Educational Innovation in Physiology: Capillary Filtration

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Abstract

The concepts underlying capillary filtration are fundamental topics in physiology courses taught to medical students and undergraduate and graduate biomedical engineering students. Students report anecdotally that this material is difficult to master. Furthermore overall student exam performance does not correlate with performance on questions regarding capillary filtration. A module that presents capillary filtration in the context of glomerular filtration is being developed as part of the **V**anderbilt-**N**orthwestern-**T**exas-**H**arvard/MIT **E**ngineering (education) **R**esearch **C**enter (VaNTH ERC) sponsored by the National Science Foundation. Module design is based on the learning and teaching principles outlined in How People Learn[1] and the goals of the VaNTH ERC. The content is delivered through a lecture, computer tutorials and a small group learning session such that the amount of time spent on the material in class and out of class is no different from time spent during previous course offerings. A computer simulation of capillary filtration that permits manipulation of independent variables while displaying the dependent variables is the cornerstone of the module and is used in the lecture, tutorials and small group sessions. Development of simulations of renal blood flow dynamics, filtration forces and sieving curves, a web interface that promotes meaningful interaction with the simulations and supporting materials is ongoing. The module is being implemented in a Harvard-MIT Division of Health Sciences and Technology course during the Spring 2003 semester. Student learning and understanding will be assessed through analysis of student responses to knowledge based exam questions. The effectiveness of the module will be evaluated through comparing these data with baseline assessment data that was collected during previous course offerings.

Introduction

Capillary filtration is an important topic in the fields of renal physiology, cardiovascular physiology and biomedical transport. Quantitative analyses of the variables and mechanisms involved provide an explanation for pathophysiological states such as edema due to congestive heart failure and azotemia due to renal failure, can be immediately applied to the design of treatments for these states such as drugs that counteract the effects of heart failure and dialysis techniques that counteract the effects of renal failure and can be secondarily applied to other designs involving passive membrane transport such as bioreactor design. Capillary filtration has

been identified as a subtopic of systems physiology in the taxonomy of biomedical engineering that is being compiled as part of the VaNTH ERC.

Capillary filtration is taught in the context of glomerular filtration in a graduate level renal pathophysiology course offered by the Harvard – MIT Division of Health Sciences and Technology (HST). Material is presented through a didactic lecture, assigned reading, quantitative homework questions and a small group discussion section. Learning is evaluated using qualitative and quantitative responses to three questions on a midterm exam. Graduate engineering and medical students who have completed the course report anecdotally that the material is difficult to master. Many students who performed well in the course performed poorly on the exam questions relating to glomerular filtration.

A learning module is being designed to teach capillary filtration in the context of glomerular filtration to undergraduate and graduate level engineering and medical students. Module design is based on the learning and teaching principles outlined in How People Learn[1]. The module is being implemented during the spring 2003 semester in the HST graduate level renal pathophysiology course. Student feedback and exam performance will be used to assess changes in the learning and understanding of material.

Applying a pedagogical framework

The *how people learn* framework presents four platforms (knowledge centered, learner centered, assessment centered and community centered) from which to design or evaluate a learning environment. The previous glomerular filtration curriculum was analyzed from each of these perspectives in order to determine reasons for poor student performance on exam questions and possible areas for improvement.

Domain content is considered from the knowledge-centered platform. Clear identification and prioritization of learning objectives along with a focus on learning with understanding rather than fact memorization are features of a knowledge centered learning environment. The previous curriculum had learning objectives that focused on advanced concepts and in order to teach these concepts spent less time on basic concepts. A fundamental topic in glomerular filtration is the interaction between variables that determine hydrostatic and oncotic pressures. These interactions were presented in a lecture using examples that sparsely sampled the parameter space and duplicated those in the lecture notes and textbook. The problem set focused on advanced concepts. These practices may have led students to memorize the discrete cases used to demonstrate the roles played by fundamental variables rather than gaining a true understanding of their interactions and importance. In order to address this concern, knowledge centered aspects of the curriculum are a focus of the new module.

The sensitivity of the environment to its students is considered from the learner-centered platform. Use of students' collective experiences as a foundation for teaching and creation of multiple individualized learning paths are features of learner-centered environments. The students taking Renal Pathophysiology have backgrounds in engineering or scientific research and have expressed interest in scientific research careers. The previous glomerular filtration

curriculum included the use of quantitative and basic science examples designed to capture the interest of this population. This learner centered aspect is maintained in the new module.

Feedback between students and teachers is evaluated from the assessment-centered platform. The existence of opportunities for formative assessment that provide feedback and time for revision prior to final summative assessment (i.e. exam) is a key characteristic of assessment-centered learning environments. Assessment in the previous glomerular filtration curriculum consisted of a graded quantitative problem set and questions on an examination. The problem set provided formative assessment. However, the questions provided little feedback to students or instructors on the students' understanding of fundamental concepts. The examination was the only opportunity for students and instructors to assess the degree to which students understood fundamental concepts. A lack of formative assessment on their basic understanding of the learning objectives did nothing to discourage memorization as an effective learning tool for students. A focus of the new module is the inclusion of formative assessment opportunities during the delivery of the curriculum that assess student understanding when opportunities remain to take corrective measures.

The learning community of the classroom is examined from the community-centered platform. Student comfort to ask and answer questions of the instructor and each other is indicative of a community-centered environment. The previous curriculum was taught to a group of students who have taken much of their coursework together. Thus, it was presented to an established community. The small group tutorial took advantage of this community to facilitate group learning. The tutorial is maintained in the new module.

Implementing a new learning module

The goals for this first iteration of the new module are to improve the knowledge and assessment centered aspects of the curriculum without increasing the time burden on the student. Efforts are being focused on constructing a computer simulation of glomerular filtration and the development of two web-based tutorials that replace the paper based problem set that has been assigned during previous course offerings. Coherence between curricular components is being achieved through the use of a legacy cycle structure.

The new module's content focuses on fundamental concepts that underlie glomerular filtration including the interaction between the variables that control it. Students complete a web-based tutorial before attending the lecture. This tutorial focuses on establishing a context for capillary and glomerular filtration, and introducing the concepts of oncotic pressure, hydrostatic pressure and filtration. During the tutorial they view audio-visual slide shows, are guided in their use of the simulation, respond to multiple choice and numerical response questions and receive immediate feedback on their responses. All answer choices, even those that initially incorrect, are recorded for the sake of assessment. The lecture reviews and builds upon the information presented in the first tutorial by considering changes in filtration along the length of a glomerular capillary and effects of extreme variation of variables. Students complete a second web-based tutorial after attending the lecture. This tutorial reinforces the fundamental concepts that were presented in the first tutorial and the lecture and prompts students to demonstrate their understanding through analysis of related situations such as systemic capillary filtration. Small

groups consisting of 5-10 students and a moderator meet during class time to further refine their understanding of fundamental concepts by applying them to clinical questions. The module concludes with an examination.

The new module relies on a computer simulation of glomerular filtration, development of which is motivated by the difficulty of illustrating interaction between a large number of variables using traditional teaching modalities. The java-based simulation (figure 1) is accessible using a web browser. It accepts graphical and quantitative inputs for the main variables that govern glomerular filtration, and displays plots of pressures, spatially varying filtration rates and integrated filtration rates. As variables are manipulated the effects on the process of glomerular filtration are illustrated simultaneously. It is believed that such manipulation capabilities will increase the number and range of examples that an instructor might employ and assist in moving students beyond memorization to intuitive understanding. It is important to note that the simulation is not an effective teaching tool in and of itself. An important consideration in the development of the accompanying tutorials was to facilitate meaningful interaction between the students and the simulation.

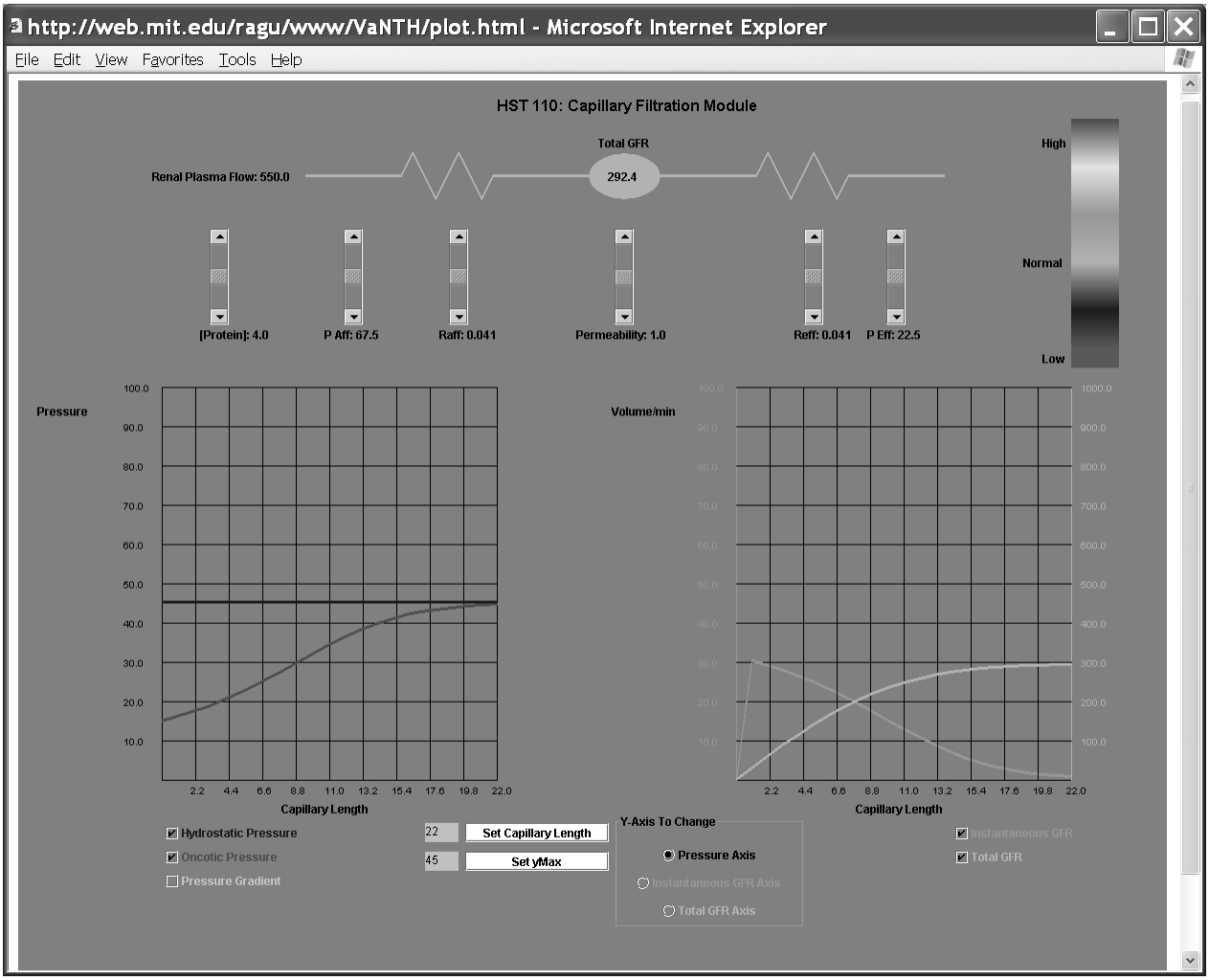

Figure 1: A Java-based simulation of glomerular filtration that is used in the module

The paper based problem set of the previous curriculum is being replaced by two web-based tutorials. These are presented using learning management software that was developed by Professor Tomas Lozano-Perez at MIT and is currently being used to administer tutorials and lectures in multiple computer science and electrical engineering courses (6.001, 6.034, 6.555J[2] at MIT). The system tracks individual students, records their responses to questions, and provides immediate feedback on their responses. This provides formative assessment to the students while they are completing the exercises and to the instructor prior to the next segment of the module. Students are graded for completing the assignment in order to relieve pressure to get the right answer, which may lead them to use other references rather than developing their own intuition.

Focus on a consistent set of fundamental learning objectives provides coherence, as does instructor use of formative assessment results to guide teaching (i.e. addressing concepts with which students had difficulty in the first tutorial during the lecture). In order to increase connectivity between the diverse instructional methods being utilized (e.g., simulation, lecture, and small group) a Legacy Cycle architecture is employed. This concept stems from VaNTH ERC research and is one method of applying the how people learn principals to instructional environments[3,4]. A Legacy Cycle revolves around an inherently interesting problem or question and the knowledge necessary to answer the question serves as a guide for the development of module. In the case of the glomerular filtration module, students are challenged to choose between instrumentation and pharmacological approaches with which to manipulate kidney function in order to treat the symptoms of congestive heart failure. The Legacy Cycle "challenge" is presented at the beginning of the tutorials. Students are then asked to answer the challenge question using whatever knowledge they bring with them to the class. Additional responses are collected at the conclusion of the first tutorial and at the conclusion of the second tutorial. The challenge (and related challenges) are also discussed during the lecture and the small group section.

The new module is being used during the Spring 2003 offering of the HST renal pathophysiology course.

Assessment of learning changes

In order to assess the glomerular filtration module, comparisons will be made between data collected during administration of the module with those collected during previous course offerings. Important dimensions to be assessed include student learning, student enjoyment and instructor enjoyment.

The objective of improving student learning will be evaluated using exam responses. The quality of responses to knowledge based glomerular filtration questions from a previous course offering will be compared with responses to the same questions by students who are taught using the new module. Both sets of responses will be quantified using a rubric that captures the degree to which students demonstrate understanding or lack thereof.

Feedback will be collected from students and instructors throughout the presentation of the new module to evaluate the degree to which the revised presentation agrees with self reported

preferences. This information will also evaluate the functionality of the learning tools being used, namely the on-line tutorials and the simulation.

Discussion

We are creating a learning module for glomerular filtration that replaces traditional teaching of the same material in a renal pathophysiology class offered by the Harvard-MIT Division of Health Sciences and Technology. The initial curricular revision focuses on improving assessment centered and knowledge centered aspects by providing feedback during learning and focusing on fundamental concepts. It is being implemented during the Spring 2003 semester and changes in student learning will be assessed using responses to exam questions.

Considerations in future iterations include addressing learner centered and community centered aspects and extending these innovations to other components of the renal pathophysiology curriculum with which students have struggled in the past. Another important consideration is creation of a sustainable curriculum that is not tied to an individual faculty member. Such a sustainable freestanding curriculum could be disseminated amongst departments and universities. One test of its disseminability will be its effectiveness as a teaching tool in an undergraduate biotransport course at Northwestern University during the Fall 2003 semester.

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Biographies

HEATHER E. GUNTER expects to receive her Ph.D. in Medical Engineering from the Harvard Division of Engineering and Applied Sciences and the Harvard-MIT Division of Health Sciences and Technology in 2003 and her M.D. from Harvard Medical School in 2005. Her interests in engineering education stem from observations made during two decades as an education consumer and more recent experience as an education provider.

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