

NOVEL CAPILLARY FILTRATION MODULE BRIDGES BIOMEDICAL SCIENCES AND ENGINEERING TO IMPROVE INTERDISCIPLINARY EDUCATION

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Abstract

The concepts underlying capillary filtration are fundamental topics in physiology courses taught to undergraduate and graduate biomedical engineering students as well as medical students. Conveying these complex biomedical concepts to diverse engineering audiences in the classroom requires novel techniques to achieve true mastery of the material. Over the years, students have reported anecdotally that this material is difficult to fully comprehend. Furthermore, student performance on exam questions regarding capillary filtration does not correlate with overall student exam performance. These concerns led us to strive to improve instruction of this material. Therefore, a module that presents capillary filtration in the context of glomerular filtration has been developed and incorporated into the curriculum of the Harvard-MIT Division of Health Sciences and Technology (HST) renal pathophysiology course.

Module design is based on the learning and teaching principles outlined in *How People Learn*¹. The module replaces the traditional instruction of capillary filtration, which consisted of a lecture, paper based problem set and assigned textbook reading with two new interactive online exercises that present content and provide real time formative assessment to students, separated by an in-class lecture. A novel java based simulation of glomerular filtration was developed to permit manipulation of independent variables while displaying the dependent variables. The simulation both expands the range of examples that are presented by the lecturer, facilitates interaction between students and the lecturer, and allows students to explore the subject on their own. Knowledge based outcomes demonstrate that students taught using the module have improved mastery of the three learning objectives compared to those taught using traditional instructional techniques. Subjective feedback from students and faculty following implementation of the module was positive.

Analysis of subsets of data collected during the past three years of module use provides insight into its effectiveness for the instruction of a diverse population. While the majority of students preferred the module to traditional instruction with a textbook and problem set, an analysis of student feedback based on each student's undergraduate major and graduate program type revealed that the novel module is most preferred by students who have a background in biomedical engineering (and less so by those with a physical sciences or biological sciences background) and by students in a Ph.D. program (and less so by those in an MD or MD/Ph.D. program). This analysis encourages the development of a more individualized module, allowing more remediation for students who require it and trying to meet the needs of students who have had less exposure to these concepts and these modalities of instruction.

Module Structure

The goals for the capillary filtration module and pedagogical framework applied are detailed in previous publications^{2,3,4}. A brief summary is presented here for those unfamiliar with our previous work. The module includes two on-line learning exercises, a lecture, a dynamic java-based computer simulation of glomerular filtration for use by faculty and students and an exam. In order to make the module interesting to a broad range of students, the fundamental concepts of capillary filtration are presented using a *How People Learn* legacy cycle format, in which a clinical case serves as the unifying challenge and intellectual basis of the module. Students complete the first exercise prior to the in-class lecture. Both on-line learning exercises are delivered on-line using the CAPE/elms learning technology that has been

developed as part of the VaNTH (Vanderbilt University, Northwestern University, University of Texas and HST) Biomedical Engineering Education Research Center (figure 1). Students are given information and concepts to consider via images and text and are prompted to answer questions on which they receive immediate feedback. The content of the lecture is informed by data from student responses collected during the first on-line exercise. The computer simulation is used during the lecture to demonstrate examples and probe student reasoning (figure 2). Manipulation of the input variables using the sliding bars causes real time changes in the output graphs of hydrostatic pressure, oncotic pressure and filtration rate. Students complete the second exercise following the lecture.

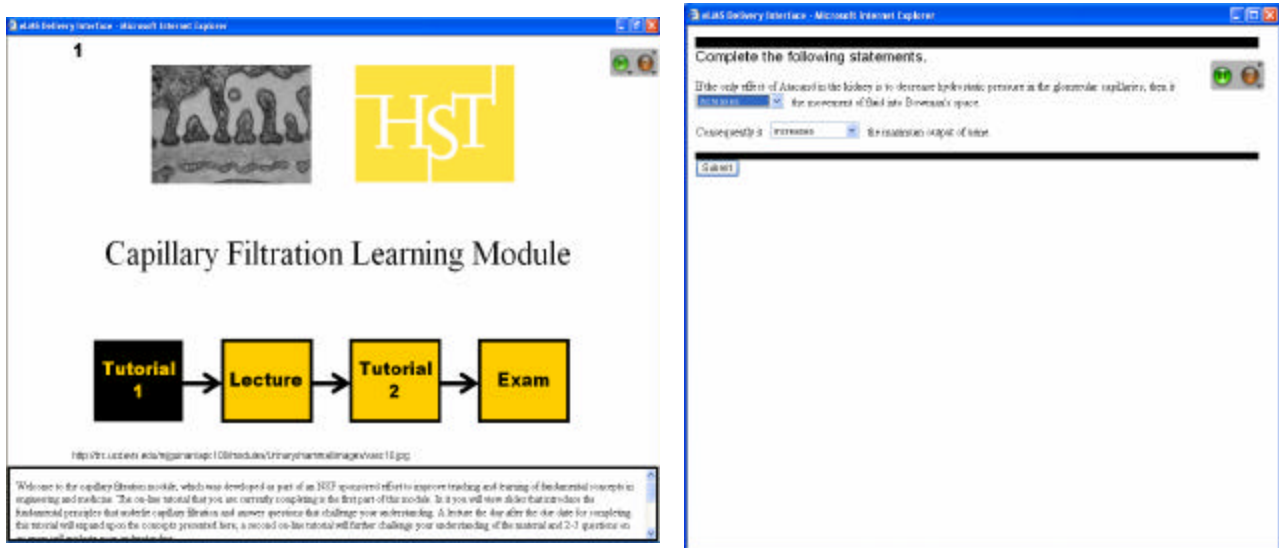


Figure 1: Screen shots of instruction (left) and formative assessment questions (right) from the on-line learning exercise

There are many innovative aspects of this module. The first is that the first online exercise substitutes for the traditional textbook reading and problem set. Formative assessment during the exercise helps reinforce and redirect student understanding. In addition, it allows the instructor to gather data on the learners' understanding prior to the lecture. Second, the use of the challenge about patient treatment in both exercises serves to motivate student learning about physical principles underlying capillary filtration and their implications for physiology and pathophysiology. This allows us to reach the biomedical engineers who have seen this material before, by using a new spin on familiar content. This also allows us to reach medical students by making the topic more concrete and important to their studies. Finally, this allows us to get students without strong physical science and engineering backgrounds to feel more comfortable with a potentially imposing and anxiety-provoking material by couching it in a biological context. Third, the glomerular filtration simulation expands the range of examples that can be explored, and its small file size and user-friendly nature make it easy for both faculty and students to use.

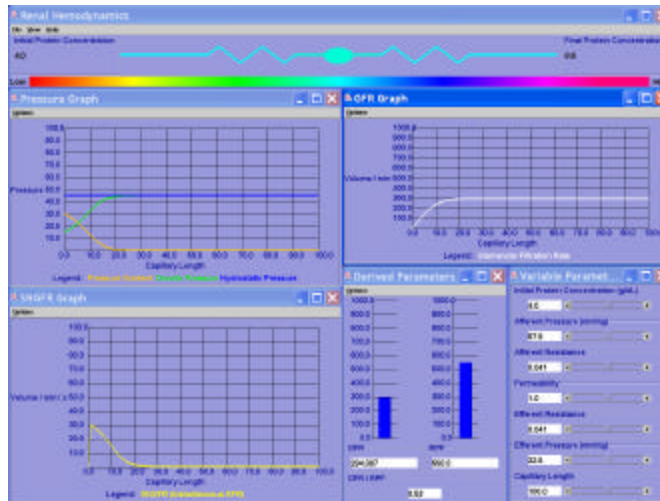


Figure 2: Screen shot of the glomerular filtration simulation

Assessment of Student Learning

The initial module was piloted each of two sites to different levels of students (graduate/medical students at HST and undergraduate students at Northwestern University) in 2003 (module 1). A dramatically revised module has been implemented at both sites in 2004 (module 2) and 2005. Student responses to relevant exam questions following completion of the module are being compared with those collected following baseline instruction of this material in 2002. Assessment of the student responses was performed using a 14-point rubric.

Two domain experts independently evaluated each student's exam responses on each point in the rubric. Consensus was reached on any points about which they disagreed. The 14 points for each student, as agreed upon by the domain experts, were then sorted according to the learning objective they represent and subtotaled within the learning objectives in order to obtain a score for each student with regards to each of the three learning objectives. These scores were normalized to scores between 0 and 1. Averages and standard deviations of the baseline results and those for each version of the module are given in table 1. Averages of the baseline results and those for the first two modules versions are illustrated in figure 3. Effect sizes were calculated by dividing the difference between the module and baseline means by the baseline standard deviation in order to compare the results.

We have found that the second version of the module demonstrates mild improvements in student knowledge for all three learning objectives and overall. Assessment of data from the second pilot site and the 2005 module are underway.

Table 1: Comparison of student knowledge of capillary filtration learning objective following three instructional methods. Maximum score is 1, n is the number of students, effect size > 0.2 is a mild positive effect of the module on student knowledge, effect size > 0.5 is a moderate effect of the module on student learning.

Learning Objective	Baseline (n=39)		Module 1 (n=46)		Module 2 (n=46)		BL vs. M1	BL vs. M2
	avg	std dev	Avg	std dev	avg	std dev	Effect size	Effect size
Oncotic pressure	0.52	0.27	0.36	0.28	0.64	0.32	-0.61	0.46
Flow, resistance, pressure	0.63	0.36	0.71	0.29	0.72	0.26	0.23	0.25
GFR determinants	0.44	0.26	0.35	0.26	0.54	0.28	-0.34	0.42
All questions	0.66	0.19	0.56	0.21	0.49	0.21	-0.34	0.47

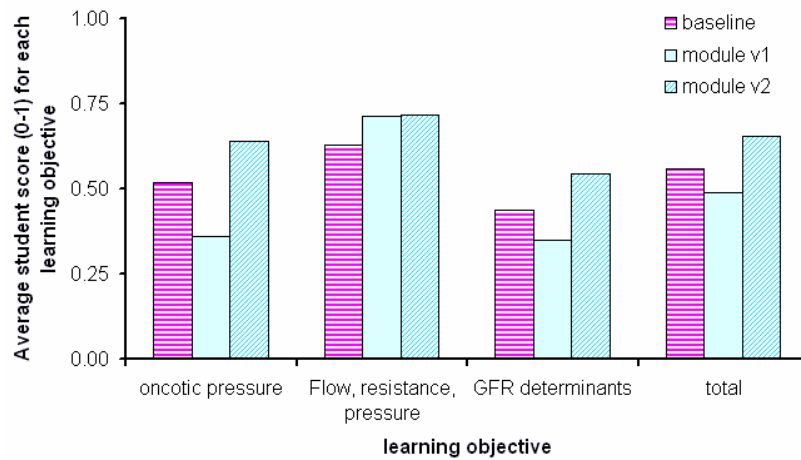


Figure 3: Effect of capillary filtration module on average student performance

Assessment of Student Feedback

Student feedback and demographics were collected at the end of each exercise using the same on-line interface. Subjective feedback has been positive with 72 percent of the graduate students who have been taught with the new module in HST expressing preference for online exercises over a more traditional textbook reading and problem set assignment. Negative feedback has been minimal and related mostly to technical difficulties, which were addressed during subsequent implementations of the module..

To take our analysis of student feedback one step further, we analyzed the effect of student background and program on their stated preference of either computer exercise or textbook reading and a paper based problem set. One might imagine that a student with an undergraduate degree in biomedical engineering would be more adept or interested in a clinical case dealing with core biomedical concepts that were familiar to them. However, it is also possible that students with an undergraduate major in biology might not have as much experience with these core concepts and might appreciate the remediation provided by the module and the use of biology to teach a complex and quantitative concept. Student demographic and feedback data collected during the three years that the novel module was used in the Harvard-MIT Division of Health Sciences and Technology was pooled to investigate this issue. While the majority of students from all backgrounds prefer the capillary filtration module to the traditional textbook and problem set instruction (Table 2 and Figure 4), there were differences among subgroups of students. Interestingly, a background in biomedical engineering makes a student most likely to favor the computer exercises over traditional homework, while those who were biological science majors were least likely to favor the new instruction methods (Table 2 and Figure 4).

Table 2: The effect of undergraduate major on student preference for learning tools

Undergraduate Major	Number of Students Who Prefer Computer to Textbook and Problem Set	Total Number of Students	Percentage of Students Who Prefer Computer to Textbook and Problem Set
Physical Sciences	34	47	72.3
Biomedical Engineering	13	16	81.25
Biological Sciences	24	35	68.6
All	71	98	72.4

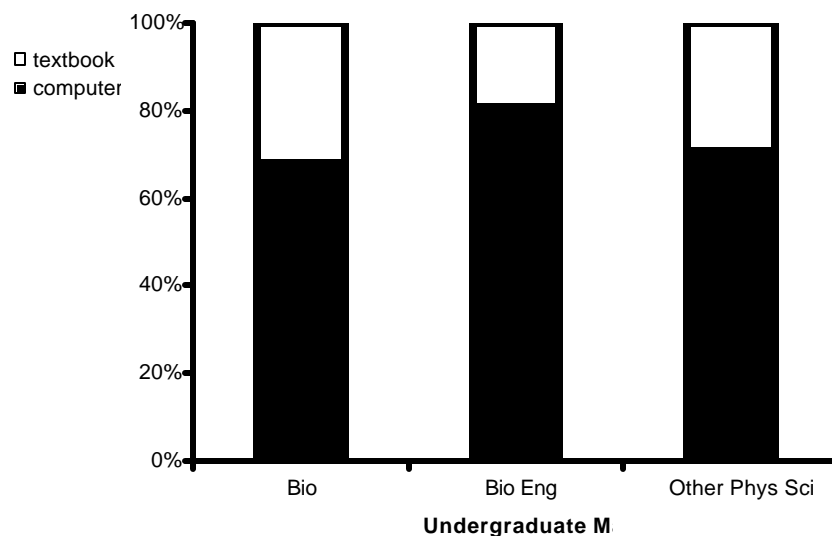


Figure 4: Effect of Undergraduate Major on Learning Tool Preference

In addition to their previous undergraduate program, the graduate program that a student has chosen to pursue may also provide a different academic background or reflect a different set of interests that may be reflected in their preferences for the new capillary filtration module versus traditional instruction (Table 3 and Figure 5). In our sample Ph.D. students prefer the computer based exercises more than the M.D. or MD/Ph.D. students, who were equivalent in their preferences.

Table 3: The effect of graduate program on student preferences for learning tools. Variability in total number of students between table 2 and 3 is due to students who did not report all of their biographical information, so could not be included in both tables.

Graduate Program	Number of Students Who Prefer Computer to Textbook and Problem Set	Total Number of Students	Percent of Students Who Prefer Computer to Textbook and Problem Set
MD	35	53	66.0
MD/Ph.D.	13	19	68.4
Ph.D.	23	28	82.1
All	71	100	71

While the majority of students prefer the new capillary filtration module to traditional instruction of the same material, we are most effectively reaching students with a background in biomedical engineering that have chosen to pursue a Ph.D. In future alterations of the module, we will try to specifically target the learning preferences students with a background in biological sciences and physical sciences, as well as the MD and MD/Ph.D. students. One element of their relative dissatisfaction may be due to a persistent lack of understanding of the core concepts. We can attempt to remediate this problem by providing additional review questions targeted to those students who are performing poorly during the online modules. The current modules require all students to go through all the questions, but to avoid penalizing students with a clear grasp of the material, additional questions for those having difficulties may be the best option. Thus we can make one module an individualized experience for students from different backgrounds and with divergent goals and programs, allowing us to achieve optimal

interdisciplinary impact. In addition, we can make a concerted effort to survey these groups of students to understand what aspect of the module they would most like to see altered.

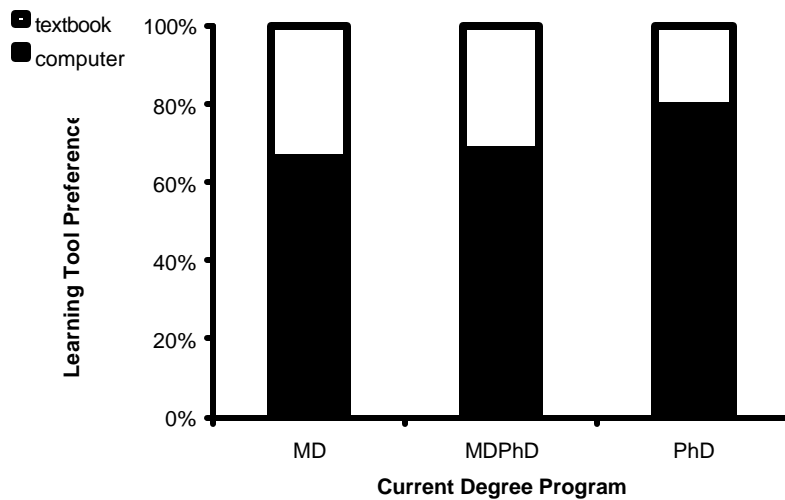


Figure 5: Effect of Graduate Program on Learning Tool Preference

Summary

We have created 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. This curricular revision focuses on improving assessment centered and knowledge centered aspects by providing feedback during learning and focusing on fundamental concepts. Qualitative feedback from students and instructors has been positive and quantitative analysis of student responses on examinations indicate that student learning of three learning objectives improved following instruction with the new curriculum compared with that following instruction with the original curriculum. We have identified subgroups within the learners who respond particularly well to the material, and we can work in the future to increase the learner centered aspects of the curriculum by providing mechanisms for students of different backgrounds to customize the module to their needs, based on the results of their formative assessments and their interests. Future efforts will also focus on packaging the module for easy dissemination to other classrooms and institutions.

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Biographies

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JOSEPH V. BONVENTRE is the co-director of the Harvard-MIT Division of Health Sciences and Technology and maintains an active research lab in the field of renal physiology. He is responsible for teaching the glomerular filtration portion of the renal pathophysiology course and is the director of this project.