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Learning from the Customer – Biomedical Engineering Clinical Correlates Taught by Physicians

Prof. Colin K Drummond, Case Western Reserve University

In January 2015, Colin re-joined the Department of Biomedical Engineering as Professor and Assistant Chair, having previously spent a year in the School of Nursing. From 2008-2013, Colin was the Director of the Coulter-Case Translational Research Partnership (CCTRP) in the Department of Biomedical Engineering. Colin's research interests are on educational pedagogy, the practical application of simulation and healthcare information technology to support clinical decision-making, including advances in understanding wearable analytics for human performance assessment. He is active in developing experiential and co-curricular activities for students, the development of standards modules for design classes, and collaborative projects that address patient need.

Dr. Matthew L Moorman, Case Western Reserve University

Chief, Division of Trauma, Critical Care, and Acute Care Surgery University Hospitals Cleveland Medical Center Clinical Associate Professor of Surgery, Case Western Reserve University School of Medicine

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Matthew L. Moorman, MD, MBA, FACS, FAWM, FCCM
Chief, Division of Trauma, Critical Care, and Acute Care Surgery
University Hospitals Cleveland Medical Center
Cleveland, Ohio 44106
Matthew.Moorman@UHhospitals.org

Jeffrey S. Ustin, MD, MS
Assistant Professor in Surgery
Adjunct Professor in Biomedical Engineering
Case Western Reserve University
Cleveland, Ohio 44106
Jeffrey.Ustin@UHhospitals.org

Colin K. Drummond PhD, MBA
Department of Biomedical Engineering
Case Western Reserve University
Cleveland, Ohio 44106
colin.drummond@case.edu

Background

Nearly all undergraduate biomedical engineering programs teach some form of human physiology. How this is taught, by what faculty (engineering, anatomy, etc.) is variable. Physiology, as classically taught in texts, contains little quantitative relationships of interest to engineers. Two practicing critical care surgeons with engineering backgrounds have encountered enumerable clinical problems ripe for engineering solutions. Some of the more common clinical problems, such as (a) intravascular volume during resuscitation, (b) optimum ventilator tidal volumes delivered to diseased lungs, and (c) assessment of injured tissue viability at surgery, are presented as engineering problems in the context of actual bedside utility. Mathematical models are utilized for quantitative analysis of these clinical principles. These clinical correlations enable synthesis of basic engineering concepts around applications in medical practice. Students draw upon prior training in biophysics, anatomic structure and function, and mathematical modeling of physiologic systems. Blending engineering and clinical concepts in this fashion expand student's medical expertise.

Curriculum Framework

The curriculum maintains two overriding concepts throughout eight modules: (i) how physicians think versus how engineers think and (ii) learning the language of the customer. This eight-week course featured critical care cases designed to associate and translate engineering concepts into relevant medical knowledge. In this "flipped" course, surgeon-instructors pose actual clinical scenarios where they see a need for an engineering solution. Students were expected to prepare for each class as if they were going to meet with a client and actively participate in the physician-lead discussion. Each class meeting was centered on a clinical problem seeking proposed solutions. Post-case homework was a written reflection of about 1000 words describing their understanding of the problem and their proposed initial solutions. These written assignments and their attendance were used to calculate a final grade.

Clinical correlations in biomedical engineering enable synthesis of basic engineering concepts around applications in medical practice. Through the course, students draw upon prior training in biophysics, anatomic structure and function, and mathematical modeling of physiologic systems in a weekly case-based critical care scenario. Blending engineering and clinical concepts in this fashion expands student medical expertise. This eight-week course featured critical care cases designed to associate and translate engineering concepts into relevant medical knowledge. Course didactic components were posted on a Learning Management System, and students were expected to read and prepare arguments for each case to be discussed in class. The framework of the course is designed to enhance systems thinking and insight on prior biomedical knowledge and innovation, as well as measurable improvement in critical thinking skills in the field of medicine.

Nine course learning objectives were developed for the course, and at the end of the course successful students were expected to be able to:

1. Have fundamental knowledge of applied physiological system function and dysfunction.
2. Analyze physiological systems from an engineering perspective.
3. Formulate practical engineering solutions to ameliorate biological disorders.
4. Appreciate the ability of bioengineering to improve the quality of life.
5. Have good written and oral communication skills.
6. Are independent, critical, and creative thinkers who seek out new points of view and who can effectively evaluate assumptions, evidence, and conclusions and can distinguish among them.
7. Formulate oral presentation skills as it applies to biomedical technology.
8. Build critical thinking and research skills.
9. Refine individual and team-based presentation skills.

Objectives 1-4 relate primarily to subject-specific objectives assessed and evaluated through weekly discussions and assignments. Objectives 5-9 have commonality to many other engineering courses, though Objective 6 was of particular interest in this course – as mentioned earlier a fundamental question was whether this new course strategy would enhance critical thinking skills.

In our inaugural course, assessment of learning objective outcomes was centered around a critical review of weekly student reflective essays (briefly mentioned earlier). Briefly, though, we used a rubric centered on argumentative writing and use of evidence. It was important that students not only engage with and understand the weekly clinical topic, but also to respond with persuasive and valuable insights. This assesses students' abilities to present their insights in the forms of clearly stated and well-structured arguments. Proficiency in achieving learning objectives is measured in part by writing that conveys precise and insightful ideas about the clinical case and basic engineering concepts applied in medical practice.

While the textbook for the class covered many of the conventional Anatomy and Physiology topics, the weekly module outlines (described below) drew on specific trauma surgical experiences. Clinical correlates are based on the following module strategy:

1. each module emphasized anatomic and pathologic concepts,
2. each module included at least one engineering principle, and
3. the above two concepts were combined via a clinical scenario.

A total of eight modules were developed on the basis of this overall curriculum framework and are highlighted below. All required class materials were posted on the *Canvas* learning management system (LMS), where each of the eight topics was supported by a separate learning module. Preparing the LMS required significant upfront effort (and team work!) by the instructors, but this investment paid off in enabling busy clinicians to add and update content remotely (in advance of class), as well as enabling tracking of literature access and module engagement.

Course Module Outlines

Although this was intended to be a senior elective course, the course was not restricted to seniors and so the design of the course featured introductory material in the first module to ensure everyone was working from the same common knowledge. The

Module 1 - Review anatomy

- Anatomic terminology
- Major blood flow (head/neck, thoracoabdominal, extremities)
- Bones / Joints (fracture pattern description, typical joint injury mechanisms)
- Cross sectional imaging, (Principles of absorption/transmission, reconstruction algebra)

  Clinical scenario: Where's the blood loss? Six spaces: intrathoracic, intraperitoneal, retroperitoneal, extremities, environment, Morel-Lavallee.

Module 2 - How Doctors think vs How Engineers think

- Pattern recognition vs Scientific method
- Bayesian analysis
- More gray in medicine
- Major principles shared: curiosity (why, why now) & reality check (does this make sense)
- Major skeletal anatomy
- Fracture patterns with mechanical engineering principles

Clinical scenario: Pelvic fracture: engineering approach versus medical approach

Module 3 - Hemorrhagic Shock

- Cardiac anatomy
- Anatomy of arteries and veins (autoregulation)
- Cell physiology re: Oxygen
- Oxygen carrying capacity of hemoglobin and saturation equation
- Fluid dynamic modeling

Clinical scenario: Ruptured spleen.
Field trip (ICU vs sim lab to see monitors)

Module 4 - Other forms of Shock

- Distributive vs obstructive vs cardiogenic
- Intro to neuroanatomy macro, concept of cell receptors and deeper dive on neurohumoral control of vascular resistance and capacitance
- Electrical modeling of system

Clinical scenario: Undifferentiated shock emphasizing initial treatment responses and further investigation

Module 5 - Traumatic Brain Injury

- Further anatomy review (intracranial, spinal, peripheral, sympathetic, parasympathetic
- Monroe-Kellie doctrine with review CPP and ICP monitoring
- Hydrostatic modeling
- Mechanisms of injury/blood spaces
- Control of ICP
- Imaging part 2 (further CT and intro MRI)

Guest: neurosurgeon

Module 6 – Respiratory

- Review pulmonary anatomy including ventilation and perfusion
- Physiologic concept of mismatch
- Fluidics modeling. Gas exchange/membrane modeling.

Clinical scenarios-ARDS, pneumothorax, pneumonia
Hands-on: Ventilators- basic modes and how they leverage fluidics and gas exchange principles

Module 7 - Surgical Tools

- Staplers
- Electrocautery devices

- Ultrasonic devices
- Lasers
- Fiber optics

Module 8 - Ballistics / Penetrating Trauma

- Muzzle velocity
- Kinetic energy
- Drag
- Yaw and rifling vs tumbling
- Terminal ballistics
- Bullet designs

Discussion of Evaluation Method

There was no "curve" for the assessed grade for the work performed; this, under the assumption that each student is motivated to seek their "personal best" against a series of tasks, not competing against each other. Evaluation was split evenly between a class participation grade and a weekly clinical scenario write-up and reflection paper.

A. Class participation

- Attendance is important but we had no difficult with 100% attendance in the pilot course offering. Class involved time to learn interactively, discuss issues with colleagues, check the knowledge of the material, and efficiently focus attention on specific class subject discussions.
- Participation requires being prepared. This elective course involved synthesis of ideas in critical care based on weekly reading material. Students learned after the first week they will be successful if they made advance reading a priority.
- In this intensive short course, active learning is a "contact sport" and students are not successful watching from the sidelines. In this interactive course, students were called on to provide their insight and analysis results.

B. Weekly Clinical Scenario

- Clinical scenarios in critical care provide the opportunity for the structured understanding and analysis (guided by targeted questions) of realistic cases in medical practice. An ability to state problems objectively, understand the role of anatomy and physiology, look at situations from various perspectives, and place medical care in context are outcomes that mark the development of a clinician. The ability to properly frame and present a case study is an important part of this course.
- Weekly clinical scenario analysis proceeded in a prescribed format and timeline, with the student deliverables not only oral "flash report" for class, but in weekly post-case reflections on case insight and lessons learned.

Summary

The course was taught for the first time in the Fall semester of 2021 with encouraging results. Student comments from the end-of-course survey reflect positive experiences with this different approach to teaching:

> *The readings in this class were interesting and related well to the course content. I liked how open ended the reflections were and they reiterated the core engineering and health concepts.*
>
> *They did a very good job of connecting their lives as surgeons to the BME course material.*
>
> *They presented the information in an interesting way; I loved the interactive nature of the class.*

Our second offering of the course is expected to have more structured outcomes assessment using, for instance, instruments that can provide insight on critical thinking skill development (see: https://web.uri.edu/assessment/files/WSU-Critical-Thinking-Project-Resource-Guide.pdf).

Students provided immediate appreciation and enjoyment of the course by their 100% attendance over eight weeks. Informal feedback to the full-time engineering faculty member was overwhelmingly positive.

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