Drag the Green Ion - An Interactive Online Quantitative Cellular Biology Learning Module

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Abstract

The goal of bioengineering education is the marriage of quantitative engineering with traditional descriptive biology. The successful merging of these two disciplines at the undergraduate level has been hampered by the limited availability of appropriate curricular materials and educational resources. Few resources have been developed to aide instructors in teaching and illustrating concepts that lie at the interface of biology and engineering.

The web-based tools currently available to engineering students for learning introductory cellular biology suffer from two major problems. The first is that the majority of engineering students are classified as learning new information most effectively through visual representations such as pictures and animations, yet most current instruction still relies heavily on textual description of phenomenon. The second problem is that many existing web-based tools are passive one-way instructors, showing information, but failing to engage students in higher-level critical thinking. There is no interactive component to the instruction. Many of the available tools that are labeled as interactive still use almost exclusively passive instruction. Due in part to the rapid advancement of technology in recent years, the ability to develop educational units that are both visually stimulating, fully interactive and scientifically accurate is more feasible than ever.

This paper discusses the design, development, and assessment of an online learning module aimed at educating undergraduate engineering students about the quantitative aspects of ion transport in cells.

I. Introduction

Bioengineering includes the study of biological phenomena using the fundamental principles of engineering. Despite the rapid growth of bioengineering as a field of study for undergraduate students, the development of educational materials for bioengineering instructors has failed to keep pace. Until only a few years ago, the subject of bioengineering was predominantly limited to graduate level coursework and research labs. Only in recent years, due in part to the burgeoning of interdisciplinary research and the general increased growth of technology has bioengineering found its way into the undergraduate curriculum. Yet despite the expansion into undergraduate coursework, most instructors are limited to professional journal articles or complex tools aimed at those working in the field. Moreover, because of the scale, complexity, and interdisciplinary nature of the study of most bioengineering phenomena, the development and implementation of hands-on experiments can be challenging at the early undergraduate level.

Though the growth of the internet has led to a general increase in web-based tools, those available to students for learning introductory cellular biology are still severely deficient in a number of areas. First, the majority of engineering students are classified as visual learners. In a validation study of the Felders-Soloman Index of Learning Style, Zywno summarized the results of 6 studies, finding that between 69% and 88% of engineering students are classified as learning material best when presented visually[1]. Though most engineers are visual learners, the vast majority of instruction is still done using textual explanations of complex phenomena, making it exceedingly difficult for students to develop a sound conceptual understanding.

The second problem that has plagued the available web-based tools is that they often lack the interactivity necessary to engage students in the higher levels of critical thinking desired. In the same validation study, Zywno found that between 55% and 69% of students were classified as active learners[1]. Many of the learning modules currently available do not require any response from the user, outside of the occasional "press here to continue" or multiple-choice question. These modules are often no better than traditional paper textbooks. Even as early as 1996, when the World Wide Web was still in its infancy, educators recognized that it had the potential to replace traditional textbooks, but would require that documents be regularly updated[2]. The idea that students learn best when they are more involved in the learning process is not a new concept, but in the face of new technology, is often a forgotten concept.

An online learning module about ion transport was specifically designed to resolve these two major problems, namely a lack of instruction that is both interactive and visually based. This paper discusses the design, implementation, and assessment of an online learning module aimed at educating undergraduate engineering students on the quantitative aspects of ion transport in cells. Student learning gains are assessed using a pre-post quiz focused on concepts presented in the learning module. In addition, students' perceptions of the interactive learning module are assessed.

II. Ion Transport Learning Module

BIOL 295F, Quantitative Biology of the Living Cell, is a new 1-credit hour computer lab based course developed at Purdue University targeted at engineering students studying bioengineering or related fields. In Fall 2004, the course met once each week for 110 minutes in a computer lab. The objective of the course is to examine traditional cellular biology topics, but place them in an engineering context, identifying the fundamental engineering concepts that underlie many biological processes. This course is designed to be a co-requisite to BIOL 295E, Biology of the Living Cell, an existing 3-credit hour traditional introduction to cellular biology for engineering students.

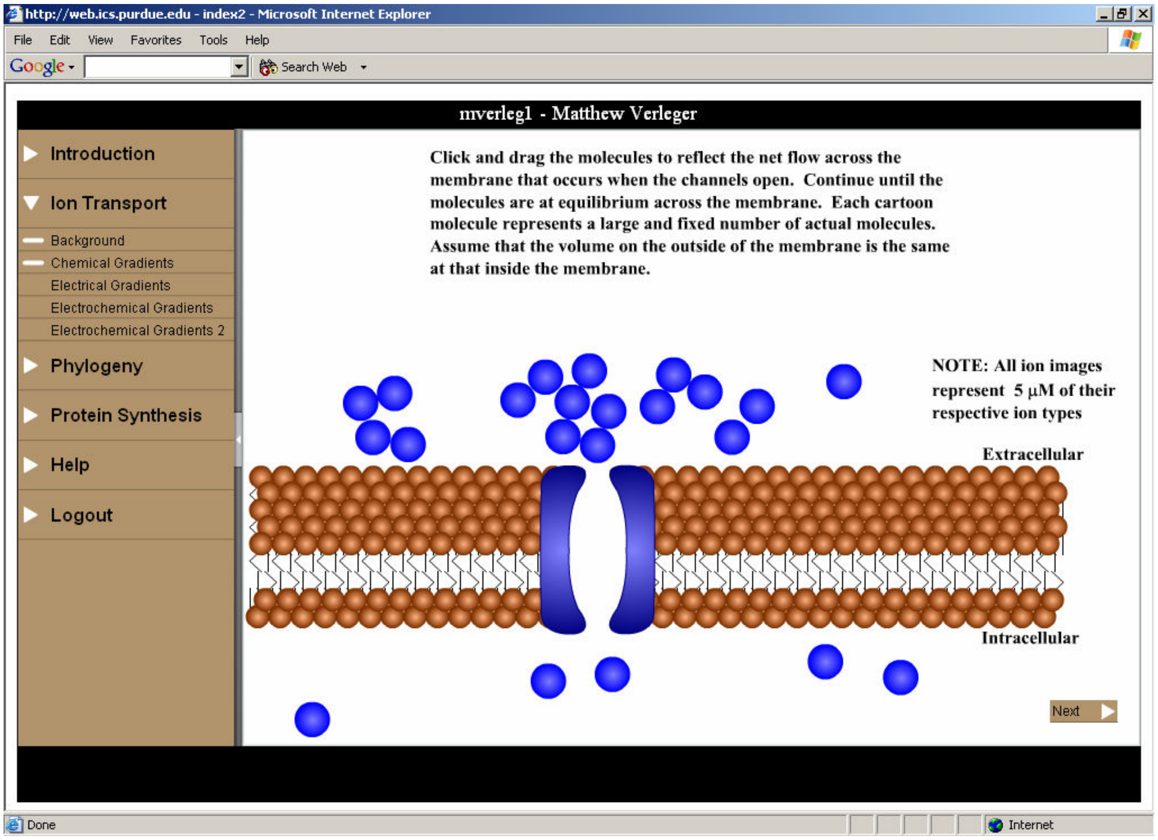
The course developer, as part of the course creation process, envisioned seven topics, each with corresponding online learning modules. To allow for more rapid development and prototyping, Macromedia Flash MX 2004 was selected as the development environment of the modules and their associated architecture. To help with the data collection process, a PHP/MySQL database was connected to the Flash architecture. For the first iteration of the course, it was decided that three online learning modules would be developed. The remaining four modules are planned for later development based on the evaluation of the first three. Ion transport, phylogenetic relationships of organisms, and dynamic gene regulation were the topics selected for initial module development. These three topics were selected as they each require a fundamentally different type of interactivity; therefore, each topic provides a unique computer-based learning experience for the user. For example, the ion transport topic allows for greater drag-and-drop interactivity to facilitate students' learning of discrete concepts at a high level of detail. The gene regulation topic requires a simulation tool that allows students to interpret the results of changing specified input parameters to a system of differential equations; the emphasis being placed on cause and effect relationships between the input and output parameters. Though both provide an interactive component, they are fundamentally different in how they allow the user to interact with the module. This paper focuses exclusively on the development and implementation of the ion transport module.

The ion transport module covers four related concepts: chemical gradients, electrical gradients, the mathematical calculation of electrochemical gradients, and the combination of all three components to form a complete cellular system. Students are asked to complete four activities, each corresponding to one of the four concepts. Each activity has a number of tasks associated with it. Though the tasks within an activity are slightly different from one another, there is some degree of repetition between the tasks. Within each task, participants are asked a series of questions and presented with a number of interactive situations. Each interactive situation requires the participant to develop a scenario that meets the given criteria.

While repetition has long been viewed as advantageous for student learning, one of the significant problems is the memorization effect, where students become better at the specific problem type they are repeating but fail to learn the underlying concepts. By utilizing computer-based instruction, more randomization can be built into the system, allowing for unique problem generation with each iteration. This approach was used in the development of the online learning module. Whenever possible, randomization was employed to change the problem. Incorporation of randomization allowed for more repetition while virtually eliminating the "memorize-and-regurgitate" response.

When students begin using the module, they are presented with a "Background" slide showing them the objects they will be interacting with for the remainder of the module. The objects include pictures of the cellular membrane, open and closed ion channels, and the ions. This slide enables students to become familiar with the objects before having to interact with them.

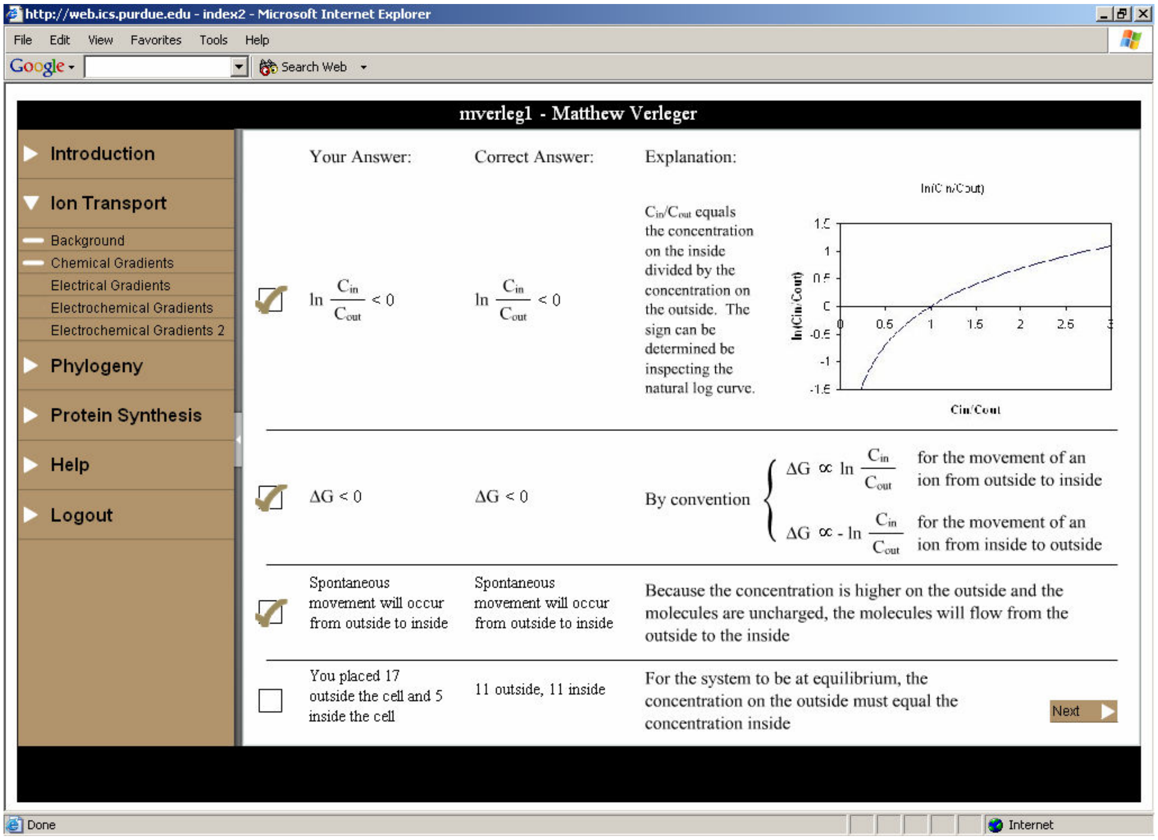
In the first task of the first activity, chemical gradients, participants are presented with a situation in which a random number of uncharged ions appear on either side of a cellular membrane resulting in a concentration ratio less than 1. The concentration ratio, by convention, is defined as the concentration inside the cell divided by the concentration outside the cell. Participants are asked to answer three multiple choice questions and describe why they selected that answer. The questions ask the student to identify the sign of the chemical gradient, the sign of the free energy change, and the direction of spontaneous flow. After answering the questions, participants are asked to interact with the image by dragging ions from one side of the membrane to the other in such a way as to bring the cell to equilibrium (Figure 1). When students reach this portion of the task, the ions become clickable, allowing the participants to use their mouse to drag an ion from one location on screen to another. After students complete this exercise, they are shown their answers side-by-side with the correct answers and an explanation of the correct answer (Figure 2). Participants continue to be presented with a randomized version of the same task until they answer the sequence of questions correctly. To help reinforce the concepts being presented, a small degree of repetition is used. Students are required to answer the questions and bring the system to equilibrium for three different concentration ratio scenarios: less than 1, greater than 1, and equal to 1.



Click and drag the molecules to reflect the net flow across the membrane that occurs when the channels open. Continue until the molecules are at equilibrium across the membrane. Each cartoon molecule represents a large and fixed number of actual molecules. Assume that the volume on the outside of the membrane is the same at that inside the membrane.

NOTE: All ion images represent 5 µM of their respective ion types

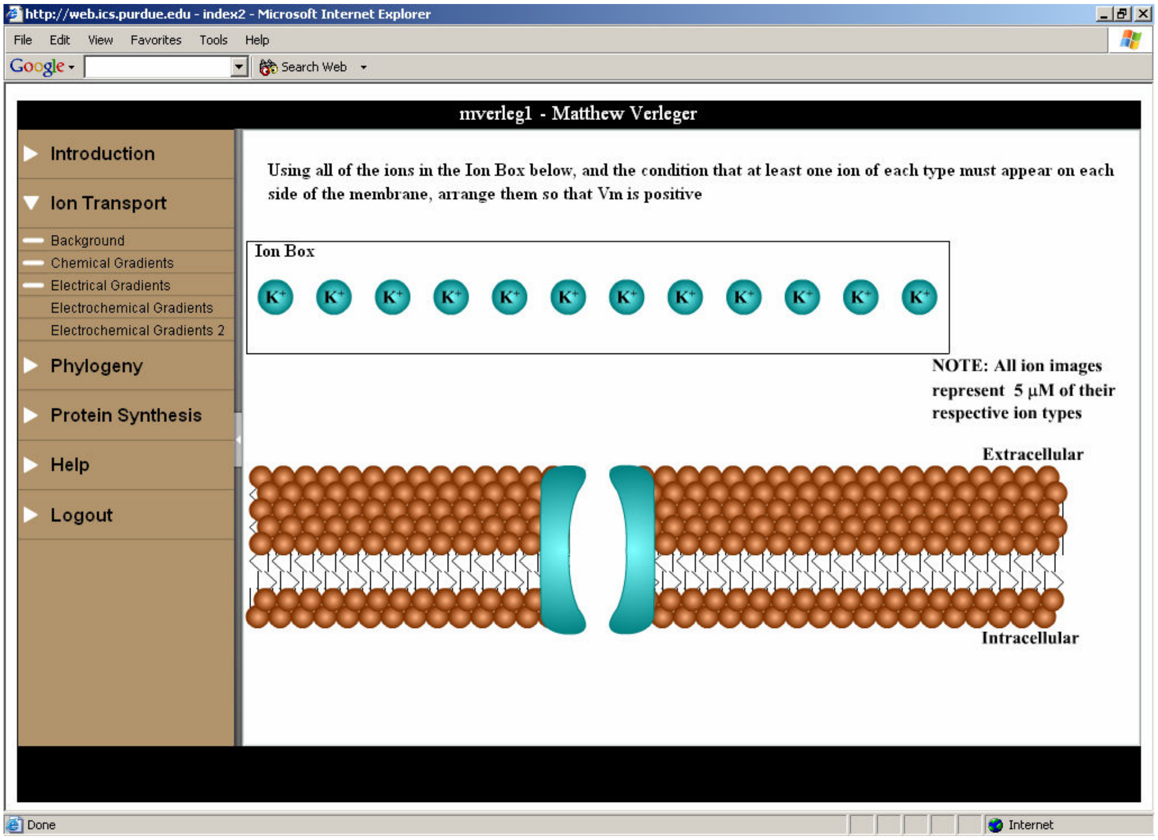
Figure 1. Chemical Gradients Equilibrium Activity



	Your Answer:	Correct Answer:	Explanation:
☑	$\ln \frac{C_{in}}{C_{out}} < 0$	$\ln \frac{C_{in}}{C_{out}} < 0$	C_{in}/C_{out} equals the concentration on the inside divided by the concentration on the outside. The sign can be determined be inspecting the natural log curve.
☑	$\Delta G < 0$	$\Delta G < 0$	By convention $\Delta G \propto \ln \frac{C_{in}}{C_{out}}$ for the movement of an ion from outside to inside $\Delta G \propto - \ln \frac{C_{in}}{C_{out}}$ for the movement of an ion from inside to outside
☑	Spontaneous movement will occur from outside to inside	Spontaneous movement will occur from outside to inside	Because the concentration is higher on the outside and the molecules are uncharged, the molecules will flow from the outside to the inside
☐	You placed 17 outside the cell and 5 inside the cell	11 outside, 11 inside	For the system to be at equilibrium, the concentration on the outside must equal the concentration inside

Figure 2. Chemical Gradients Feedback

The second activity, electrical gradients, utilizes the same ion dragging approach as the chemical gradients activity. Students are introduced to the "Ion Box", a collection of ions they must use to complete each problem. Students begin each task by being asked to drag charged ions from the Ion Box to form a membrane potential (V_m) of a randomly specified sign (Figure 3). After students have placed all of the ions either inside or outside of the membrane and selected "Next", they are given feedback about the V_m value for their scenario before being asked a series of questions about their arrangement. As with the chemical gradients activity, students are asked to repeat the task until they correctly arrange the ions for the given V_m and answer the multiple choice questions. Also like the chemical gradients activity, a repetitive component was used. The electrical gradients activity is broken into four similar tasks where the initial contents of the Ion Box are change with each task. First, they are given a single type of positively charged ion in the Ion Box, then a single type of negatively charged ion. For the third task, multiple types of ions with charges of ± 1 are used, and finally multiple types of ions with a variety of charges appear in the Ion Box.

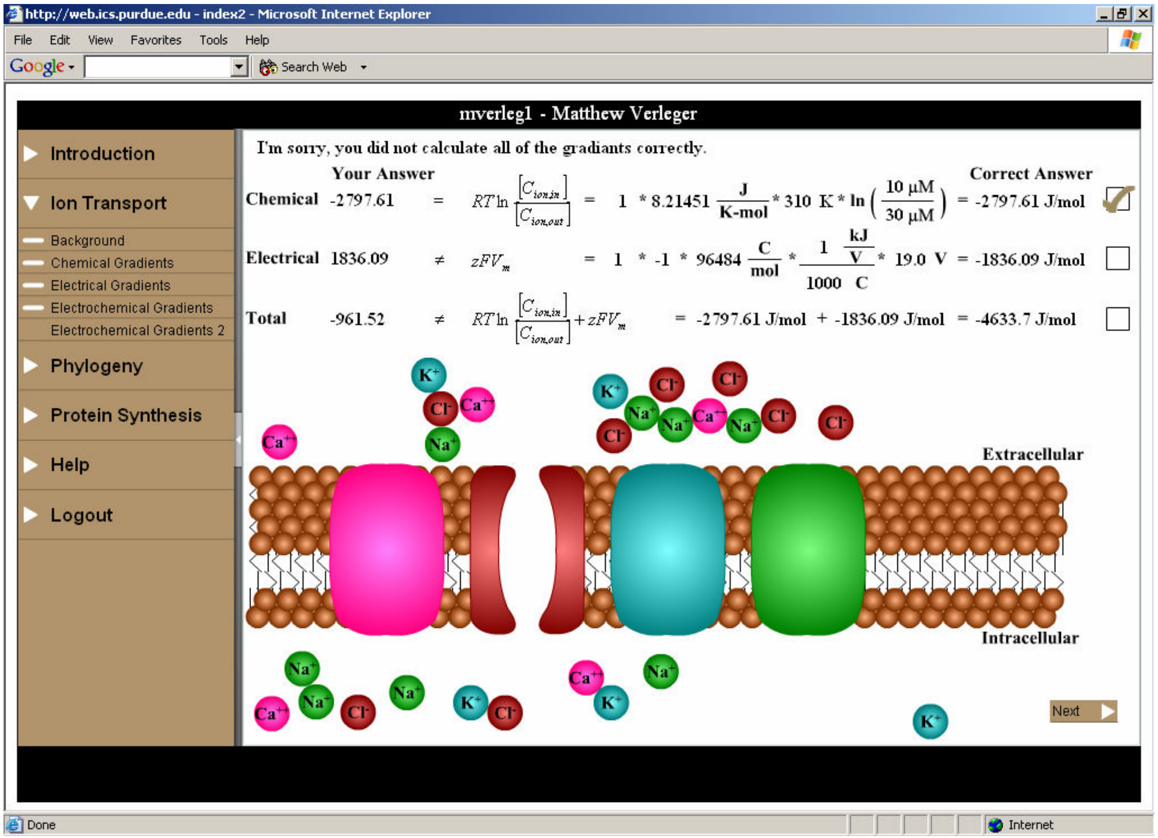


Using all of the ions in the Ion Box below, and the condition that at least one ion of each type must appear on each side of the membrane, arrange them so that Vm is positive

NOTE: All ion images represent 5 µM of their respective ion types

Figure 3. Electrical Gradients V_m Activity

The third activity, electrochemical gradients, contains one task that combines the conceptual elements from the first two activities to ask the students to calculate the chemical, electrical and total contributions to the free energy change associated with a particular ion moving in a particular direction. The chemical gradient is defined as $RT \ln \frac{[C_{ion,in}]}{[C_{ion,out}]}$ where R is the molar gas constant, T is the temperature, $C_{ion,in}$ is the concentration of the ion of interesting inside the cellular membrane, and $C_{ion,out}$ is the concentration of the ion of interest outside the cellular membrane. The electrical gradient is defined as zFV_m, where z is the charge of the ion of interest, F is Faraday's constant, and V_m is the membrane potential. By convention, these equations are correct for a gradient from outside to inside the ion, but must be multiplied by -1 if the gradient is from inside to outside. The total gradient is the sum of the chemical and electrical gradients. Here, the participants are presented with a number of ions of differing charge and asked to calculate the chemical, electrical, and total contribution to the free energy to move that ion across the membrane through an open protein channel. Once students have entered their calculated values for each of the three components, they are presented with a worked solution and a comparison to their answer (Figure 4).



I'm sorry, you did not calculate all of the gradiants correctly.

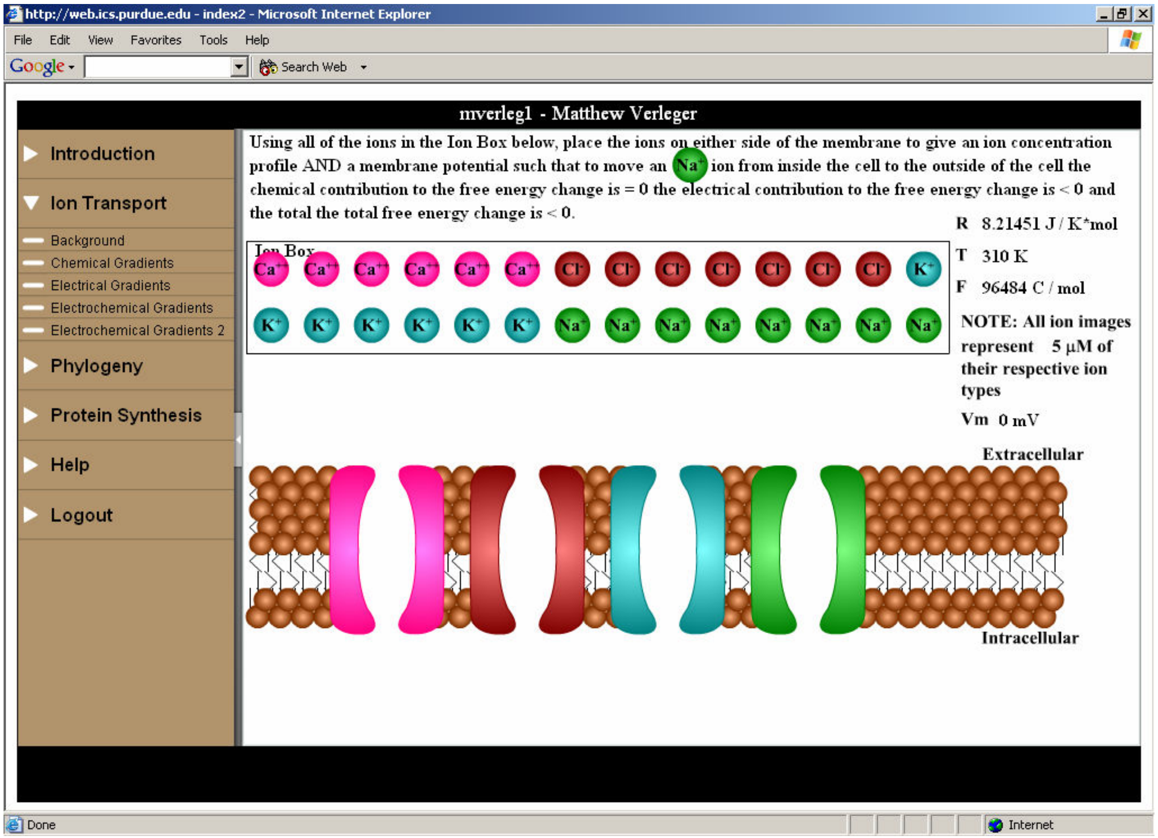
	Your Answer				Correct Answer	
Chemical	-2797.61	=	$RT\ln\frac{[C_{ion,in}]}{[C_{ion,out}]}$	$= 1 * 8.21451\,\frac{\text{J}}{\text{K-mol}} * 310\ \text{K} * \ln\left(\frac{10\ \mu\text{M}}{30\ \mu\text{M}}\right)$	= -2797.61 J/mol	☑
Electrical	1836.09	≠	zFV_m	$= 1 * -1 * 96484\,\frac{\text{C}}{\text{mol}} * \frac{1\ \frac{\text{kJ}}{\text{V}}}{1000\ \text{C}} * 19.0\ \text{V}$	= -1836.09 J/mol	☐
Total	-961.52	≠	$RT\ln\frac{[C_{ion,in}]}{[C_{ion,out}]}+zFV_m$	= -2797.61 J/mol + -1836.09 J/mol	= -4633.7 J/mol	☐

Figure 4. Electrochemical Gradients Feedback

Combining concepts covered in the first three activities, the fourth and final activity is a problem with no unique solution wherein students must use the provided ions to create a scenario that meets the specified criteria. For example, a student may be asked to use the ions to create a situation where the chemical gradient is positive, the electrical gradient is negative, and the total gradient is negative (Figure 5). When the participant has used all of the ions in the Ion Box, they are then given feedback similar to the feedback given for the third activity (Figure 4). If the participant fails to develop a correct scenario, they will be given a new set of criteria with a new set of ions in the Ion Box.

III. Implementation

Though the course is required for agricultural and biological engineering students, BIOL 295F was made available to any student currently enrolled in BIOL 295E, providing a cross-section of students from a variety of engineering disciplines. In total, 15 students registered for the course from six different engineering fields of study. Six students were pursuing degrees in Agricultural and Biological Engineering; making it the most well represented engineering discipline. Five students were classified as second year students, eight as third year, and two as fourth year. All participants had or were currently enrolled in thermodynamics which provided some of the background necessary for understanding concepts such as free energy.



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Using all of the ions in the Ion Box below, place the ions on either side of the membrane to give an ion concentration profile AND a membrane potential such that to move an Na+ ion from inside the cell to the outside of the cell the chemical contribution to the free energy change is = 0 the electrical contribution to the free energy change is < 0 and the total the total free energy change is < 0.

R 8.21451 J / K*mol

T 310 K

F 96484 C / mol

NOTE: All ion images represent 5 μM of their respective ion types

Vm 0 mV

Figure 5. Electrochemical Gradients Activity 4 – Putting It All Together

The ion transport lesson began during the sixth week of the semester with an instructor led discussion. The discussion provided the background material necessary to begin using the online learning module. It also provided a brief introduction to the topics found in the module so as to give students a starting point. The modules were not designed to be complete stand-alone learning modules independent of other instruction, but more as an extension to a more traditional instructional package. Over the course of six weeks, students took a pre-quiz, worked through the online module, took a post-quiz and completed an attitudinal survey. A full timeline can be seen in Table 1.

Table 1. Timeline of Ion Transport Lesson

Week	Activity
6	Lecture Pre-Quiz Begin module work
7	Independent work on learning module
8	No class – October break
9	Post-Quiz
10	No class
11	Attitudinal Survey

The pre-quiz and post-quiz were paper-based multiple-choice quizzes (Appendix). Though the pre-quiz consisted of eight questions and the post-quiz, nine questions, only six pairs of questions are analyzed in this paper. Six of the eight questions from the pre-quiz were selected and a variant of each question was written for the post-quiz. As they were written to map directly to activities found in the online learning module, these six questions pairs are analyzed below (Section V).

After students had completed the lesson, they were given an attitudinal survey to assess their perceptions of the online learning module. The survey was broken into three sections. The first section consisted of questions asking how students felt the module related to the course and learning the course material. The second section asked students to compare the online learning module to other forms of instruction, including traditional lectures and live demonstrations. Finally, students were asked to rate the usability of the learning module. All sections were rated using a 5-point Likert scale. Open-ended questions followed the first two sections asking students to explain their responses.

As participants work through the problems in the learning module, they must answer questions. Their answers are stored to a database for later review by the course instructor. At the same time, a number of time-based measurements are collected, including how long a student spends on any particular problem. Though both of these pieces of data were collected over the six-week period, their analysis is outside the scope of this paper.

IV. Data Analysis

Due to the relatively small class size (N = 15), no statistical analysis was performed beyond simple counts. It should be noted that one student was not present for the pre-quiz and therefore this student has been excluded from the pre-post quiz results and discussion. This student's data are included in the attitudinal survey.

V. Pre-Post Quiz Results & Discussion

Table 2 contains a detailed breakdown of the responses to each option on the pre-and-post quizzes. Each question pair contained one question on the pre-quiz and a question of similar design on the post-quiz. Each pair of questions is also identified by which concept they cover and whether they are conceptual or computational in nature. There are two questions mapped to each of the first three activities from the learning module: one conceptual question and one computational question.

Table 3 contains a question pair breakdown of pre-quiz to post-quiz performance. For example, for question pair 5, eight participants answered both the pre and post quiz questions correctly, while one student answered the pre-quiz correctly but missed the corresponding post-quiz question.

Table 2. Pre-Post Quiz Responses[a]

Question Pair	Concept	Question Type	Quiz	Number of Responses				
				A	B	C	D	E
1	Chemical Gradients	Conceptual	Pre	0	3	0	**11**	0
			Post	**11**	0	0	3	0
2	Chemical Gradients	Computational	Pre	2	**11**	0	0	1
			Post	**14**	0	0	0	0
3	Electrical Gradients	Computational	Pre	**10**	2	1	0	1
			Post	**13**	1	0	0	0
4	Electrical Gradients	Conceptual	Pre	0	1	**7**	0	6
			Post	0	0	**6**	2	6
5	Electrochemical Gradients	Computational	Pre	2	**9**	0	1	2
			Post	**11**	1	0	0	2
6	Electrochemical Gradients	Conceptual	Pre	1	0	**11**	1	1
			Post	2	1	8	**3**	0

[a]Shaded answer is correct

Table 3. Performance on Pre-Post Quiz Question Pairs

		Question Pair					
Pre-Test Answer	Post-Test Answer	1	2	3	4	5	6
Correct	Correct	8	11	10	3	8	2
Correct	Incorrect	3	0	0	4	1	9
Incorrect	Correct	3	3	3	3	3	1
Incorrect	Incorrect	0	0	1	4	2	2

Chemical Gradients.

Question Pair 1. Students were asked to identify, based on the relative concentrations of an uncharged molecule inside and outside of a cell, the spontaneity and direction of flow of the molecules. The three students that answered the post-quiz question incorrectly had answered the pre-quiz question correct. These students incorrectly identified the direction of spontaneous flow. All three students incorrectly chose that "d) both b and c are true." Though d is the incorrect selection, those students did correctly identify that responses b and c are internally consistent with one another in that if molecules spontaneously move in one direction (answer b), that it takes work to move them in the other direction (answer c).

Question Pair 2. Here, students were required to determine the sign of the chemical gradient given numerical values for the concentrations inside and outside the cellular membrane. On the post-quiz, all participants correctly identified the sign of chemical contribution to free energy is negative for spontaneous movement of an ion from outside to inside for a higher outside concentration.

Question pairs 1 and 2 each mapped to the chemical gradients activity of the online learning module. Based on pair 1, the module does need some improvement with helping students understand direction of flow, however pair 2 would seem to indicate that the module successfully helps students identify the sign of the chemical gradient, as all of the students who incorrectly identified the sign on the pre-quiz were able to correctly identify the sign on the post-quiz.

Electrical Gradients.

Question Pair 3. This pairing required the students to determine the sign of the electrical gradient given an appropriate membrane potential. Similar to question pair 2, this pairing required students to have a usable understanding of the mathematics governing a cellular membrane. With the exception of one student, everyone who missed this question on the pre-quiz was successful in their attempt on the post-quiz.

Question Pair 4. The participants were asked to quantify the amount of relative charges based on the sign of the membrane potential. Though the results from pair 4 are not favorable towards the learning module, they do provide insight into an area where the tool is clearly deficient. Based on the post-test scores, the tool does not do an adequate job of helping students differentiate between numbers of ions versus net charge, as nearly half of the participants (6/14) selected the answer corresponding to more negative ions being equivalent to greater total negative charge.

Question pairs 3 and 4 each mapped to the electrical gradients portion of the online learning module. Based on pairing 3, it seems participants have a good ability to utilize the electrical gradient formula to solve problems, a fact that is not surprising, given that all of the students are studying engineering. While currently the electrical gradients tool contains four tasks where students are dealing with the charge of ions, it clearly fails to provide enough examples which differentiate between number of ions and net charge.

Electrochemical Gradients.

Question Pair 5. To correctly answer this question, students needed to identify the sign of the total free energy change given appropriate numerical values. Much like pairings 2 and 3, this question was computational in nature. As such, students did quite well, with half of those that missed the question on the pre-quiz successfully completing it on the post-quiz.

Question Pair 6. This question pairing proved to be the most challenging, requiring the students identify the same type of results as pairings 2, 3, and 5, but at a more abstract level. Whereas questions 2, 3, and 5 required participants to utilize mathematical formulas, pairing 6 required them to have an understanding of the fundamental operation of the formulas. The majority, 9 out of 14, of respondents answered the pre-quiz question correctly, but answered the post-quiz question incorrectly. Of those 9, seven of them selected the same incorrect answer on the post-quiz. The only difference between the pre-quiz and post-quiz was a change in the directionality of flow, indicating that this is an area where the module is strongly deficient.

Question pairs 5 and 6 mapped to the electrochemical portions of the online learning module. Clearly, based on question pair 6, students still have difficulty with the conceptual understanding of direction of flow. The results from pairing 5 however, align with those found in pairs 2 and 3, showing that students are readily capable of comfortably utilizing the necessary mathematical formulae without necessarily understanding the underlying concepts needed to relate the physical phenomena to the computational results.

VI. Attitudinal Survey Results & Discussion

Attitudinal Survey – Relation to Course Material. Table 4 contains the responses for the two questions on the attitudinal survey about how the online learning module relates to the course material. In general, participants felt the module was well related to the course material, ranking it positively in both its benefit towards learning and its relation to the course objectives. Of the 12 students who chose to comment on the learning benefits of the tool, 10 participants specifically mentioned that the online module helped them to better visualize the concepts. One student noted, “I liked the visual! It helped to understand the material and having to do it until right helped.” Three other participants also mentioned the repetition and requirement of getting correct answers before continuing. All four students agreed that the tool was appropriate for meeting the learning objectives.

Table 4. Attitudinal Survey - Relation to Course Material

Item	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
This tool was of benefit to me when learning the concepts taught in this module	0	1	0	5	9
This tool was appropriate for meeting the learning objectives for this module	0	0	1	9	5

Attitudinal Survey – Comparison to Other Forms of Instruction. Table 5 contains responses for the three questions on the attitudinal survey asking students to compare the tool to more traditional forms of instruction. As with the relation to course material, the response towards the module was favorable when compared to other forms of instruction. Overwhelmingly, students preferred the online module to traditional textbook reading, with 11 of the 15 respondents stating that the module was significantly better. The student who stated that the tool was somewhat worse than textbook reading stated that the ion transport tool didn’t provide the same level of background information that a textbook would carry. All respondents found the online module to be as much or more preferable than a traditional lecture. As one student stated, “I am more of a hands on person, so listening and taking notes is good, but then being able to apply those concepts really helps me understand.” While the response was still positive, a few students still preferred traditional laboratory experiments, though as one student pointed out, “It is hard to see ion channels in a beaker.”

Table 5. Attitudinal Survey – Comparison to Other Forms of Instruction

Item If given the choice between the Ion Transport tool and…[a]	**Significantly Worse**	**Somewhat Worse**	**About the Same**	**Somewhat Better**	**Significantly Better**
Independent Reading such as textbooks and journal articles	0	1	0	3	11
Traditional Lectures	0	0	4	6	5
Live Demonstrations or Lab Experiments	0	2	8	5	0

[a] i.e. "If given the choice between the Ion Transport tool and Traditional Lectures, I would find using the Ion Transport tool to be:"

Attitudinal Survey - Module Usage. Table 6 contains responses for the five questions on the attitudinal survey that asked students about their perceptions of using the module. Positive responses were recorded here as well, with most students finding the tool both easy to use and worth the time spent. Two respondents indicated that they disagreed that the online module complemented the course material, though neither provided comments as to why they felt such.

Table 6. Attitudinal Survey – Module Usage

Item	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
Complimented the course materials	0	2	0	5	8
Was relatively easy to use	0	0	1	7	7
Was worth the time spent using it	0	0	2	7	6
There was sufficient support provided to effectively use the tool	0	0	0	10	5
I learned more in class as a result of using the tool outside of class	0	1	3	4	7

VII. Conclusion & Next Steps

An interactive online quantitative cellular biology learning module for ion transport was developed for an undergraduate engineering course at Purdue University. Analysis of student performance on the pre-post quiz reveals that the module successfully helped students to learn the mathematical formulas that govern the phenomena surrounding ion transport, but did fall short of fostering student's ability to build the necessary conceptual base. Overall, students did show some improvement in their computational abilities related to ion transport as well as modest improvement in their conceptual understanding of chemical gradients. Students did not show improvement in their conceptual understanding of electrical and electrochemical gradients. Based on the attitudinal survey, they clearly enjoyed using the module more than other forms of instruction.

In order to better understand why students are not improving their understanding of the more difficult concepts, students' use of the tool should be analyzed. This includes the time based data as well as student responses to the in-module short answer written questions. Following this analysis, changes should be made to the tool to further improve the student understanding of the conceptual information and its connection to the mathematical relationships.

Though there are still areas for improvement, the initial results of module use warrant further development and usage of both the ion transport module as well as other similar modules.

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Biographical Information

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Mr. Verleger is a graduate student in Agricultural and Biological Engineering. He received his undergraduate degree from Purdue University in Computer Engineering in 2002 with an emphasis on software development. Matthew will be in charge of the design of the overall system architecture, creation of the on-line modules, and analysis of data collected.

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Dr. Rickus joined the Purdue faculty in 2003 as an Assistant Professor in the Department of Agricultural and Biological Engineering with a joint appointment in the Department of Biomedical Engineering. She herself is dually trained (engineering and biology) with degrees in engineering, biochemistry, and neuroscience. She served as the content expert for the development of the learning modules as well as the instructor for BIOL295F.

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Dr. Schaffer is an Assistant Professor in Educational Technology. He has software design and development experience in the private sector and teaches courses, EDCI 561, 660, 664, related to the design and evaluation of software for learning. He is currently working on an AT&T grant developing mathematics animation tools, and a NCER grant developing software to support scientific reasoning and modeling skills.

Appendix

Question Pair: 1
Concept Map: Chemical Gradients
Pre-Test Question: If the uncharged molecule, glucose, has a greater concentration outside the cell than inside the cell then…

a) glucose would spontaneously move from the intracellular to the extracellular space if glucose channels opened.
b) glucose would spontaneously move from the extracellular to the intracellular space if glucose channels opened.
c) the cell would have to exert work to move glucose from the intracellular to the extracellular space.
d) both b and c are true.
e) no net movement of the molecule would occur.

Post-Test Question: If an uncharged molecule has a lower concentration outside the cell than…

a) the molecule will spontaneously move from the intracellular to the extracellular space.
b) the molecule will spontaneously move from the extracellular to the intracellular space.
c) the cell would have to exert work to move glucose from the intracellular to the extracellular space.
d) both b and c are true.
e) no net movement of the molecule would occur.

Question Pair: 2
Concept Map: Chemical Gradients
Pre-Test Question: Suppose for a particular cell $[K]_{outside}$ = 5 mM, $[K]_{inside}$ = 120 mM, and V_m = -42 mV. The chemical contribution to the free energy change for a K^+ ion to move from the outside to the inside is…

a) negative.
b) positive.
c) zero.
d) it depends upon the Na^+ concentration outside the cell.
e) it depends upon the Na^+ concentration gradient.

Post-Test Question: Suppose for a particular cell $[Na]_{outside}$ = 120 mM, $[Na]_{inside}$ = 5.0 mM, and V_m = -42 mV. The chemical contribution to the free energy change for a Na^+ ion to move from the outside to the inside is…

a) negative.
b) positive.
c) zero.
d) it depends upon the Na^+ concentration outside the cell.
e) it depends upon the Na^+ concentration gradient.

Question Pair: 3
Concept Map: Electrical Gradients
Pre-Test Question: Suppose for a particular cell $[K]_{outside} = 5$ mM, $[K]_{inside} = 120$ mM, and $V_m = -42$ mV. The electrical contribution to the free energy change for a K^+ ion to move from the outside to the inside is…

- **a) negative.**
- b) positive.
- c) zero.
- d) it depends upon the Na^+ concentration outside the cell.
- e) it depends upon the Na^+ concentration gradient.

Post-Test Question: Suppose for a particular cell $[Na]_{outside} = 120$ mM, $[Na]_{inside} = 5.0$ mM, and $V_m = -42$ mV. The electrical contribution to the free energy change for a Na^+ ion to move from the outside to the inside is…

- **a) negative.**
- b) positive.
- c) zero.
- d) it depends upon the Na^+ concentration outside the cell.
- e) it depends upon the Na^+ concentration gradient.

Question Pair: 4
Concept Map: Electrical Gradients
Pre-Test Question: If the membrane potential of a cell is negative then…

- a) there must be more negative ions inside the cell relative to outside the cell.
- b) there must be more positive ions inside the cell relative to outside the cell.
- **c) the inside of the cell has a net negative charge relative to outside the cell.**
- d) the outside of the cell has a net negative charge relative to outside the cell.
- e) both a and c.

Post-Test Question: If the membrane potential of a cell is negative then…

- a) there must be more negative ions inside the cell then outside the cell.
- b) there must be more positive ions inside the cell then outside the cell.
- **c) the inside of the cell has a net negative charge then outside the cell.**
- d) the outside of the cell has a net negative charge then outside the cell.
- e) both a and c.

Question Pair: 5
Concept Map: Electrochemical Gradients
Pre-Test Question: Suppose for a particular cell $[K]_{outside}$ = 5 mM, $[K]_{inside}$ = 120 mM, and V_m = -42 mV. The total contribution to the free energy change for a K^+ ion to move from the outside to the inside is…

a) negative.
b) positive.
c) zero.
d) is opposite in sign to the free energy change to move Cl^- into the cell from the outside.
e) both a and d.

Post-Test Question: Suppose for a particular cell $[Na]_{outside}$ = 120 mM, $[Na]_{inside}$ = 5.0 mM, and V_m = -42 mV. The total contribution to the free energy change for a Na^+ ion to move from the outside to the inside is…

a) negative.
b) positive.
c) zero.
d) is opposite in sign to the free energy change to move Cl^- into the cell from the outside.
e) it depends upon the Na^+ concentration gradient.

Question Pair: 6
Concept Map: Electrochemical Gradients
Pre-Test Question: If there is more K^+ inside a cell than outside of a cell then…

a) K^+ would never flow into the cell through an open K^+ channel because this is against the chemical gradient.
b) K^+ would flow into the cell if the membrane potential was any negative value.
c) K^+ would flow into the cell if the membrane potential was negative enough to overcome the chemical gradient.
d) K^+ would flow into the cell if the membrane potential was positive.
e) K^+ will always flow out of the cell.

Post-Test Question: If there is more Na^+ outside a cell than inside a cell …

a) Na^+ would always flow into the cell through an open Na^+ channel because this would be the direction of the chemical gradient.
b) Na^+ would flow out of the cell if the membrane potential was any negative value.
c) Na^+ would flow out of the cell if the membrane potential was more negative than the equilibrium potential for Na^+.
d) Na^+ would flow into the cell if the membrane potential was more positive than the equilibrium potential for Na^+.
e) Na^+ could never flow out of the cell.