Ten-Year Evolution of an Accredited, Multisite Bachelor's in Biomedical Engineering Technology (BBET) Program

Chad E. Kennedy
DeVry University
ckennedy@devry.edu

William B. Phillips
DeVry University
wphillips@devry.edu

Anup Majumder
DeVry University
amajumder@devry.edu

Abour Cherif
DeVry University
acherif@devry.edu

Robert Aron
DeVry University
raron@devry.edu

Abstract

The growing demand for biomedical engineering technology personnel compounded by the rapid expansion and integration of medical device technology has led to a severe deficit of qualified professionals. The newly coined "Health Technology Management" (HTM) professional requires expanded technical, management and communication skills beyond the traditional biomedical technician. Furthermore, the broader medical, clinical, and biotechnology device industries have an unmet need for biomedical engineering problem solving, diagnostic and failure mode analysis skills. In answer to this need, our institution created a Bachelors of Biomedical Engineering Technology (BBET) degree. The BBET program was built upon an already existing Electronics Engineering Technology (EET) program as a specialization. The goals of the BBET program were to adequately prepare students for the medical device and clinical healthcare fields, by providing multi-location, campus based, hands-on learning labs combined with blended learning and industry internship experience. Since its inception, the BBET program and has undergone Engineering Technology Accreditation Commission (ETAC) of ABET accreditations. To date, it is the only BS BET degree accredited by ABET.

The curriculum combines fundamentals of mathematics, physics, biology, chemistry, anatomy and physiology, electronics as prerequisites to advanced studies in biomedical

instrumentation, biomedical imaging, medical device integration and networking, ethics and medical informatics. This paper presents the overall curriculum structure, course sequence within the biomedical engineering technology specialization, a general description of the content within each course and a program outcomes and assessment strategy. The program has been graduating students since 2006 and plans to make major overhauls to its laboratory environment and pedagogical models, to split the program into a two and four year offering, and to develop fully online deliverable version of the curriculum.

Introduction

The growing demand for biomedical engineering technology (BMET) personnel compounded by the rapid expansion and integration of medical device technology has led to a severe deficit of qualified professionals. According to the US Bureau of Labor Statistics *Occupational Outlook Handbook*, the biomedical engineering and engineering technologist still outpace expected job growth rates through the year 2022 at 27% and 30%, respectively [1]. This is startling growth rate projection and reflects an opportunity for institutions to expand their program base.

Although a handful of two-year BMET programs have enjoyed strong reputations in the past, the increasing requirements demanded by the medical device and healthcare institutions have made it increasingly difficult to train the students for the variety of roles that industry beyond medical device repair. This led universities such as Southern Polytechnic State (SPSU), Purdue, and DeVry to look into the feasibility of developing a Bachelor of Biomedical Engineering Technology [2].

Justification of Bachelor of Science in BET

Biomedical engineering and engineering technology industry research and feedback recognized the needed skill sets for the biomedical technology industry are rapidly expanding to include networking, medical device integration, and advance imaging systems understanding [3]. In addition, many soft skills, such as written and verbal communication, conflict management, and customer service, were not adequately addressed in many traditional two-year programs. The latter characteristics have long been shown to lead to career advancement to leadership positions [4].

Faculty at SPSU and DeVry University separately analyzed the feasibility of developing a stand-alone BBET program with similar conclusions [2]. The initial time and cost investment along with regulatory considerations for state approvals were significant. An expedient alternative was to incorporate BBET as a track in the already existing Bachelors in Electronic Engineering Technology (BEET) programs, although implementations between the institutions varied.

DeVry University in particular created the BBET degree using the foundations of the existing (BEET) program. The BEET founding team formulated and positioned an initial curriculum to meet the needs of the medical device industry, (clinical and medical device manufactures) based upon industry advisory committee feedback, existing two-year program models and industry research.

Curriculum Design

The biomedical engineering technology program design took into consideration many factors. First, programmatic accreditation requirements as specified by the Engineering Technology Commission (ETAC) of ABET Inc. were upheld [5]. Secondly, adjustments to the program of study were required to incorporate biomedical content into an existing electronics engineering technology program. The topics and number of biomedical and science courses chosen were based upon those used in traditional two-year programs at a rigor commensurate to a bachelorette degree, while still maintaining a strong electronics foundation. By doing this, graduating students would be potentially be prepared for two career pathways: one in a traditional electronics industry position and the other as a biomedical technologist or medical equipment repair specialist. In 2004, the BBET founding team created an initial curriculum comprised of 154 credits that took nine semesters to complete. As of 2008, the credits were reduced to 139 credits, with completion possible in just over four years. Figure 1 shows a typical plan of study.

Standard Mathematics and Science Requirements

There are some standard math and science requirements for all engineering technology students at our institution. These include one term of pre-calculus, followed by two terms of calculus. The second calculus term provides a brief introduction to differential equations. A 300-level course in Signals and Systems is then taken to support studies in upper-term courses in controls, signal processing, and telecommunications. Finally, critical topics to engineering technologies, such as Newtonian physics, electricity, thermodynamics, and electromagnetism, are studied across two calculus-based physics courses.

Two focused science courses are also included to address the specific needs of the BBET curriculum. A 100-level algebra-based, hybrid course in chemistry and biology was adopted to survey basic chemical and biological concepts that would later support the understanding of many biological processes and medical technologies, such as blood chemistry analysis and medical imaging, including nuclear medicine modalities. This option was chosen over a more traditional approach of having a standalone chemistry and biology sequence due to limited space in the program of study. A second course covers fundamentals of human anatomy and physiology while providing dynamic insights into body systems and physiology. Supporting concepts in chemistry and biology are reinforced, while lab exercises provide experience in measuring biological and physiological signals and processes.

Foundations in Electronics and Electrical Engineering Technology

A four-course sequence is taken by all engineering technology students where fundamentals of DC and AC analysis, electronic devices, circuit simulation, and use of test equipment are presented and reinforced. Additionally, some basic power topics such as amplification, power devices, and transformers are presented. Students purchase a kit that provides them all the general materials (wire, breadboards, components, tools, etc.) necessary to conduct hands-on laboratory work throughout their curriculum. Students are also given access to facilities with workbenches replete with electronic test equipment for laboratory exercises. A fifth and final introductory course covers the basic design and analysis of digital circuits, a basis for virtually all electronic systems in use today.

Seven additional courses are required by all majors to complete their fundamentals coverage. Structured and object oriented programing, assembly language, microprocessor architecture and peripheral control, applied programming, embedded systems, and networks and data communications are introduced. These are important pre-requisite areas of study for the biomedical students later when topics, such as biomedical system design and networked biomedical devices are covered.

Upper-Division Coursework in Electrical and Biomedical Technologies

Fundamental biomedical equipment and instrumentation technologies are formally presented in two 300-level courses. The first course presents principles of biomedical devices used to measure biological and physiological processes. Coursework addresses general purpose bioamplifier and filter units, electromyographs, noninvasive blood pressure systems, spirometers, pulse-oximeters, plethysmographs, tonometers, digital thermometers, phonocardiographs, and Doppler flow meters. Various transduction processes are presented, emphasizing physiological signal measurement and basic quantitative analysis techniques. The second course covers integrated biomedical systems and their associated medical applications, as well as troubleshooting techniques, safety practices, and maintenance procedures for various instruments and devices. Topics include electrocardiographs, brain activity monitoring recorders, patient monitors, pacemakers, defibrillators, electrical stimulators, electrosurgical units, dialysis equipment, and related equipment used in clinical environments. Throughout this course, students examine the basics of calibration, troubleshooting, repair, and certification necessary to determine if equipment and instruments meet specifications.

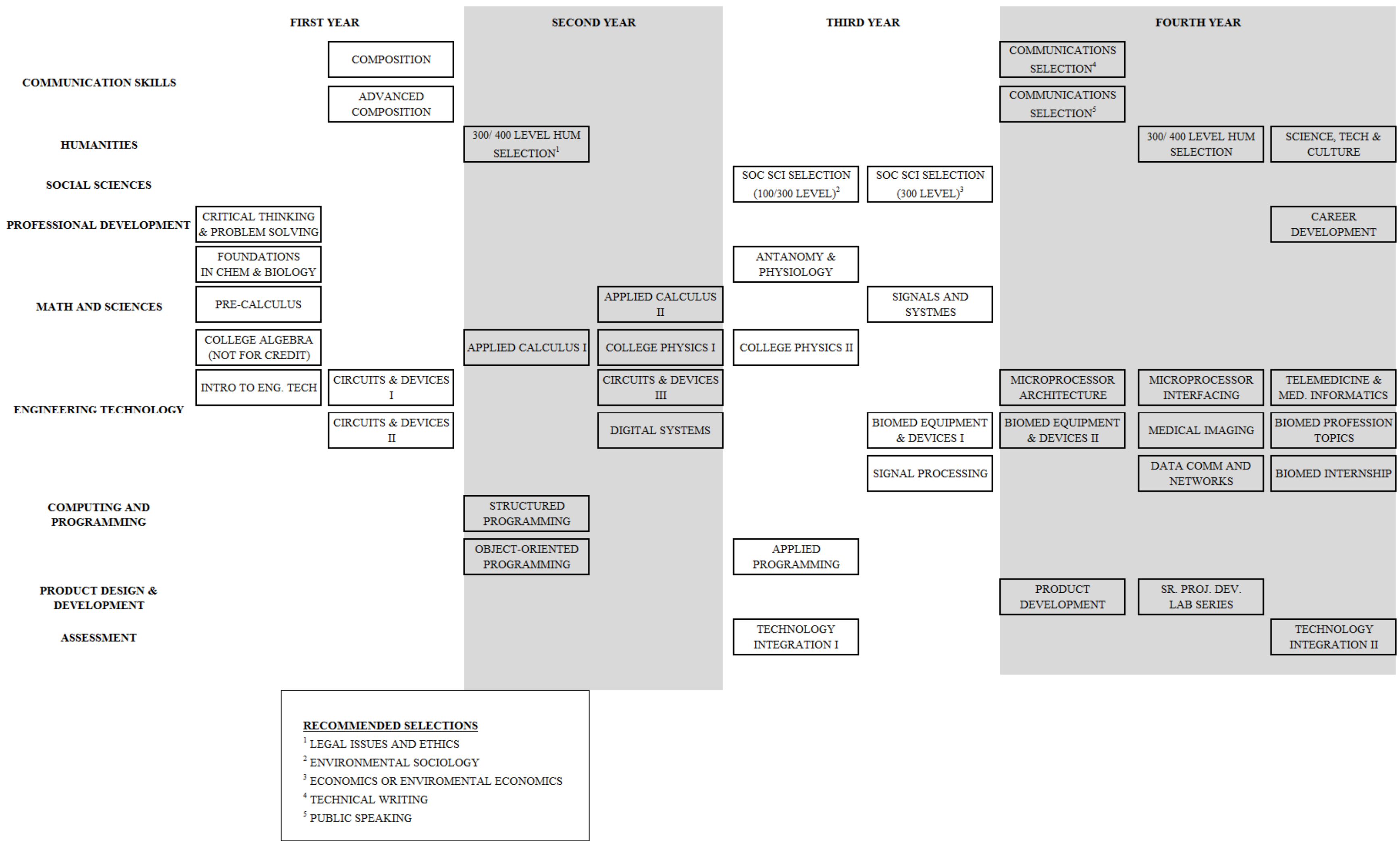


Figure 1. Typical plan of study at 139 credit hours

Students then advance to a series of 400-level courses including medical imaging, telemedicine and medical informatics, and professional topics. In medical imaging, various transmission- and emission-based imaging techniques including X-rays, computed tomography (CT), ultrasound (Doppler and basic imaging), magnetic resonance imaging (MRI), and positron emission tomography are presented. Fundamental physics of these technologies are addressed as needed, as are basics of image acquisition, processing, image format construction and storage types, and safety standards. Picture Archive and Communications (PACs) and Digital Image communication in medicine (DICOM standards) are also introduced and then reinforced in the telemedicine course. The Telemedicine and Medical Informatics course presents design principles and implementation of computer infrastructure as related to accessing medical databases, visualizing medical techniques, and transferring and manipulating medical data over communication networks using PACs, DICOM, and Health Level 7 protocols.

Finally, in a two-course sequence, students complete a 90-hour minimum internship experience at a biomedical facility and study professional topics related to the field in the classroom. Topics include projections for regulatory policy revision, advancements in equipment technology, and new medical and biotechnology frontiers. Students keep a detailed journal logging their internship time and activities, and review their field experience with faculty.

Integrated Technology Experiences

All senior engineering technology students undertake a 32-week senior project sequence with focus on their chosen field of study. The sequence starts with a product development course that examine product life cycle from initial concept through manufacturing. Students establish teams to develop a senior project, while the coursework addresses project management, total quality management, codes and standards, prototype development, reliability, and product testing. Teams prepare a written proposal for the senior project and make oral presentations to class. The teams are often interdisciplinary in nature, with a mix of biomedical, computer, and electronics engineering technology majors working together. To ensure the appropriate experience is provided to students with different areas of emphasis, the proposals are reviewed and approved to ensure program specific outcomes are met in this experience. These outcomes are addressed below in Table 3.

There is also a humanities capstone course that all students complete in their senior year called Technology, Society, and Culture. In this course, the relationship between society and technology is investigated through reading, reflection, research, and reports. The course identifies conditions that have promoted technological development and assesses the social, political, environmental, cultural, and economic effects of current technology. Discussions combined with oral and written reports draw together students' prior learning in a specialty area and general education courses. BBET students are encouraged to focus on contemporary issues concerning the development and utilization of biomedical technology. Further, there are several general education courses recommended that the students take to aid in the creation of meaningful capstone report in this course to support achievement of the published program student outcomes (discussed in later section) and development an inspiring biomedical technologist professional. These recommendations involve development of communication skills, business acumen, as well as legal, ethical, and environmental awareness (see notes at the bottom of Figure 1).

Lab Environment and Model

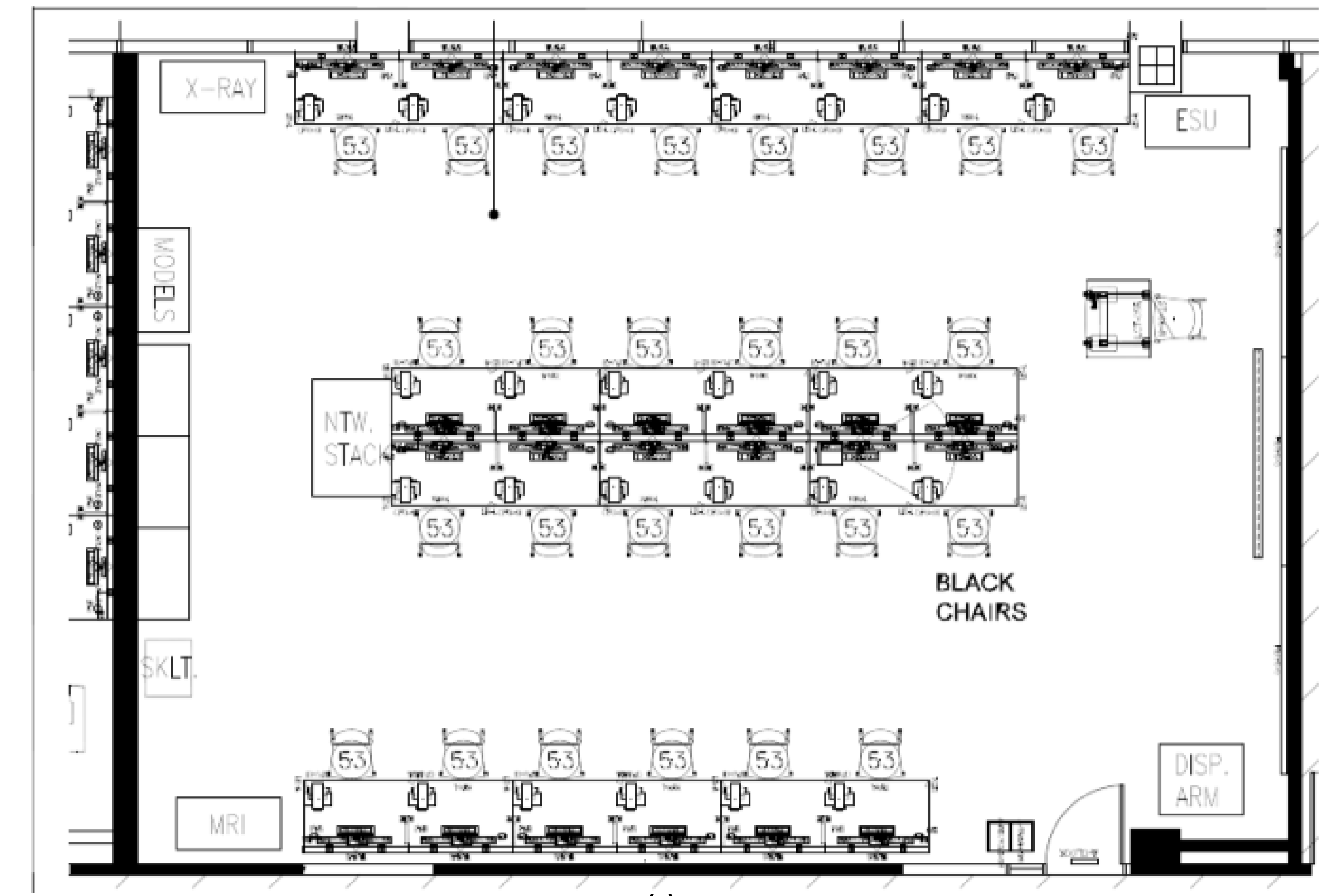
The biomedical engineering technology program is heavily rooted in hands-on, experiential active learning. The lab model has been refined over the years implementing best practices and continuous improvement feedback from faculty, students, and employers. The standard Biomedical Engineering Technology Lab Model consists of state of the art equipment and workstations where mini-lectures are integrated with lab activities (see Figure 2). Proxima, whiteboard, and screen are remotely connected with a podium to demonstrate or discuss a concept with the class and then immediately dive into an activity with the students.

A general lab station consists of a workstation computer connected to a National Instruments Elvis II+ with breadboarding, AI, AO, DIO, PWM, or encoder edge detection capabilities. In addition, standard workstations include function generators, power supplies and DMMs separately or integrated versions via the Elvis II+ units. Typically, labs have this setup for each pair of students due to cost constraints (see Figure 3a).

The workstation furniture is designed to address human factors such as posture and fatigue along with workspace factors, so the student can not only interact with the computer, but also has enough depth and width to the desk space to be working on a circuit design, taking notes, building a device etc. by simply moving the swivel arm flat screen away and pushing back the keyboard and mouse (see Figure 3b).

Several “device specific” stations are placed throughout the facility for team labs where equipment cost is a factor. As seen in Figure 3b, the lab includes ultrasound imaging station (*Sonosite 180Plus*, Sonosite, Inc.) where students get to experiment with ultrasound imaging and Doppler devices (*Model 811-B*, Parks Medical Electronics) with a variety of phantom models. Other stations focus on various skill sets such as MRI/NMR imaging and signals (*TEL CWS 12-50*, Techtronics, Inc.), infusion pumps preventative maintenance (*Alaris Systems*, CareFusion, Inc.), X-ray/fluoroscopy imaging (*JewelBox-70T*, Glenbrook Technologies, Inc.), patient monitoring and nurse monitor integration (*Nightingale Patient Monitor System PPM2 171-7100*, Zoe Medical, Inc.) seen in Figures 3c and 3d.

Other lab specific equipment not permanently set up is stored in labeled cabinets and bins at the back of the room, along with human anatomy and physiology models used throughout the curriculum. It is important to note that internship students and program graduates have been adequately prepared for the career field utilizing this lab model. This suggests a program built around a large hospital suite environment replete with expensive pieces of biomedical equipment, devices, and tools may not be necessary, as long as relevant hands-on activities are made available and an internship experience is required.



(a)

Figure 2. Classroom workspace model with both didactic and lab capabilities

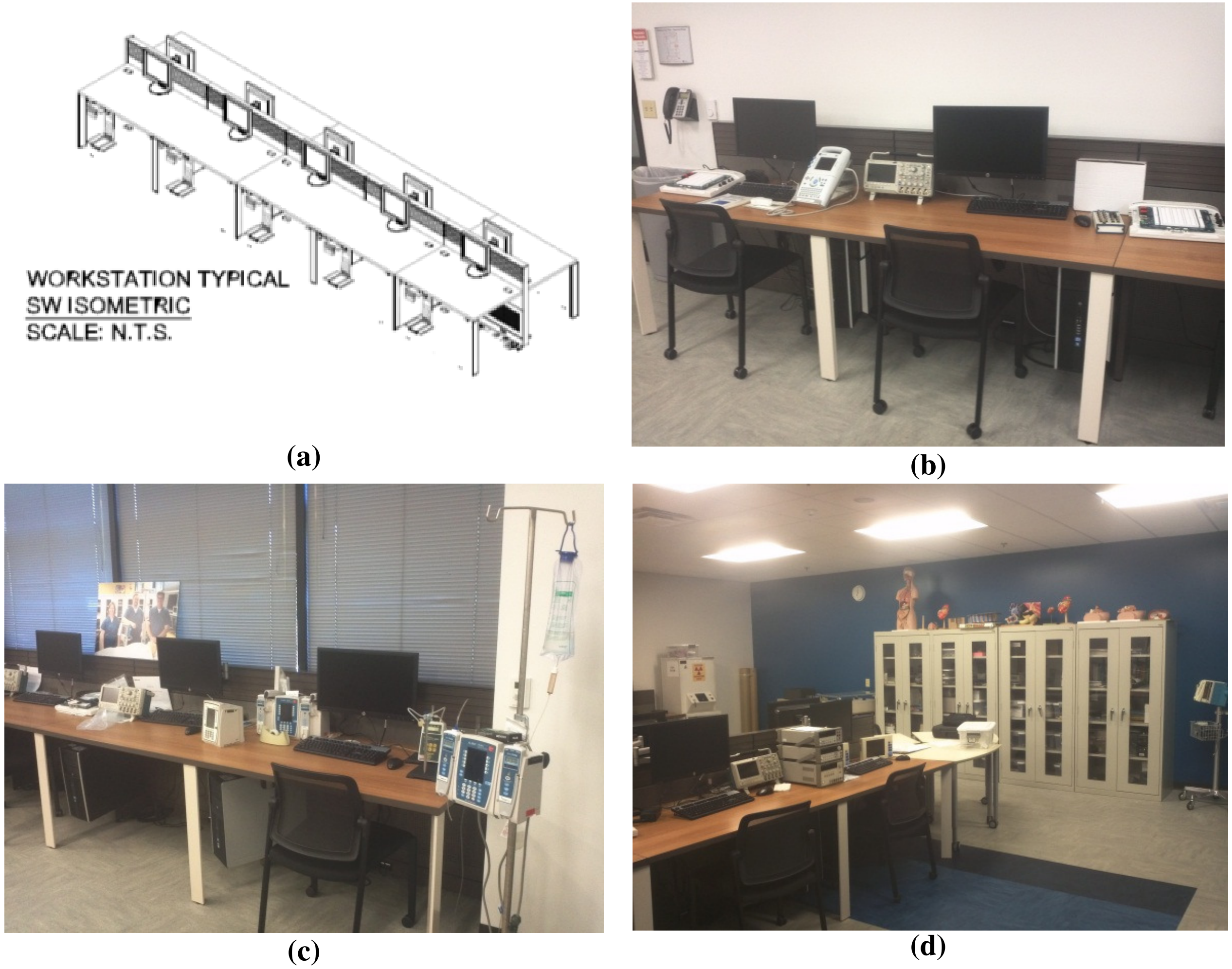


Figure 3. (a) shows the design of a workstation bench set to standard seating height instead of bench top height based on human factors such as posture and fatigue. (b) Shows the ultrasound station next to a standard station with the Elvis II+ units while (c) shows the infusion pump station for preventative and corrective maintenance and (d) shows the lab cabinet storage behind the patient monitoring station, next to the X-ray machine on the back left corner.

Program Educational Objectives, Student Outcomes, and Assessment Strategies

Program Educational Objectives

Program educational objectives (PEOs) are those attributes graduates are expected to attain within a few years of graduation. The PEOs for the biomedical engineering technology education have been written to meet the needs of and have been reviewed by the stakeholders of the program and are listed in Table 1. These statements are particularly board and adaptable to any engineering technology field.

Table 1. Program education objectives for the Biomedical Engineering Technology Program

Objective	Description
PEO #1	Finding employment in a biomedical technology-related position with appropriate title and compensation
PEO #2	Achieving a successful professional career
PEO #3	Adapting to change through continuous personal and professional development

Student Outcomes

The skills, knowledge, and behaviors expected of our biomedical students at the time of graduation are provided in Table 2. These student outcomes, listed A through L, have been written to satisfy the guidelines published by ETAC of ABET Inc. under the General Criterion 3a-k and Program Specific criteria for Biomedical Engineering Technology Programs. Table 3 presents specific attributes expected of students completing the biomedical program. These attributes are a subset of the Program Criteria found in ABET's Program Specific accreditation criteria for BET programs [5]. Table 4 summarizes the primary assessment strategy leveraged to measure attainment of SOs.

The senior project and humanities capstone are previously described. The BBET program also includes two additional integrated technology experiences that also serve as formative and summative assessment points. In first course (Technology Integration I in the program of study given in Figure 1), students apply and integrate concepts learned in computer programming, mathematics, and electronics and computer engineering technology courses in the first four semesters of the program by solving problems in the particular discipline or subject area. In Technology Integration II, students review math, science, electronics and biomedical-specific engineering technology concepts and then work to solve problems related to these concepts. Often, guest speakers and/or mini-projects are also conducted to enrich the student experience.

Table 2. Student outcomes mapped to PEOs and ABET criteria

Rating: 0 = No applicability; 1 = Low applicability; 2 = Medium applicability; 3 = High applicability

PEO #1	**PEO #2**	**PEO #3**	**Student Outcome (SO)**	**Description**	**ABET Criteria**
3	2	1	**A**	An ability to select and apply the knowledge, techniques, skills, and modern tools of their disciplines to broadly defined engineering technology activities.	General Criteria - Criterion 3a
3	1	1	**B**	An ability to select and apply knowledge of mathematics, science, engineering, and technology to engineering technology problems that require the application of principles and applied procedures and methodologies.	General Criteria - Criterion 3b
3	1	2	**C**	An ability to conduct standard tests and measurements; to conduct, analyze, and interpret experiments; and to apply experimental results to improve processes.	General Criteria - Criterion 3c
3	2	2	**D**	An ability to design systems, components, or processes for broadly defined engineering technology problems appropriate to program educational objectives.	General Criteria - Criterion 3d
2	3	1	**E**	An ability to function effectively as a member or leader on a technical team.	General Criteria - Criterion 3e
3	1	1	**F**	An ability to identify, analyze, and solve broadly defined engineering technology problems.	General Criteria - Criterion 3f
2	3	2	**G**	An ability to communicate effectively regarding broadly defined engineering technology activities.	General Criteria - Criterion 3g
1	3	3	**H**	An understanding of the need for and an ability to engage in self-directed continuing professional development.	General Criteria - Criterion 3h
1	3	3	**I**	An understanding of and a commitment to address professional and ethical responsibilities including a respect for diversity.	General Criteria - Criterion 3i
1	2	3	**J**	Knowledge of the impact of engineering technology solutions in a societal and global context.	General Criteria - Criterion 3j
1	3	2	**K**	A commitment to quality, timeliness, and continuous improvement.	General Criteria - Criterion 3k
3	2	2	**L**	An appropriate level of achievement of the body of knowledge required by the Biomedical Engineer Society (BMES)	Program Specific Criteria

Table 3. Delineation of student outcome L

Subset Criteria for Outcome L	Description
L1	Demonstrate knowledge and hands-on competence in the application of circuit analysis and design, analog and digital electronics, microcontroller, programming, bioengineering systems, and safety in the building, testing, operation, and maintenance of biomedical equipment
L2	Demonstrate knowledge and hands-on competence in the application of physics, chemistry, and biological sciences to building, testing, operation, and maintenance of biomedical equipment in a rigorous mathematical environment at or above the level of algebra and trigonometry
L3	Demonstrate knowledge and hands-on competence in the ability to analyze, design, and implement bioengineering systems
L4	Demonstrate knowledge and hands-on competence in the ability to utilize statistics/probability, transform methods, discrete mathematics, or applied differential equations in support of bioengineering systems
L5	Demonstrate knowledge and hands-on competence in an understanding of the clinical application of biomedical equipment

Table 4. Primary assessment strategies

Assessment	Description / Summary
Formative Assessment Exam	Examination administered after 200 –level technical courses have been completed to address achievement of Student Outcome A and Program Specific Outcomes (L1 – L2).
Summative Assessment Exam	Examination of all technical coursework to address achievement of Student Outcome A and Program Specific Outcomes (L1 - L5)
Senior Project	This is an integrated curriculum experience used to assess Student Outcome B to K and L1 to L5.
Humanities Capstone	This is an integrated curriculum experience used to indirectly assess Student Outcomes E to K.

Initial Evaluations and Improvements

The initial collective feedback from our industry advisory committees, Technology Accreditation Commission of ABET (now ETAC of ABET), alumni and faculty was obtained through the accreditation process in 2006 and continuously revisited annually. The main focus for initial improvement was in three areas: faculty development, internship program development, and addition of breadth to topics.

Ensuring that there were enough "qualified" faculty to support the program was addressed with additional hiring of PhD-level faculty with biomedical engineering degrees or a combination of electrical or mechanical engineering PhD-level faculty with extensive biomedical engineering experience in clinical, industrial or research settings. Follow up visits validated the faculty improvements. At flagship campuses, multiple faculty overlap to teach the cross-disciplinary nature of the Biomedical Engineering Technology program.

The internship program evolved from a tertiary form of educational experience for our students to a primary, integrated experience designed into the curriculum. A formalized internship program remains a requirement for graduation. The institution has partnered with local hospitals, third-party service organizations, medical device manufacturers and industries to provide real-world, hands-on experiences for our BBET students. Oftentimes these internship experiences lead to gainful employment for a win-win-win relationship for the student, employer and university.

The curriculum has expanded the number of competency topics to include a broader base of medical devices, testing and analysis tools and increasing networking and health systems integration. Technical topics, such as image-guided radiation therapy, mobile telemedicine, and distributed healthcare and soft skills topics such as conflict management, customer service, project management are just a short list of added topics in the curriculum. This demonstrates the adaptability of this program to new technologies and competencies desired by the career field as they arise.

Continuous Improvement and Future Work

The ABET criteria for engineering technology programs and our outcome-based assessment model serve as the corner stone to the program's continuous improvement and quality assurance. The BBET program has had graduates since spring of 2006, and our institution holds and maintains ETAC of ABET accreditation for a campus-based delivery of its BBET program at 12 locations. Originally, each location offering the program was accredited separately. In 2010, our institution successfully executed a comprehensive, multi-site evaluation of these programs nationally by ETAC of ABET.

Faculty and engineering technology administration revisited the applicability and relevance of the program educational objectives student outcomes in the 2012-13 academic year. Although the PEOs and SOs are generally viewed to be acceptable, there are plans to improve and update them. Further, the internationally recognized framework of conceive, design, implement, and operate (CDIO) [6] will be employed in a program redesign, following a proposed paradigm shift for engineering technology programs by Houston's Department of Engineering Technology in the College of Technology [7].

Recently, the Association for the Advancement of Medical Instrumentation (AAMI) provided an additional classification for the biomedical profession - Health Technology Management (HTM). It is particularly applicable to a four-year program in biomedical engineering technology education, as the HTM definition requires expanded technical, management and communication skills beyond the traditional biomedical technician with an associate's degree. The *minimum* core competencies published last year by the AAMI Education Committee is a standard set of competencies based upon a two-year program, but also include recommendations for expanded skill sets [8]. The demand for such graduates, as well as international needs, will also drive future improvements and online capabilities to train next generation of BMET and HTM professionals. Hopefully, this program and information will encourage and empower other countries, especially developing communities, to create similar curriculum and prepare BMET and HTM professionals for their respective communities.

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Biographies

DR. CHAD E. KENNEDY is a professor and chair of Biomedical Engineering Technology Program for the College of Engineering and Information Sciences at DeVry University. Dr.

Kennedy is responsible for curriculum design and development. Dr. Kennedy holds both a bachelor's degree in Mechanical Engineering from the University of Texas at Austin and a master's and doctorate degrees in Bioengineering from Arizona State University. Dr. Kennedy may be reached at ckennedy@devry.edu.

DR. WILLIAM B. PHILLIPS is an associate dean for the College of Engineering and Information Sciences at DeVry University. Dr. Phillips is responsible for program development, curriculum, instruction, assessment and accreditation matters. He holds a Ph.D. and master's degree in Bioengineering from Arizona State University and a bachelor's degree in Electrical Engineering from the University of Illinois. Dr. Phillips may be reached at wphillips@devry.edu.

DR. ANUP MAJUMDER is a senior professor teaching Biomedical and Electrical Engineering Technology at the DeVry Columbus, Ohio campus. Dr. Majumder has over 30 years of experience in teaching and R&D in areas of instrumentation, signal processing and engineering. He received a MSEE in Control Engineering and Ph.D. (Engg) in Biomedical Engineering from Jadavpur University. Dr. Majumder may be reached at amajumder@devry.edu.

DR. ABOUR H. CHERIF is the national associate dean of curriculum for math and science, and clinical laboratory sciences at DeVry University Home Office, Downers Grove, IL. He is past president (2008–2009) of the American Association of University Administration. He holds a B.S. from Tripoli University, an MS.T. from Portland State University, and a Ph.D. from Simon Fraser University, Canada. Dr. Cherif may be reached at acherif@devry.edu.

ROBERT D. ARON is dean of New Program Development for DeVry University where he leads the development of new degree programs and new majors across disciplines. He received his M.A. in International Relations from the University of Chicago, MBA from the Illinois Institute of Technology, and M.A. in Education and Ph.D. in Instructional Design and Organization Development from Ohio State University. Dr. Aron may be reached at raron@devry.edu.