: BEPI Summer 2016 Course Outline

Module	Topic
0	Welcome, Peer Introductions, Safety Training, Matlab Training
1	Lab 1: Skeletal Muscle Function Lab 2: The EMG
2	Lab 3: Myocardial Contractility Lab 4: The EKG, Sensors and Transduction
3	EKG Workshop Lab 5: Biointerfacing
Lab Weekend 1	Labs 1, 2, 3, 4, 5, and EKG Workshop
	Week off to submit post-lab reports
4	Cardiac Catheterization Workshop Image Processing and 3D printing Workshop
5	Lab 6: Microfabrication Lab 7: Contact Printing
6	Lab 8: Biophotonics Design Challenge
Lab Weekend 2	Labs 6, 7, 8, Cath Workshop, Imag. Proc. Workshop, Design Challenge
	Week off to submit post-lab reports
7	Course Wrap Up

Table 4: BEPI Summer 2016 Lab/Workshop Schedule

Weekend 1	JUNE		
	17th	18th	19th
	Friday	Saturday	Sunday
8:30am-9am	Orientation		
9:00am-12pm	Lab 1: Skeletal Muscle Function	Lab 3: Myocardial Contractility	EKG Workshop (hospital)
12pm-1pm	LUNCH - Group work time		
1pm-4pm	Lab 2: The EMG	Lab 4: The EKG, sensors and transduction	Lab 5: Biointerfacing

Weekend 2	JULY		
	22nd	23rd	24th
	Friday	Saturday	Sunday
8:30am-9am	Orientation		
9:00am-12pm	Cardiac Catheterization Workshop (hospital)	Lab 6: Microfabrication	Lab 8: Biophotonics
12pm-1pm	LUNCH - Group work time		
1pm-4pm	Image Processing and 3d Printing Workshop (hospital)	Lab 7: Contact Printing	Design Workshop

A diverse cross section of faculty participates in the residency program. This provides our online students an opportunity to develop a relationship with the faculty which makes future online courses much more personal and successful for students. The small cohort of students enrolled in the course (12-18 each summer) provides our students with the opportunity to learn from each other face-to-face.. The BEPI course is often a turning point in the master's program for our students. Not only do they obtain the background they need to specialize in a focus area, they have also built personal relationships with both faculty and peers. As illustrated in Figure 2, the BEPI course is usually the fourth out of the ten courses so that the students acquire the essential laboratory, clinical, and design experiences they need to benefit their upper level focus area courses.

Each of the twelve modules has an intensive program of online preparation as shown in Figure 3. Students work through two units each week, which includes background reading, viewing recorded videos, and completing pre-lab calculations and analysis. During their weekends on campus, students start each of the 12 labs or workshops with a multiple choice quiz covering preparatory material for that session. Thus, in addition to the online preparation throughout the semester, students are motivated to review the material prior to each practice. One of the last workshops of the residency program is a design challenge, where students draw from their prior learning to come up with solutions to healthcare problems they've observed in their clinical workshops. The final week of the course is used to integrate themes across the course.

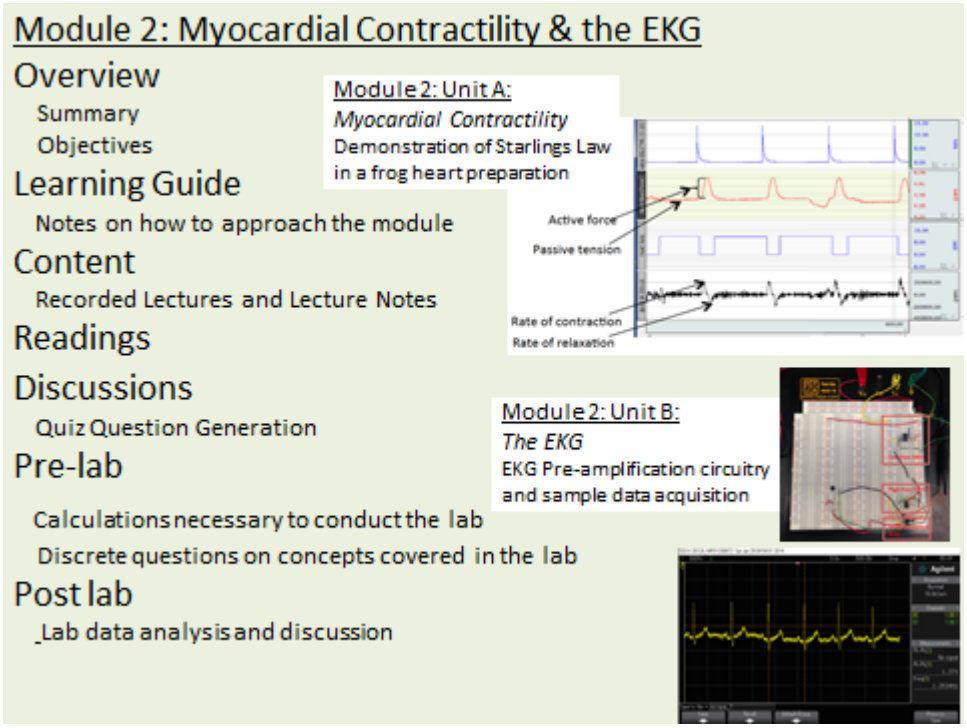

Figure 3: Details of the online structure for Module 2 on Myocardial Contractility and the EKG. Each module has one week of online preparation, and one day of the on-site residency. In Unit A of Module 2, students record from an isolated frog heart to demonstrate the Frank-Starling law. In Unit B, students use a bread board to build an EKG amplifier circuit.

The residency course modules are aligned together by human organ systems, such as the cardiovascular and musculoskeletal systems. Students study each organ system from multiple levels and perspectives. For example, the cardiac units includes a physiology lab using a whole heart preparation to investigate cardiac mechanics, an instrumentation lab where students build a circuit to acquire electrocardiograms, and a clinical session at the hospital's emergency department where students observe first-hand how physicians use ECGs for patient diagnosis. As part of the clinical session students participate in team-based problem solving using the fundamentals from both the physiology and instrumentation labs to analyze patient data.

As an example, a schematic of the cardiovascular system units is illustrated in Figure 4.

Figure 4: Cardiovascular System

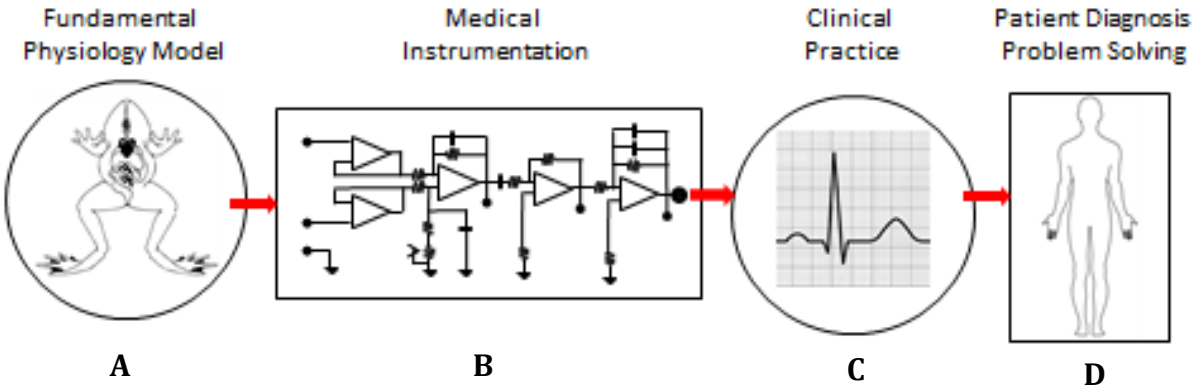

Figure 4: During the BEPI residency course, modules containing training from different focus areas are knit together through organ systems. An example of cardiac physiology, instrumentation and clinical labs is shown in this figure. (A) Students will first learn the fundamental physiology of the heart by measuring contraction and stress-relaxation in a frog preparation. (B) This is followed by an instrumentation lab on electrocardiography where students will build part of the circuitry to acquire ECGs and examine common noise rejection. (C) Students will visit the hospital Emergency Department to observe first-hand how physicians use ECGs for patient diagnosis and (D) Students will participate in team-based problem solving sessions.

In addition to learning and performing state-of-the art experimental techniques, this course also emphasizes the business related aspects of biomedical engineering including the identification of clinical needs, the process of developing innovative solutions, and the FDA regulatory process.

Results and Discussion

The JHU ABE Master's program has taught online courses in biomedical engineering for three years. We currently offer a dozen online courses, including courses in each of the focus areas, with another five courses scheduled to be moved online within the next year. Students may enroll in any relevant online course offered by other EP departments, close to 300 online engineering courses in total. Students in the ABE program may also take courses in the full time MSE program offered at the JHU campus. A number of our ABE students have engaged in advanced independent study projects with JHU full time faculty as part of their degree.

Prior to developing BEPI we surveyed our students extensively to develop a hybrid residency course that meets the needs of working professionals. We continued to solicit student feedback after the completion of each course offering during the last three years. Based on feedback from our end-of-semester surveys, we have made a number of changes since the initial residency course offering. Specifically:

- We added an extra week after the first three-day weekend to complete the post-lab reports. This gives students a chance to catch-up at work and with their families before submitting the reports.
- We included two additional clinical immersion workshops at the hospital.

- We built an online Matlab tutorial which students work through during Module "0" to prepare for the Matlab requirements.
- We incorporated modules on each of the program focus areas: specifically Imaging, Instrumentation, and Translational Tissue Engineering in addition to Systems Biology.

Before starting the Master's program, students are required to complete courses in Molecular Biology and Signals & Systems, in addition to having an engineering degree or a strong math and science background. Prior to taking BEPI students must complete at least three of the program courses: Math Methods, Applied Physiology I and Applied Physiology II (see Figure 2). These courses provide the mathematical and physiological background needed to allow the depth of understanding required for the summer residency. The online material for the residency built upon the material covered in these courses. Over the past three years 93% of students felt "completely prepared" for the weekend labs and workshops. 100% of students enjoyed the online/on-site hybrid format and believe that these weekend commitments were well worth the effort.

We have continuously improved the labs/workshops over the past three years in response to student evaluations. Consequently, we can only evaluate online preparation for both weekends for 2016. For eleven of the twelve labs, all of the students felt the online material completely prepared them for the on-site sessions. Table 5 summarizes the results of the online, anonymous end-of-semester survey posted in Blackboard to obtain feedback on the BEPI summer course. Since completion of the survey counted as extra credit, we had over a 90% participation rate each year.

Table 5: Summary of student comments from anonymous surveys

Survey Question: Did you feel that the required prerequisites prepared you for this course? (Math Methods & Physiology I & II) (n=33 over 3 years)	
Over prepared	3%
Completely Prepared	93%
Under Prepared	3%
Poorly prepared	0%

Survey Question: Did you enjoy the online/on-site format? (n=33 over 3 years)	
Strongly agree	57%
agree	33%
Neither agree nor disagree	9%
Disagree	0%
Strongly disagree	0%

Survey Question: Do you feel the online material prepared you for the labs/workshops? Summary for all 12 labs/workshops (n=11; 2016 data)	
Yes, I felt completely prepared for the lab	40%
I studied the material thoroughly, but I still had a few questions during the lab/workshop	49%
The material should have prepared me for lab, but I did not spend enough time on it.	6%
I did not feel at all prepared for this lab/workshop	5%

We also asked students for their general comments about the BEPI course in the anonymous survey, some of which are listed in Table 6.

Table 6
General Student comments on Biomedical Engineering Practice & Innovation Course

I very much appreciate the online/lab hybrid style of this course. I highly recommend building follow-on/specialized courses around this BEPI lab course.
BEPI is the most interesting course that I have taken in the program. I especially enjoyed the wide range of topics covered. The course exposed me to many areas of Biomedical Engineering that I was not familiar with.
The course is definitely worthwhile as it offers a great combination of flexibility for professionals and much needed hands on experience and interaction with experts. It was a challenging course that did not allow the students to fall behind or procrastinate, but it still offered enough flexibility and freedom so that professional students could handle the coursework while managing their personal lives. I would recommend the course to all my peers and future students of the program.
Excellent!! The course was very well run and organized, despite the NUMEROUS moving parts and logistics.
My favorite part of this trip was going into the clinical setting… I would like to see more classes have this type of structure... In the future, I would like to take another lab course with different labs, as I think that these skills translate over into a career as a biomedical engineer, especially in industry.
I had a really great time and the experience was worth it!
I think the flow of the weekend worked well. The labs were very hands-on and there was never a dull moment!
I felt comfortable with the labs from the lectures provided, and the office hours sessions were very helpful. I enjoyed the direction and topics covered in BEPI, and hope to see more courses like this created for future classes.
I appreciated all the instructors' enthusiasm and obvious knowledge in the subjects.
I appreciated the wide range of skills and topics they all presented. Everybody was accessible and wanted to help us all learn.
The instructors for the course were all exceptional at what they taught. They all truly worked hard on their material, knew their material by heart and were always available to answer questions and comment on concern. They are all exceptional mentor and invaluable instructors. I enjoyed my time learning from all of them.

JHU surveys all of their students upon graduation, with an approximately 50% survey participation rate. Table 7 lists results from the Class of 2016, which include the first cohort of fully online students. Interestingly, over two-thirds of our students felt a sense of community was important. We feel the design of the online Master's program to include the hybrid residency course can increase this sense of community.

Over the last four years, the majority of our students (>60%) have been personally responsible for funding their Master's degree, while only a third have been funded through their employers. Many of our Master's students are working hard to change their careers. Obtaining a Master's degree requires significant time and expense, and we have an obligation to ensure that rigorous well-designed courses are available as needed. The results from the JHU alumni survey indicate that we are achieving that goal.

Table 7: JHU Survey Results from Recent Alumni (Class of 2016, n=9)

Online courses were available when I needed them	100%
During my graduate studies at EP, I was able to successfully balance the needs of my academic work with those of my professional/personal life	100%
Courses in my program were rigorous	89%
A sense of community is important to me	67%
I would recommend (this university) to someone considering a part-time master's degree in engineering	89%

Since JHU first started offering online courses in ABE in Fall 2013, the number of applicants to the program has increased five-fold and the number of enrolled students has more than doubled. The number of students enrolled in online courses in ABE has increased considerably since we started in fall 2013. Simultaneously the number of students who attend face-to-face courses is 20% of what it was five years ago, and is projected to decrease significantly based on the number of newly enrolled masters students in the JHU ABE program who do not live in or near Maryland. These data are summarized in Table 8 below.

Table 8: % change in number of students in ABE

Applications (2013-2016)	+517%
Active students (2013-2016)	+244%
Face-to-Face enrollments (2011 to 2016)	-79%

As the number of applicants has increased, the quality and diversity of our students has also increased, and include people with a range of backgrounds and experiences from all over the world. ABE students have contributed their skills and expertise to benefit JHU through independent projects. One such example is the Ebola Personal Protective Equipment project, in which an ABE student working full time at the JHU Extreme Materials Institute contributed essential thermodynamic knowledge in developing the cooling system [5]. We have also enrolled a number of our own Johns Hopkins biomedical engineering undergraduate alumni.

Conclusion

An online program can provide the rigorous coursework and background needed to pursue a career in biomedical engineering, as evidenced by the growing number of universities offering online biomedical engineering Master's programs, such as those listed in Table 9.

Table 9
Online Master's Programs in Biomedical Engineering

Case Western Reserve University		Villanova University
Colorado State University		University of Illinois
Columbia University		University of Maryland (Clark)
Johns Hopkins University (Whiting)		University of Southern California (Viterbi)
Purdue University		

Online education has been shown to be as effective as face-to-face instruction in a number of studies [6], [7], particularly for higher performing students [8], which would include students in a Master's program. However, there is evidence that students enrolled in an online versus face-to-face course were significantly less satisfied [9] with the experience, despite achieving the same learning outcomes. We believe combining online coursework with a challenging residency program gives students the best of both worlds: online convenience and flexibility with hands-on experience in world-class clinical and laboratory settings. The summer residency course, BEPI, builds a sense of community between students and faculty. The combination of online required courses in math and applied physiology, in addition to BEPI, prepare students for more advanced courses in imaging, instrumentation, and translational tissue engineering, and consequently offers new career options for our students. To our knowledge, the JHU ABE program is the only online biomedical engineering Master's program, which includes an on-site residency specifically developed for working professionals. The program was designed to meet the needs of our working students and continues to evolve each year, offering new opportunities for future students whenever possible.

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