AC 2011-166: TRANSDISCIPLINARY BIOMEDICAL INSTRUMENTATION LABORATORY

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Transdisciplinary Biomedical Instrumentation Laboratory

Abstract

The paper describes a transdisciplinary biomedical instrumentation laboratory that will serve as a research, educational, and training facility for Biomedical Engineering, Biomedical Engineering Technology, and Nursing prejunior, junior, and senior students at Drexel University. The developed laboratory will be utilized by the number of courses, such as Biomedical Instrumentation, Biomeasurements, Healthcare Technology, Biomedical Electronics, Medical Device Development, etc. Teams of biomedical engineering, biomedical engineering technology, and nursing students will be created to participate in a series of laboratory experiences and clinical simulations designed to foster a deeper appreciation of the issues and opportunities faced by individuals in these different occupations. Each team of three students will have the opportunity to participate in high impact laboratory experiences designed to promote clinical efficiency and efficacy while improving medical device design and maintenance and thus reducing medical errors. In a pilot-scale biomedical instrumentation laboratory, biomedical applications and techniques will be studied through experiments that closely simulate health care-relevant processes or scenarios. Biomedical engineering, biomedical engineering technology, and nursing students will work together to understanding fundamental issues involving medical device performance and maintenance. These teams will also participate in clinical simulations so that biomedical engineering and technology students will come to understand the environment in which their devices must perform, the individual users' needs and expectations, and the workload as it relates to maintenance. The developed laboratory procedures will expose students to typical applications of medical equipment in various medical settings and will include characterization of this equipment based on specific regulations of health care industry, including safety and effectiveness issues.

Introduction

The main goal of this project is to develop a biomedical instrumentation laboratory that will serve as a research, educational, and training facility for Biomedical Engineering, Biomedical Engineering Technology, and Nursing students at Drexel University. Students from the School of Technology and Professional Studies, School of Biomedical Engineering, and College of Nursing will also utilize the developed laboratory for senior design projects (capstone sequence), which will measure the impact on the students from all disciplines. This is part of a new and innovative transdisciplinary approach to the education of health care professionals, which links design and development of medical devices (biomedical engineering) with maintenance of those devices in a clinical environment (biomedical engineering technology) and clinical application and use of the devices in actual patient care (nursing). We believe that cross-training of individuals from these programs will facilitate the design and development of medical devices, which are easier and more cost-effective to maintain as well as more useable and thus more clinically effective. Additionally, knowledge of the design and development of medical technology will facilitate proper maintenance in the clinical environment thus avoiding patient adverse events and errors and promoting optimal care. Finally, a more fundamental understanding of the technology with which they must interact will better acquaint nursing

students with both the advantages and disadvantages of specific devices as well as the expected operating parameters. This will improve nurses' ability to deliver effective patient care.

The complete project includes the following components:

1. Clinical simulations.
2. Biomedical Instrumentation Laboratory.
3. Inventorium for Medical Device Design and Development.

The first part of the project, which includes the new state-of-the-art Critical Skills Simulation Lab (CSSL) at the College of Nursing and Health Professions using Human Patient Simulators (HPS), Standardized Patient (SP) or hybrid cases, was completed in May 2010 (Figure 1).

Figure 1. Nursing students during the laboratory exercises in the simulation lab.

The physical space (2300 square feet) consists of 2 large labs, control, and 'prop' room, which can be transformed into acute (ICU, OR, ER, Medical Surgical, or Women's Health) or community (home, board room, community center) environments. By exposing teams of nursing, biomedical engineering technology, and biomedical engineering students to scenarios involving the use of medical devices in these various environments, these students will become familiar with the actual clinical situations, in which medical devices are used. Such exposure will result in better device design, maintenance, and utilization.

The second part of the project, which includes the development of the biomedical instrumentation laboratory, will provide students with a more fundamental understanding the basic structure and function of various common medical devices. Experiments will be designed to demonstrate normal and abnormal function of devices, the role of calibration, variability and expected values, quality control issues, and error detection[1-4]. Part of the process will be to develop a solid understanding of design criteria for medical devices and how this interacts with maintenance and usability issues[5-8]. This laboratory will serve as an essential bridge between clinical simulation and the Inventorium, in which biomedical engineering students will lead teams of biomedical engineering technology and nursing students in the creation of innovative products, devices and processes. While it cannot be expected that every idea thus investigated will reach the market as a medical device or product, the act of creation and development will help to train students' minds in the engineering development process.

The proposed curriculum is envisioned as follows. Teams of biomedical engineering technology, biomedical engineering, and nursing students will participate in each of three simulation/laboratory experiences as part of their educational experiences. In the clinical simulations, nursing students will serve as team leaders and guide their teams through a series of clinical simulations involving the use of various medical devices and procedures. In the biomedical instrumentation laboratory, biomedical engineering technology students will act as team leaders to investigate a series of experiences and projects designed to thoroughly acquaint student participants with the basic design and implementation issues associated with application of current medical technology. The final part of this transdisciplinary curriculum will be the Inventorium, where the design process for new medical technology will be investigated through the leadership of biomedical engineering students.

A major benefit to this approach is that it is entirely modular – each experience can either be implemented independently or as part of the larger curriculum. Thus, the first two tiers of the curriculum, such as the clinical simulations laboratory and biomedical instrumentation laboratory, will be completely developed and tested prior to developing and implementing the Inventorium. This also has significant advantages in terms of replicating aspects of the curriculum at other institutions. Not all institutions may have the ability to implement all phases of the curriculum simultaneously. Some colleges may only be able to implement a subset of the proposed experiences. Since each tier can be evaluated on its own merit, other institutions can determine the value of each tier and implement those, which fit that institutions needs, requirements, and/or abilities.

Objectives and Outcomes

The Critical Skills Simulation Lab (CSSL) is currently in use for the training of nursing students. The curriculum will be adapted to include teams of nursing, biomedical engineering technology and biomedical engineering students. In these simulations, the nursing students will act as team leaders and will facilitate the introduction of the biomedical engineering and biomedical engineering technology students to an active clinical environment.

The biomedical instrumentation laboratory described here will support courses for the School of Technology and Professional Studies (SoTAPS), School of Biomedical Engineering, Science and Health Systems (SoBESHS), and College of Nursing and Health Professions (CoNHP). The laboratory work will be supported and supplemented with lectures and seminars on health care-related topics. Experiments and projects focus on two key areas: (1) medical diagnostics, such as biomedical ultrasound, cardiography, electromyography, and electroencephalography and (2) medical therapeutics.

The objectives of this innovation are to:

1. Develop an approach to cross-educate biomedical engineering, biomedical engineering technology, and nursing students in the fundamentals of medical technology design, maintenance and use.
2. Attract students with an interest in biomedical engineering to biomedical engineering technology and biomedical engineering programs by developing a state-of-the-art

biomedical instrumentation laboratory, which simulates environment of various medical facilities creating an in-depth case study approach.

3. Prepare students for employment in the health care field in areas, such as development, maintenance and utilization of medical devices and systems for diagnostic and therapeutic applications. Special attention will be placed on a breadth of medical facilities-related activities with emphasis toward developing a biomedical engineering, biomedical engineering technology, or nursing professional with a wide range of skills and competencies of value to the health care organization.
4. Train the students in the methodology of the development and maintenance of medical equipment according to the medical industry and FDA (Food and Drug Administration) requirements.
5. Foster a team approach in the laboratory process simulation to develop skills and learn the importance of medical industry-based progress rather than individual advancement, especially in health care-related fields.
6. Develop the laboratory- and project-based simulation from several biomedical areas related to development and maintenance of medical equipment.
7. Provide biomedical engineering technology, biomedical engineering, and nursing students with toolsets designed specifically for application in health care settings, including co-op cycles for Drexel students.

The outcomes of this project will provide a needed component of practical biomedical-related education for biomedical engineering technology, biomedical engineering, and nursing students destined for employment in health care industries. The outcomes are similar for all participating students, even though different students bring different skill sets to the table and are being evaluated on the "team" endeavor. The effective delivery of health care is heavily reliant on the appropriate and timely utilization of medical technology and equipment. The demand for specialists in this field is increasing and has become a driving force for innovative biomedical instrumentation-related education and research as a means to meet current and future needs of the health care industry. Students in the developed laboratory are expected to gain:

- Hands-on experience with diagnostic and therapeutic medical equipment in a simulated clinical environment;
- Direct experience with medical equipment fostering an understanding of basic functions, expected values, error detection and quality control;
- Hands-on experience with calibration methods, appropriate and inappropriate settings of medical devices and the results of those settings;
- Competency in evaluation of safety and effectiveness of medical equipment;
- Understanding of concepts related to rules and regulations in health care industry according to the industry and FDA requirements.

The development of the interdisciplinary biomedical instrumentation laboratory represents an innovative approach for integrating courses in biomedical engineering technology, biomedical engineering, and nursing. Current educational practices result in a significant siloing of the processes involved with deployment and utilization of medical technology. Biomedical engineers design and develop, biomedical engineering technologists maintain, and nurses and other health care professionals use medical technology. Moreover, those who maintain and use technology

gain a more thorough understanding of the technology's advantages and limitations if the basics underlying the design and implementation of that technology can be understood. The biomedical instrumentation laboratory-based curriculum creates a developmental feedback loop, by which clinical requirements and procedures are integrated with biomedical engineering industry methods and principles using hands-on laboratory- and project-based learning in biomedical technology development, maintenance, and use. Close collaboration between the School of Technology and Professional Studies, School of Biomedical Engineering, Science and Health Systems, and College of Nursing and Health Professions will expose students to real-world applications of medical equipment in various medical settings and will include characterization of this equipment based on specific regulations of health care industry, including safety and effectiveness issues.

The overall purpose of the new laboratory is to create a transdisciplinary approach to the education of biomedical engineers, technologists, and nurses so that each group has the opportunity to participate in high impact laboratory experiences designed to promote clinical efficiency and efficacy while improving medical device design, development, and maintenance and thus reducing medical errors. This will involve creating teams of biomedical engineering, biomedical engineering technology, and nursing students who participate in a series of laboratory experiences and clinical simulations designed to foster a deeper appreciation of the issues and challenges experienced by individuals in these different occupations. The differences in technical and clinical backgrounds of the students involved will be addressed pro-actively and concurrently by providing:

- Initial training, such as interdisciplinary collaboration strategies and communication techniques. Providing these essential interdisciplinary collaboration skills, will prepare students to not only work effectively with other disciplines, but actually thrive in this role.
- Ongoing group process facilitation including peer-coaching during laboratory sessions.

The developed biomedical instrumentation laboratory, including laboratory procedures and manuals will be made available to community colleges partnering with Drexel University and also to middle and high schools participating in activities organized by the Drexel's faculty. Specifically, the hands-on laboratory- and project-based courses described below will be offered to the students of Burlington County College (BCC), Delaware County Community College (DCCC), Montgomery County Community College (MCCC), Community College of Philadelphia (CCP), and Pennsylvania Institute of Technology (PIT), which have articulation agreements with Drexel's engineering technology program.

Background

During the last decade, medical science underwent significant technological changes. Clinical medicine has become increasingly dependent on more sophisticated technologies and the complex equipment associated with it. New generation of state-of-the-art-medical equipment replaced the previously installed equipment in hospitals and clinics and requires a new generation of clinical engineers to properly repair, service, and maintain this equipment. As a result, the National Science Foundation and other federal and state agencies have recognized the importance of engineering technology specialists[9]. The need for a large number of practical

engineers with background in advanced and emerging technologies over the next decade has been clearly outlined[10-13]. Engineering education is changing with its focus, shifting from the traditional theory-based curriculum to more team-based learning, problem solving with open-ended solutions, hands-on projects, and team-oriented communications[14]. Addressing the need for skilled engineering technology and engineering workers is a required competitive and survival strategy for various industries[13]. The new educational laboratories can significantly contribute to the development of technologically literate students and workforce that will be in great demand nationwide[15]. During the development of the biomedical instrumentation laboratory, existing educational materials and teaching strategies based on the prior results of the courses offered to students of Engineering Technology, School of Biomedical Engineering, and College of Nursing and Health Professions will be revised and exchanged.

The Curriculum

Tier 1 – Clinical Environment

The Clinical Simulations Laboratories are based at the College of Nursing and Health Professions. This integrated hardware and software system includes multidisciplinary case scenario building functionalities, live & archived viewing of simulation encounters, manual or automatic recording capabilities, documentation of learner behaviors, communication, and the assessment of skills. A fully customizable training tool assists in the training of standardized patient actors. In addition, the software allows for 1) controlled access, 2) live & archived viewing with blinded "grading" & "scoring" of items and the ability to generate more than 50 reports.

Types of standardized patient (SP) encounters include a) clinical skills, b) ethical dilemmas, and c) communication (such as communicating bad news). Participants who utilize the SP labs for formative and summative experiences include 1) multidiscipline academic programs (undergraduate/graduate nursing, physician assistant, physical therapy, women's health, radiology technology, couples and family therapy, creative arts therapy, and behavioral health); 2) research based activities (faculty development, delegation and conflict resolution) and 3) practical training in supervisory counseling of 'problem' staff. For this curriculum, scenarios will be developed using medical technologies in simulated clinical environments. Although nursing students will take the lead and engage in the actual 'patient care', biomedical engineering technology and biomedical engineering students will participate as active observers. After each scenario, each team will write an 'after action' report describing the scenario with implications for medical device design, maintenance and use. In particular, suggestion for improvement in procedures and the possible development of new medical technology will be emphasized.

The clinical simulations will be held in alternate quarters from the biomedical instrumentation laboratory. Thus, the initial simulations with biomedical engineering technology and biomedical engineering student participants will be in the fall and spring terms. Faculty from School of Technology and Professional Studies (SoTAPS), the School of Biomedical Engineering, Science and Health Systems (SoBESHS), and the College of Nursing and Health Professions (CoNHP) will evaluate the team reports and determine the effectiveness of the approach in generating sufficient understanding of the opportunities and limitations of operating in a clinical environment in the biomedical engineering and biomedical engineering technology students.

Tier 2 – Biomedical Instrumentation Laboratory

The biomedical instrumentation laboratory is being built around a three-credit course BET 301-Healthcare Technology consisting of two hours of lecture and two hours of laboratory work each week. Labs will be organized around current developments in the field of biomedical instrumentation. Measurement procedures and experiment descriptions will be adapted and implemented from the clinical simulations. As in Tier 1, students from nursing, biomedical engineering technology, and biomedical engineering will work as teams to research problems involving applications of medical technology, develop possible approaches to solving the problems, and begin to structure possible solutions. For this experience, the biomedical engineering technology students will serve as team leaders. During the labs, students will be introduced to tools, methodologies and techniques that may be useful to understanding the design and function of each device or technology. They will carry out experiments and investigations and describe the results of the experiments in team reports for each experiment or investigation. As before, each team member will not only contribute to the overall report but also describe how these data and results affect their own specific situations and the design of future medical technology. After completion of all laboratory sessions, each team would be responsible for writing a final report that summarizes the current state in the area, describes the experimental techniques utilized, discusses the expected outcomes, provides data of the actual outcomes, and explains the reasons for the departures between the expected and the actual results. The team will analyze the data, draw conclusions and suggest possible ways for improving the accuracy of their experiments. The team will also suggest ways in which the medical technology thus investigated could be improved for more effective use and maintenance. Afterwards, the team presents their findings to the class as a whole.

The BET 301 course will be offered to undergraduate students of SoTAPS, SoBESHS, and CoNHP in alternate academic quarters with planned course review in intervening quarters. Comprehensive laboratory manuals will be developed. The biomedical instrumentation laboratory-based courses for these multidisciplinary teams will be offered in winter and summer quarters following the clinical simulations experience (Tier 1).

As described above, this biomedical instrumentation laboratory is being developed as part of an innovative transdisciplinary curriculum designed to serve primarily students pursuing a B.S. degree in biomedical engineering technology, biomedical engineering, and nursing. However, the state-of-the-art facility also will serve working individuals interested in improving their skills in biomedical instrumentation and medical device regulations, as well as those seeking knowledge for professional advancement. These can include working nurses and other medical professionals desirous of increasing their knowledge and facility with medical technology. In addition, the Biomedical Instrumentation Laboratory will support a variety of laboratory and project components for existing courses in the biomedical engineering and biomedical engineering technology programs at Drexel University (Table 1).

Table 1. Existing courses to be supported by the biomedical instrumentation laboratory.

Rubric	Course Title	Quarter Credits
BET 301	Healthcare Technology	3
BET 302	Biomedical Electronics	4
BET 303	Medical Imaging Systems	3
BMES 302	Biomeasurements Laboratory	2
BMES 391	Biomedical Instrumentation I	3
BMES 392	Biomedical Instrumentation II	3
BMES 488	Medical Device Development	3

When applied to the Biomedical Engineering Technology program at SoTAPS, for example, these laboratory-based courses will provide students with the knowledge they need to work in the medical field operating complicated diagnostic and patient care equipment. After graduation, students will be able to work in a variety of medical facilities from doctor's offices to hospitals. Specifically, they will be responsible for problem solving, data interpretation, complex troubleshooting, preparation of specifications, scheduling, planning, analysis, project management, and decision-making. The new curriculum will allow for broader participation from three School's undergraduate population in a clinical experience while simultaneously enhancing that experience through a close association with the students from partnering program.

Evaluation and Assessment

Evaluation of the project and data collection will begin soon after the start of each course, which utilizes the new laboratory. Students will be administered a pre-test, which assesses the entering knowledge requirements for the course. For example, their knowledge of appropriate mathematics, physics, and chemistry will be evaluated. Based on the results of the test, students will be divided by groups according to the think-share-report-learn (TSRL) process, which will involve student peer coaching to help each other during the laboratory procedures[16-18].

An independent evaluator will manage the implementation of an integrated collection of formative and summative assessment strategies for the laboratory-based courses utilizing the Biomedical Instrumentation Laboratory. Evaluation evidence will be generated through activities integrated into the natural flow of the project. The formative evaluation will provide evidence of the strengths and weaknesses of the project, informing the PI's understanding of what works and what does not in order to inform project progress and success. Document analysis will interpret the quality and usefulness of materials produced in project delivery, while surveys will reveal attitudes and levels of understanding among participants. Participant observations conducted in the form of self-assessment journals and logs, as well as more objective professional non-participant observations, will reveal underlying project and personal dynamics. Knowledge outcomes and skill development in the form of instructional materials and strategies, as well as applied knowledge products will be evidenced in the form of content generated in the course. Data generated by students during the laboratory procedures in the Biomedical Instrumentation laboratory will be used by instructors in assessing the progress of the students in learning of development, operation, and troubleshooting of biomedical equipment. A summative evaluation will assess the quality and impact of an implemented strategies based on the students' final

exams and presentations, including corrections of the collected results and conclusions. Standard course evaluation forms will ask students to compare their level of competence in areas identified in the course objectives at the end of the course to their level before taking the course. This provides immediate feedback on the success of the course in meeting its objectives. To assess the long-term impact of the course, information will be derived from several sources. For undergraduate participants, information from senior exit interviews can be used. Additional data will be collected on the career choices of students who have taken the proposed course and their overall employment rates.

Summary

The new transdisciplinary program based on the biomedical instrumentation laboratory to be developed is described in this paper. The main participants in this development are the School of Technology and Professional Studies, School of Biomedical Engineering, Science and Health Systems, and the College of Nursing and Health Professions. Teams of biomedical engineering, biomedical engineering technology, and nursing students will participate in a series of laboratory experiences and clinical simulations designed to foster a deeper appreciation of the issues and challenges faced by individuals in these different occupations. The range of laboratory exercises will include latest development of the biomedical instrumentation and implementation of laboratory procedures correlated to more complicated experimental techniques and emerging technologies while keeping the course within prescribed time and credit limits. In addition, documentation, including manuals for biomedical simulation and laboratory procedures, will be developed. The laboratory procedures and experiments will be evaluated for effectiveness and flexibility of the developed techniques as well as student learning outcomes of acquired knowledge and competence. This innovative approach promises to have significant, transformative impact upon the educational processes and preparation of future professionals in the health care industry.

References

1. Kohn, L.T., Corrigan, J.M., and Donaldson, M.S. (Eds.) (2000). *To Err is Human: Building a Safer Health System.* Institute of Medicine. National Academy Press: Washington, D.C.
2. *Medical Errors: The Scope of the Problem*. Fact Sheet, Publication No. AHRQ 00-P037. Agency for Healthcare Research and Quality, Rockville, MD. http://www.ahrq.gov/qual/errback.htm. Accessed December 27, 2010.
3. Page, Ann (Ed.) (2004). *Keeping Patients Safe: Transforming the Work Environment of Nurses*. Committee on the Work Environment for Nurses and Patient Safety. National Academy Press: Washington, D.C.
4. Bogner, S. (1994). *Human Error in Medicine*. CRC Press: Boca Raton, FL.
5. Powell-Cope, G., Neslon, A.L., Patterson, E.S. Chapter 50: *Patient care technology and safety* in *Patient Safety and Quality: An Evidence-Based Handbook for Nurses*. Agency for Healthcare Research and Quality, Rockville, MD. http://www.ahrq.gov/qual/nurseshdbk/. Accessed December 21, 2010.
6. Reason, J. (1997). *Managing the Risks of Organizational Accidents*. Ashgate Publishing: Farnham, UK.
7. *Medical Device Use-Safety: Incorporating Human Factors Engineering into Risk Management*. (2000). U.S. Department of Health and Human Services, Food and Drug Administration. http://www.fda.gov/downloads/MedicalDevices/DeviceRegulationandGuidance/GuidanceDocuments/ucm094461.pdf. Accessed December 21, 2010.

8. Fennigkoh, L. and Haro, D. *Human factors and control of medical-device related error*. (http://www.freescale.com/files/microcontrollers/doc/brochure/HumanFactorsMedicalError.pdf) Accessed May 15, 2010.
9. *Science and Technology from a Global Perspective*. AAAS Annual Report 2008. http://www.aaas.org/publications/annual_report/2008/aaas_ann_rpt_08.pdf. Accessed March 25 2008.
10. *Investing in America's Future: Strategic Plan FY 2006-2011*. National Science Foundation (http://www.nsf.gov/pubs/2006/nsf0648/NSF-06-48_5.pdf). Accessed November 5, 2009.
11. U.S. National Science Board (2004). Chapter 3: *Science and Engineering Labor Force. Science and Engineering Indicators*, pp. 3-30. (http://www.nsf.gov/statistics/seind04/c3/c3h.htm). Accessed November 5, 2009.
12. *Workforce 2002: Measuring what matters*. The Reinvestment Fund. October 2002. http://www.brookings.edu/es/Urban/pa/Chapter7.pdf. Accessed June 3, 2009.
13. Pennsylvania Economy League's Report, *Building a World-Class Technical Workforce.* Report #686.
14. *The Greater Expectations*. National Panel Report. http://www.greaterexpectations.org. Accessed February 8, 2008.
15. Felder, R.M. and Brent, R. (2004). *The Intellectual development of Science and Engineering students. Part 2: Teaching to Promote Growth*. Journal of Engineering Education. 93, No. 4, 279, 2004.
16. Westat, J.F. *The 2002 User Friendly Handbook for Project Evaluation* (NSF 02-057). (The National Science Foundation, Arlington, VA, Last modified 06/14/2004).
17. Thomas A. Angelo and K. Patricia Cross. (1993). *Classroom Assessment Techniques. A Handbook for College Teachers. Second edition*. John Wiley & Sons: San Francisco, CA.
18. Danley, W. and Genis, V (2009). *Assessment and Evaluation Process for Engineering Technology Program*. Proceedings of the ASEE Mid-Atlantic Conference, pp. 1-9, 2009.