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Work in Progress: Development and Dissemination of Interactive Didactic Modules for Biomedical Engineering: Bridging Fluid Mechanics and Systems Physiology

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Work-in-Progress: Development of Interactive Didactic Modules for Biomedical Engineering: Bridging Fluid Mechanics and Systems Physiology

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1. Introduction

Biomedical Engineering (BME) is a rapidly evolving, new area of engineering that focuses on the application of the traditional, core engineering principles and design concepts to medicine and biology. This field seeks to close the gap between engineering and medicine, by combining the design and problem solving skills of engineering with medical and biological sciences.

The BME curriculum in focus exposes students to several core engineering courses that cover concepts such as Fluid Mechanics from a pure scientific, engineering perspective, followed by application-specific courses, such as Systems Physiology. While the former category ensures mastering of fundamental, core engineering principles, the latter category truly differentiates this curriculum design from other BME programs across the country: direct application of the engineering to medicine, biology and the human body as an inter-connected network of systems.

Systems Physiology introduces students to the various systems in the human body and how these systems interact with one another to perform bodily functions. Besides learning about normal function, students also learn about pathologies that perturb the system, and they can make predictions on how theses disturbances may affect the system and normal bodily functions. This class is a critical component of the curriculum, as it focuses primarily on the human body. Students begin to grasp the complexity of the human and its implications on design parameters for medical devices, drugs or treatments.

Current pedagogical approaches entail a thorough description and analysis of the core engineering principles in courses like Fluid & Solid Mechanics, as well as a more biologically inclined flavor for courses such as Physiology. While the traditional “textbook, pen & paper” approach enables students to master the fundamental concepts in engineering science, it provides limited exposure to the biomedical application domain. Similarly, the biology- and physiology-flavored courses cater more to the application, without emphasizing the core engineering principles and their effect on the application.

2. Objectives

The work described here is aimed to bridge the fundamental knowledge gained during the Fluid Mechanics course with the applied knowledge gained in the Systems Physiology course. In light of these efforts, we have developed several interactive modules implemented in Matlab – a technical computing platform used extensively in undergraduate engineering education institutes – that allow students to interactively change different parameters and observe, in real time, their direct changes on the system.

The first set of modules focuses on the fundamentals of fluid mechanics and entails different flow patterns featuring variable parameters. The second set of modules is aimed more toward the application, for instance the diffusion principles and applications of fluid mechanics and flow analysis to cardiac output and the circulatory system as a whole.

Our objective is to deploy the modules into both the Fluid Mechancis course (a second year level course) and the Systems Physiology course (spanning over year 3 and 4) and assess their benefit to the students via questionnaires, brief surveys and some fundamental engineering questions they can study by means of the proposed modules.

3. Module Implementation

The MATLAB platform allows for versatility and ease of use, in both the creation and operation of the developed modules. MATLAB's flexibility to operate on both Windows and OSX operating systems, limits restrictions caused by availability of licensing on institution-owned machines. This method also provides students with the ability to use the modules on any machine with a MATLAB license, both on campus or on a personal computer. Once installed on a system, these modules are present in the MATLAB Apps ™ toolbar and are accessible for as long as the user wishes to keep them installed. Moreover, there are no source files which can be misplaced or mistakenly deleted.

To provide equal learning opportunities to all students in the course, it is important to address those who may not have access to a licensed campus or personal machine. This objective was achieved through use of MATLAB's standalone executable software compiler. Standalone applications operate license-free and install easily on any windows or OSX computer with "administrator" access. Modules can be distributed via two methods: a complete file including the software, or a link to a download from the Mathworks server. The distribution of the software can be achieved through email or a link posted to a central course website. Once downloaded, the executable file and run time software can be installed in just a few minutes and can be removed at the user's discretion.

4. Module Design

Within each application lies a module accompanied by a central documentation page that allows users to access educational literature, as well as instructions for individual controls and inputs. Real example problems from Fundamentals of *Fluid Mechanics (Munson)* and *Quantitative Human Physiology (Feher)* are included in each documentation page. [1,2] Students have the ability to navigate between the desired module and its documentation, comparing results and seeking help, all without losing their current work. With every module, quantitative results are displayed as visual representations such as 2D and 3D surface plots. The provided tools allow users to interact with the plots, and save screen-captures of results for later assessment.

5. Module Examples

The developed applications include modules in the fields of ***fluid transport***, ***solute diffusion***, and ***cardiac function***. The ***Fluid Transport*** application is designed with three modules focusing on the concepts of Poiseuille's Law with regards to pipe, parallel plate, and Couette flow. Fundamental concepts such as these are important in a biomedical curriculum, as these phenomena are responsible for understanding blood flow, respiratory function, and quantifying many other physiological events. Variables include fluid velocity, density, radius of pipes, and pressures. Users are free to enter a wide range of information, allowing the simulation to represent every real world condition from a large pipeline, to a human capillary.

An important concept in the understanding of dynamic fluid interactions is the Reynolds number, used in both the Fluid Mechanics and Systems Physiology courses. Defined as the ratio of momentum forces to viscous forces, the unit-less number is responsible for determining the interactions between moving fluids and contact surfaces such as pipes and blood vessels. To observe the relations between the Reynolds number, a pipe's relative roughness, and friction factor, a Moody diagram is commonly used. This log scaled plot features a Laminar flow portion, as well as multiple turbulent flow curve lines that are used to find unknowns in a specific condition. An educational module was developed to assist in the understanding of this frequently used resource by creating an interactive digital version of the moody diagram.

With many approaches to using the Moody diagram, logical interaction was necessary in developing an easy to use graphical interface. Students are able to input real world values such as the material and dimensions of a pipe to find the relative roughness, or if the values are already known the user can input them in a separate field. When doing so, the programs logic determines the method for approaching the problem and solves for the unknown values. All drop-down style selections include true values for materials commonly used in biomedical engineering, such as steel, glass, plastic, blood vessels, and titanium. This method allows the module to assist students in approaching a variety of real world problems, an insures that there is a better understanding of the concept. Once all inputs have been made, the results are shown on an interactive plot of the moody diagram, providing a visual understanding of how specific variables alter the output.

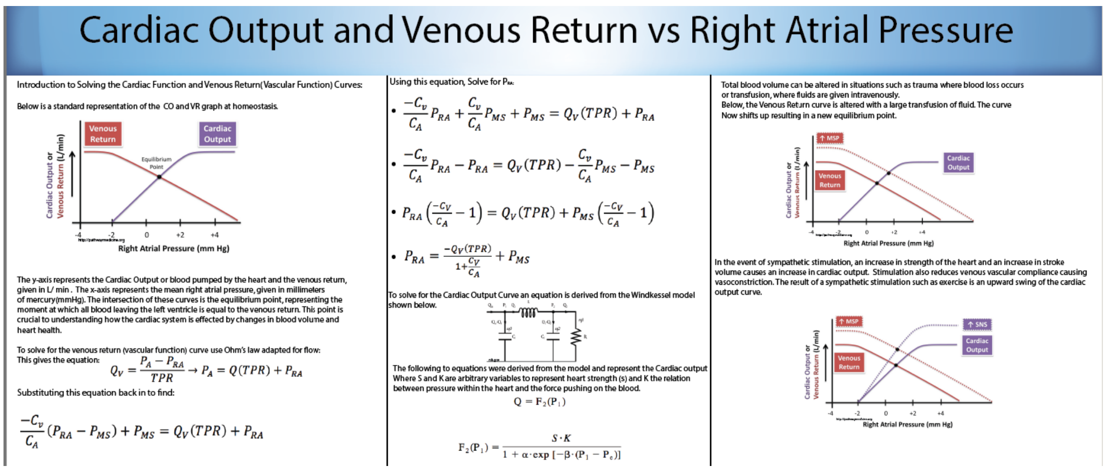

Fig. 1: Example of a module designed to provide users with an interactive approach to understand the behavior of cardiac output. This figure shows the Theoretical Tab associated with the module, which is intended to provide the user with a refresher in terms of the fundamental principles and equations involved.

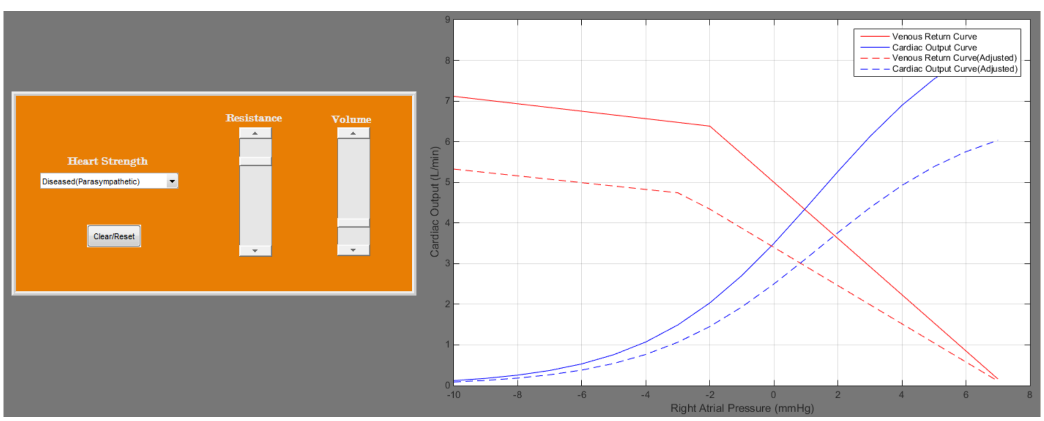

Fig. 2: This illustration provides an overview of the Interactive Tab that allows the user to change various parameters and automatically observe the changes by means of a graphical display.

Similar to the previous applications, the ***Solute Diffusion*** application includes multiple modules and documentation pages. Solute diffusion is an important concept in Systems Physiology, responsible as a vehicle for chemical and electrical signaling in the body. These concepts are critical for understanding mechanisms for the creation of drug delivery systems and cellular interactions. Using differential equations, simulations of instantaneous localized release and semi-infinite source diffusion are plotted as curves representing the current solute concentrations at various time intervals.

Lastly, the ***Cardiac Function*** application exposes users to the concepts behind the modeling of cardiac function and the cardiac output response to changes in venous return and right atrial pressure. The module involves an information tab that points the user to the fundamental concepts behind the system modeling, the governing equations and typical graphical relationships between the cardiac output, venous return flow and right atrial pressure (**Fig. 1**). Cardiac function for sympathetic and parasympathetic conditions were derived from a simplified heart strength variable, combining heart rate and vascular conditions.[3]

It is important to notice that the structure and overall curriculum of both courses will remain more or less similar following the introduction of the proposed modules. These modules are intended as an additional tool designed to serve as an interactive tool that enables students to observe the changes various parameters have on a system in an online, real-time, and graphical fashion, as opposed to solely via computations isolated from physical meaning.

6. Evaluation Strategies

The developed modules will be introduced into the course and students will be prompted to use the modules in parallel with the leaning of theoretical concepts during the lectures. Students will be asked to complete an assignment following the introduction of the material during the traditional lectures. Subsequently, the developed modules will be introduced to the class and the student will be asked to familiarize with the modules via a set of exercises designed to explore the different functionalities provided by the modules. Following exercise completion, students will be asked to perform another assignment designed to asses the understanding of the concepts following exposure to the modules. In essence, this second assignment will be similar to the first assignment, with the expectation that the interactive modules would have provided a deeper understanding of the concepts in terms of parameter sensitivity and application to real world examples. In addition, an assessment of student performance against previous cohorts will be conducted, although any changes to student performance cannot be solely associated with the incorporation of the modules, as the effect of other variables may be need to be considered.

7. Future Work

This work has focused on the development of several engineering modules designed to complement the traditional learning experience of biomedical engineering students in the area of fluid mechanics and its application to systems physiology. While they were developed with the intention to deploy them into the courses associated with the BME curriculum at our institution, we intend to make them available to other instructors within the College of Engineering, as well as other engineering program interested in their implementation as an added pedagogical tool.

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