

AC 2007-412: INDIVIDUALIZED FORMATIVE ASSESSMENT IN ONLINE MODULE IMPROVES LEARNING OF GLOMERULAR FILTRATION

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ABSTRACT

While capillary filtration is a fundamental physiology topic, students report that this material is difficult to master. In addition, overall exam performance in related courses does not correlate with performance on questions regarding capillary filtration. 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 renal pathophysiology course.

Water is a major constituent of the human body. Exchange of fluids between different body systems, therefore, is an important process to understand. Capillary filtration plays a fundamental role in all physiology¹. This is a complex topic, requiring understanding of foundations in fluid and vascular mechanics. These topics are important but have generally proven difficult for students in medical physiology classes to master. To relay the material in a renal physiology class we develop a module concerning glomerular filtration. The glomerulus is a capillary bed that acts as the main filtration unit of the kidney.

The module is based on the principles outlined in *How People Learn*². These include creating a learning-centered environment, focusing on core concepts and big ideas in the learning environment, being assessment centered to help students' thinking become more visible to both themselves and the instructors. Previously, it has been shown in our and others' work that an HPL-informed instruction strategy improves student learning of material^{3,4}. The module replaces traditional instruction, which consisted of an in-class lecture followed by a problem set and assigned textbook reading. The module replaces both the problem set and textbook reading with two interactive online exercises that introduce core content and provide real time formative assessment to students. The first exercise is assigned before the lecture and presents basic concepts including hydrostatic and oncotic pressure. Student performance and feedback collected during this exercise allows the lecturer to tailor the lecture to the learners. A novel Java simulation of glomerular filtration that permits manipulation of independent variables while displaying the dependent variables is projected during the lecture. The second online exercise is assigned after the lecture and reviews and extends the concepts presented in the lecture.

To improve student understanding, the newest version of the module includes adaptive feedback; described in more detail below. Also this year we analyzed the patterns of incorrect responses in the past iterations of both online exercises and developed specific feedback for common mistakes, to help students revise their specific misconceptions about the material, which the majority of students found to be helpful.

Knowledge based outcomes demonstrate that students who used the module have improved mastery of the three learning objectives compared to those taught using traditional techniques. While the majority of all students prefer the new module to a traditional problem set, we have found that both student undergraduate major and student graduate program had an impact on their preference of learning tools. Future efforts will focus on dissemination to other programs as well as continued improvements to ensure that students from all backgrounds find the module useful.

Module Structure

The goals for the capillary filtration module and pedagogical framework applied are detailed in previous publications^{5,6,7,8,9}. A brief summary is presented here for those unfamiliar with our previous work. The

module includes two on-line learning exercises, an in-class lecture, a dynamic java-based computer simulation of glomerular filtration for use by faculty and students and questions designed to be used as part of a course exam. This topic is covered in a wide array of disciplines (traditional engineering, biomedical engineering, natural sciences, applied sciences) and to a diverse group of students even within a single graduate class such as in the Harvard-MIT HST Division. In order to make the module interesting to such 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 (Fig. 1). We present the fundamental concepts and the clinical case for the students to consider using both graphics and text, and throughout the module they are prompted to answer questions on which they receive immediate feedback. The feedback is customized to address common patterns of incorrect responses. A second form of feedback occurs during the lecture. The lecturer uses data from student responses collected during the first online exercise to inform the focus of the lecture. The computer simulation is used during the lecture to demonstrate examples and probe student reasoning (Fig. 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.

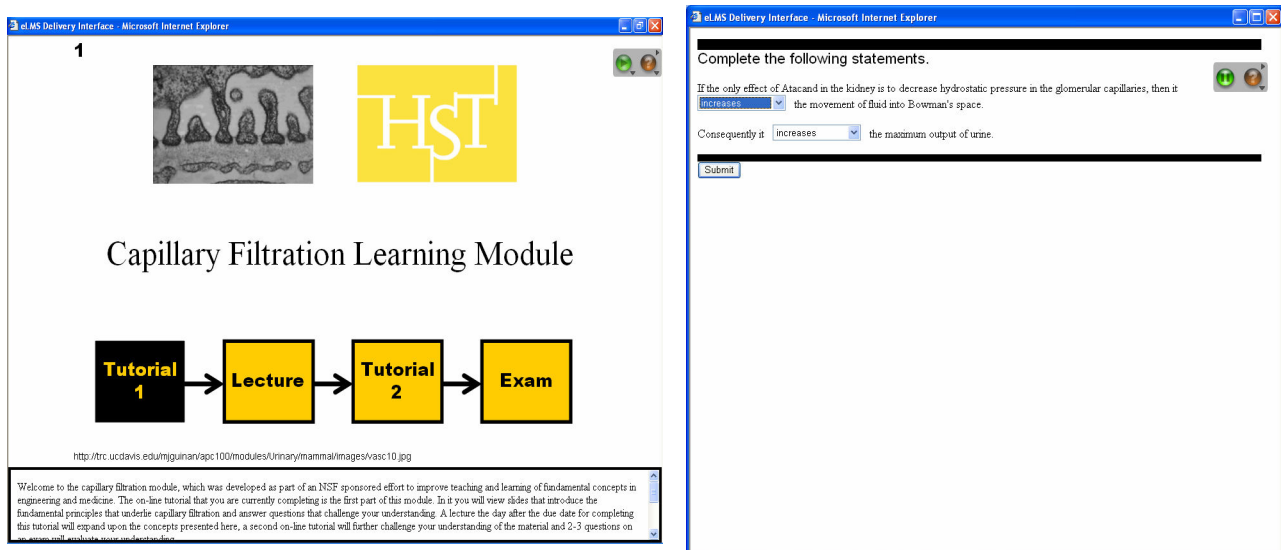


Figure 1: Screen shots of instruction (left) and formative assessment questions (right) from the on-line learning exercise

There are many innovative aspects of this module. The first is that the online exercise substitutes for the traditional textbook reading and problem set. Formative assessment during the exercise helps reinforce and redirect student understanding. Feedback is an inherent aspect as mentioned above. It allows students to understand why their thinking is along correct or incorrect lines during the module itself. In the newest version of the module, for questions with limited sets of potential answers, specific feedback is given to the student based on their answer to the question. For quantitative questions, patterns of incorrect responses have been analyzed and specific feedback has been designed to address the core

concepts that have been confused by the student have been misunderstood. This way each student's individual needs are specifically addressed in real-time. In addition, the module format 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 related to their studies. In addition, this allows us to help 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.

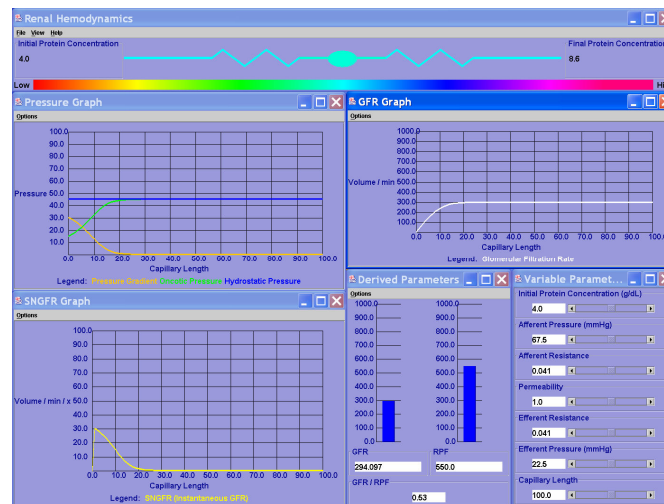


Figure 2: Screen shot of the glomerular filtration simulation

Assessment of Student Learning

The initial module was piloted at each of two sites to different levels of students (graduate and medical students at HST and undergraduate students at Northwestern University) in 2003 (module 1). A dramatically revised module (module 2) has been implemented at both sites since 2004. Module 3 is the newest version in 2006 (with adaptive feedback). Trends in student learning from past implementations can now be used to optimize the module by addressing common misunderstandings from year to year. This year, student responses to relevant exam questions following completion of the module was compared with those who completed the first versions of the module in 2003 and 2004 as well as those collected following baseline instruction of this material in 2002. Assessment of the student responses was performed using a 56-point rubric and also organized into a 14-point rubric sorted by Learning Objectives. The learning objectives chosen represent fundamental aspects of capillary filtration (oncotic pressure, flow/pressure/resistance relations and glomerular filtration rate determinants). In addition, the exam questions were designed to reflect these objectives. The rubric is designed around demonstration of essential understanding of the material and assigns credit for patterns of thought that would lead a student towards the correct answer. For example, in an exam question about how a change in a specific vessel property would affect pressure in the glomerulus, the rubric assigns credit for expressing the relationship between the property and pressure, as well as credit for determining the actual change, which is the only explicit requirement. All of the rubric credits for that question are in the learning objective for Flow, Pressure and Resistance relationships. Out of the total 56 points in the rubric, 14 were selected which encompass the spirit of the exam questions. Out of those 14, 3 were in the GFR determinants learning

objective, 7 in the Flow, Pressure, Resistance relation objective and 4 in the Oncotic Pressure objective. The exact questions and the rubric are beyond the scope of this paper.

Three 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. Fourteen 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 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.

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.

Average Student Score (0-1) for each learning objective

Learning Objective	Baseline (n=39)		Module 1(n=46)		Module 3(n=44)		BL vs M1	BL vs M3
	avg.	std dev.	avg.	std dev.	avg.	std dev.	effect size	effect size
Oncotic Pressure	0.53	0.29	0.40	0.30	0.65	0.29	-0.46	0.39
Flow, Resistance, Pressure	0.37	0.18	0.45	0.20	0.43	0.16	0.43	0.33
GFR Determinants	0.64	0.27	0.51	0.26	0.49	0.21	-0.51	-0.57
All Questions	0.14	0.06	0.14	0.05	0.15	0.04	-0.12	0.13

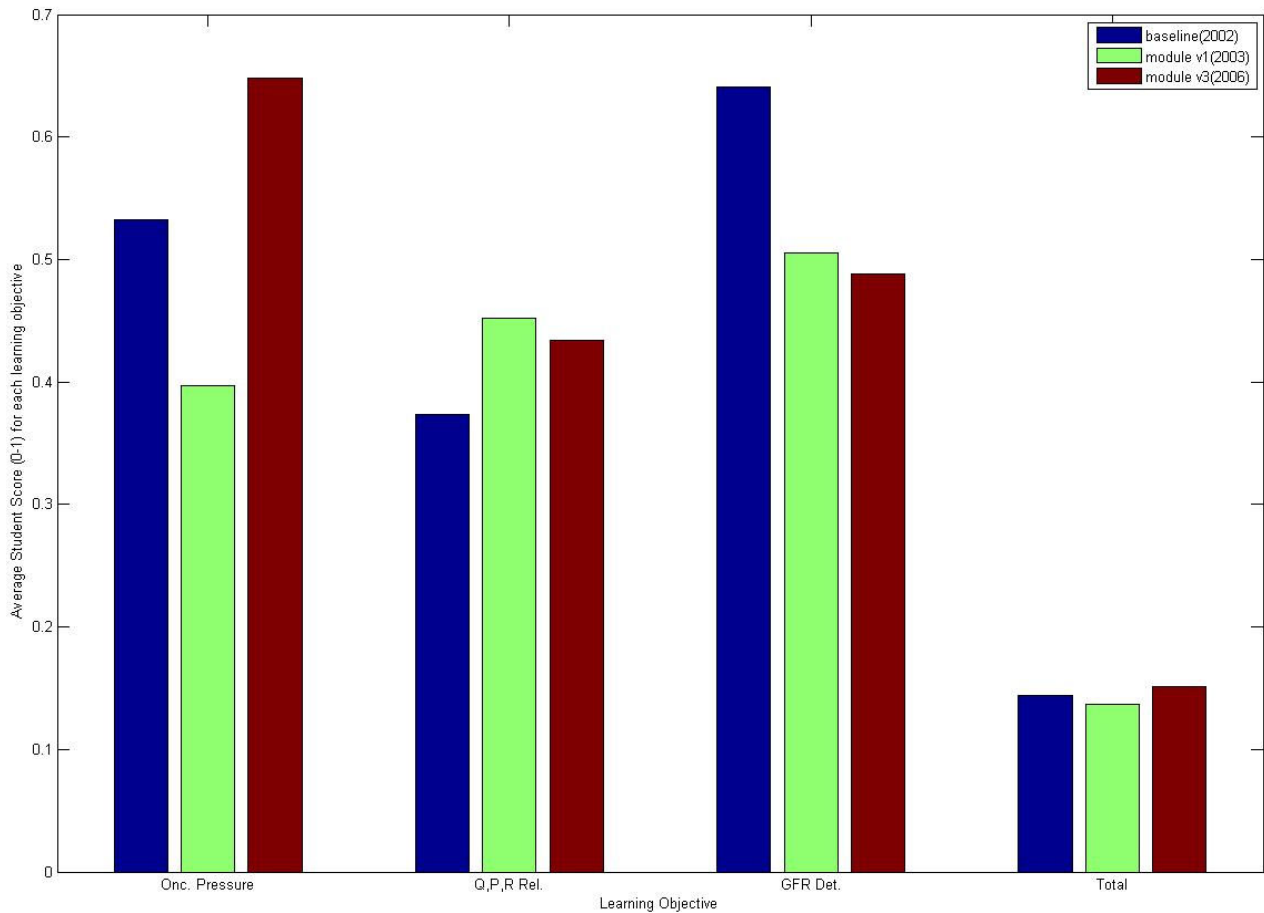


Figure 3: Effect of capillary filtration module on average student performance

Further analysis was performed to examine class performance as a whole from year to year, since the module has been in use and has undergone two revisions since 2003. Individual data from module 2 (2004) was not available, but aggregate class data was available, so the scores for all students in each year were averaged to give a class score. Class scores and their effect sizes are noted in table 2, and the scores are illustrated in figure 4. The effect sizes were computed using the variance of scores for each year. In this case, a large positive effect size indicates that relative to the baseline year, the year being assessed had a larger spread about its mean than the baseline year. This analysis gives insight into clarity of the questions on the assessment, especially sorted by learning areas. If a particular concept was not well understood by most students, class performance is inconsistent and the class score will have a large variance. This indicates that the material was not relayed effectively in that year, whether through the module or other supporting forms of instruction. It is interesting to note that in 2006 the individual student scores as well as the class score surpasses the baseline year in all learning objectives except one (GFR determinants). We hypothesize a few reasons for decreased performance in 2006 versus previous years. First, the module was made a required portion of the curriculum in this year. Previously the population of students who chose to take the module may have self-selected for those who were already best familiar with the material. Second, the number of students in the 2006 class with the background previously shown to tend to best performance (biomedical engineering) was decreased. This knowledge allows us to specifically adjust the content of the module to target the areas where instruction could be enhanced- which we will focus on for the next iteration. In particular, we find that learning objective 3

(GFR determinants) has decreased performance on the individual and class level, particularly compared to the baseline year when there was no online module. Although revisions in module 2 and 3 attempted to address this learning area, this result indicates that students are not grasping this material any better. This brings us to reexamine the exam questions pertaining to those topics. We see that there is a common tendency for students to go astray when answering exam questions pertaining to learning objective 3. Thus we will revise these questions for future versions of the exam, making them clearer and more directed. The questions will continue to address the same learning objective, permitting us to still compare student performance on the learning objectives as a whole.

Table 2: Comparison of class performance for each year of the module implementation as well as the baseline year. The score, as described above, for all students in a given year was averaged. Maximum value for the class is 1, and the effect size is a measure of the variability of correct answers within the class.

Learning Objective	Average Class Score (0-1) for each learning objective										
	Baseline (n=39)		Module 1 (n=46)		Module 2 (n=46)		Module 3 (n=44)		BL vs M1	BL vs M2	BL vs M3
	avg.	std dev.	avg.	std dev.	avg.	std dev.	avg.	std dev.	effect size	effect size	effect size
Oncotic Pressure	0.53	0.24	0.40	0.20	0.76	0.09	0.65	0.18	-0.55	0.94	0.47
Flow, Resistance, Pressure	0.37	0.20	0.45	0.27	0.46	0.27	0.43	0.26	0.40	0.43	0.31
GFR Determinants	0.64	0.20	0.51	0.27	0.64	0.26	0.49	0.38	-0.69	0.00	-0.77
All Questions	0.47	0.23	0.45	0.24	0.57	0.26	0.50	0.27	-0.10	0.44	0.10

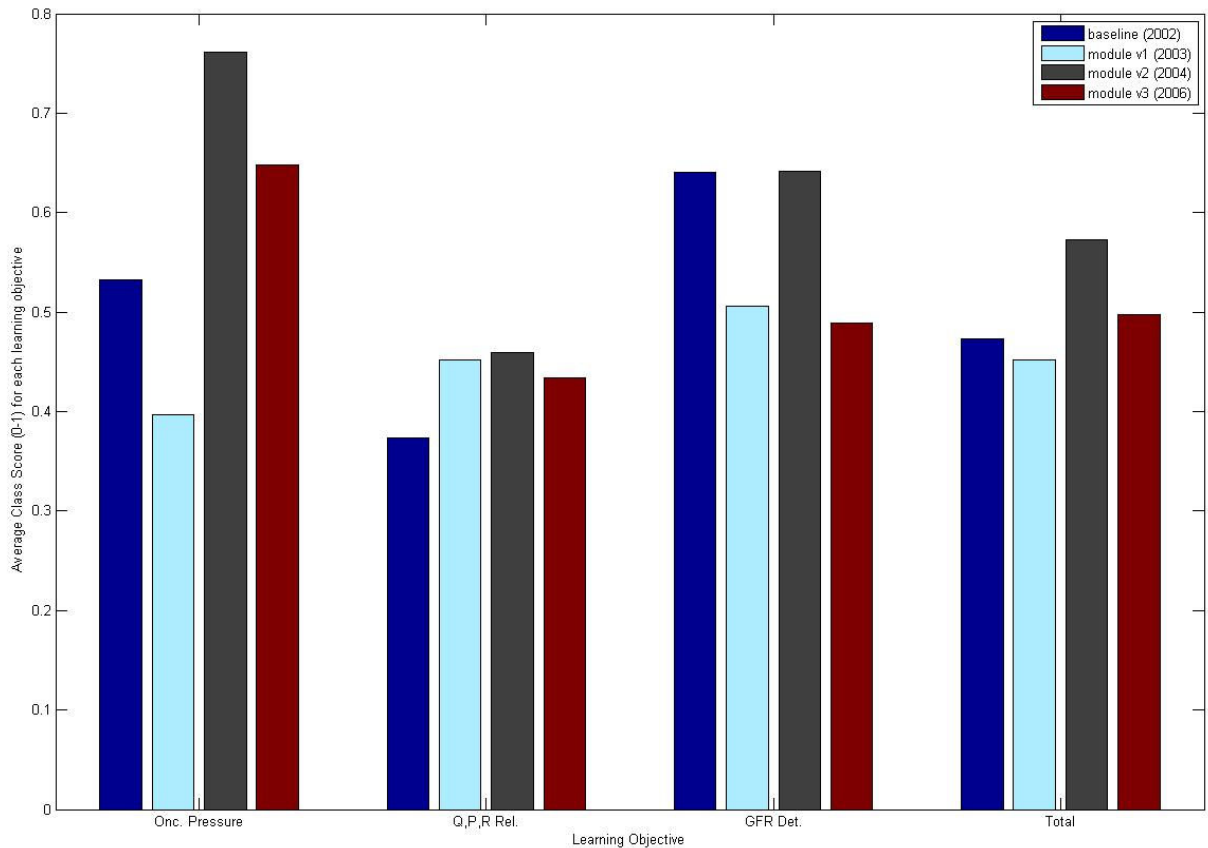


Figure 4: Effect of capillary filtration module on average student performance

Assessment of Student Feedback

Because one of the goals of the module is to address a diverse audience, we also studied students' preferences based on their background. Student feedback and demographics were collected at the end of each exercise using the same on-line interface. Students were asked, amongst other questions, if they prefer this type of learning experience it over traditional methods. Subjective feedback has been positive with 73 percent of the graduate students (Masters, Ph.D., M.D. and M.D./Ph.D) 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 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. Learning styles of students may vary depending on the type of instruction they are used to which could vary based on the types of material they have previously studied.

Student demographic and feedback data collected during the four 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 3 and figure 5), there were consistent differences among subgroups of students throughout the years. The trend shows that 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 3 and figure 5). Although the trend continued in 2006, there were only 2 participants with a background in biomedical engineering.

Table 3: 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	44	60	73.3
Biomedical Engineering	14	18	77.8
Biological Sciences	34	48	70.8
All	71	98	72.4

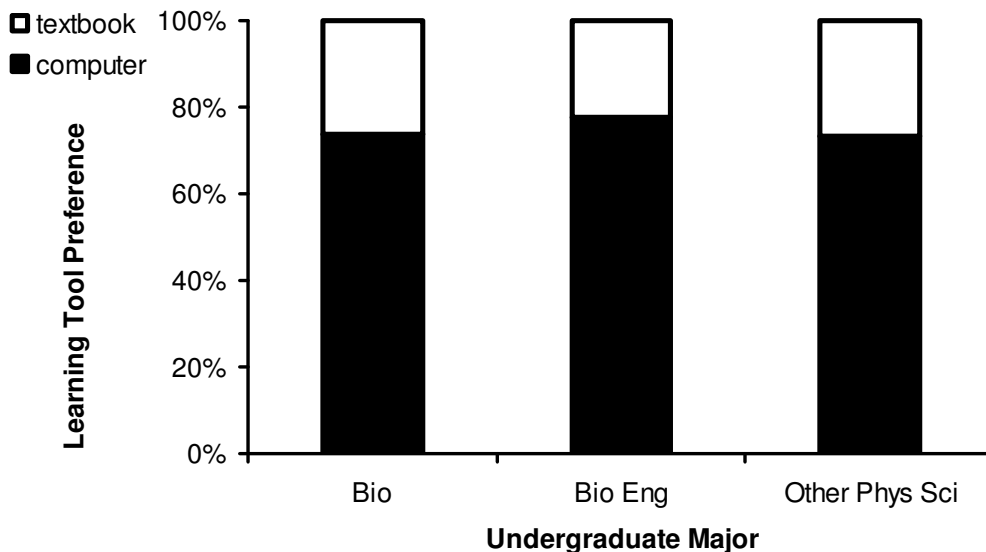


Figure 5: Effect of Undergraduate Major on Learning Tool Preference

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 could be reflected in their preferences for the new capillary filtration module versus traditional instruction (Table 4 and Figure 6). Again, consistently through the years in our sample, Ph.D. students prefer the online exercises more than the M.D. or MD/Ph.D. students who were equivalent in their preferences.

Table 4: 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, and Masters students who were not included in Table 4.

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	44	64	68.8
MD/Ph.D.	18	26	69.2
Ph.D.	29	36	80.6
All	91	126	72.2

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. Preference for the traditional method of instruction (textbook and lecture) could exist due to desire for familiar forms of learning, bad experiences with the software, preference to be able to study at leisure or desire not be actively tested on something in a temporally continuous manner.

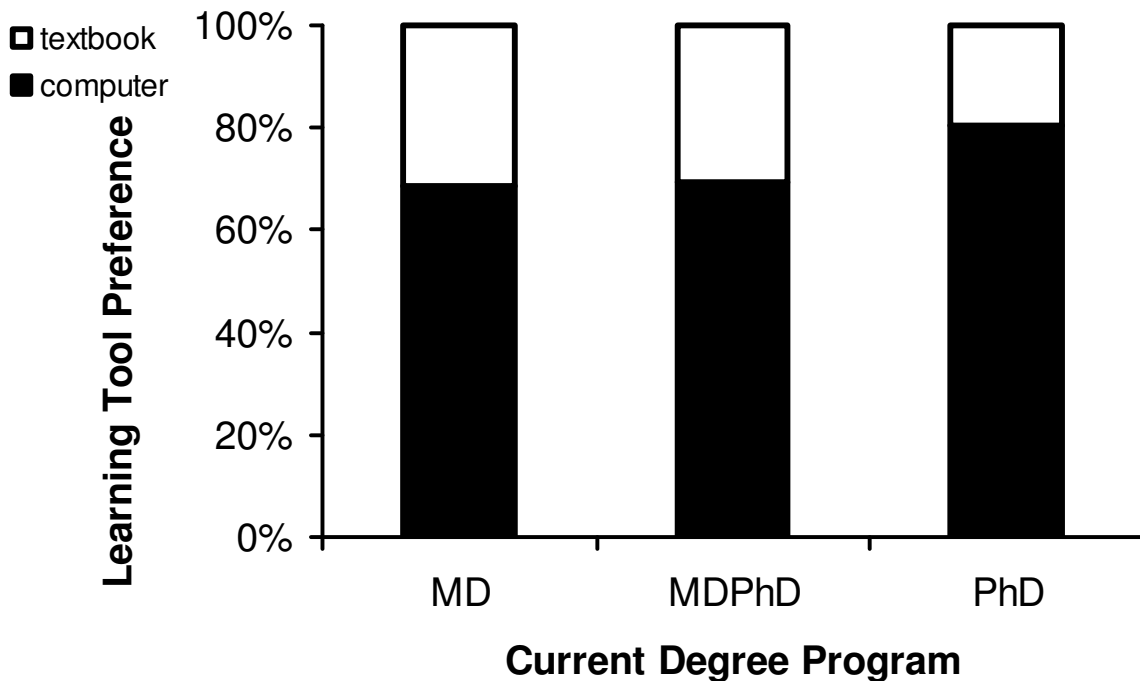


Figure 6: Effect of Graduate Program on Learning Tool Preference

In the implementation for 2007, as discussed above, we have added specific course material that students may be exposed to in other mediums (textbook, lecture) but were not previously incorporated into the

module and showed a greater variability of student performance throughout all years of the module use. This attention to group trends was made possible only after a measurable, quantitative assessment method such as the module was implemented. We feel that along with individualized feedback, study of group trends will allow for greater dissemination of the particular learning objective and concepts as a whole.

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 medium is an ideal opportunity to gauge how well the module format works, given the complexities of the material and student audience. This curricular revision focuses on improving which content is covered in the module after a few years of assessment and evaluation have been completed. 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 a next step could involve tuning the module to those groups who currently do not prefer or excel at learning the material through this format. Analysis of trends by type of degree and background enable us to adjust the module in this respect.

We have learned that an online module tool works as a dynamic tool, allowing catered feedback for student performance. At the same time, maintenance and updating of it must also be a continuous process. Also, this sort of module must work in conjunction with other instructional methods (textbook, lecture) to ensure that background concepts are available and students understand the material. We find it a good tool to introduce notably difficult concepts, bring variety to the classroom and to make use of increasingly common technologies. Future efforts will focus on packaging the module to other classrooms and institutions, as this format of instruction is suited easy dissemination.

Acknowledgements

This work was supported primarily by the Engineering Research Centers Program of the National Science Foundation under Award Number EEC-9876363. The authors are grateful to Professor Tomas Lorenzo-Perez, and *Learning by Doing*, an I-Campus project of the MIT-Microsoft Alliance for assistance with the implementation of the on-line tutorials, to Larry Howard, for assistance with the CAPE system and extremely valuable advice on module design, to Jairam Eswara for providing the exam data from the original curriculum, to Itty 'James' Samuel for his work implementing the tutorials, to Ragu Vijaykumar for his work implementing the simulation, and to Professor Robert Linsenmeier of Northwestern University for his valuable insights on module design.

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