RELEVANCE

Pharmacology in the High-School Classroom

Making learning relevant improves students' knowledge of biology and chemistry.

Nicole C. Kwiek,[1]* Myra J. Halpin,[2] Jerome P. Reiter,[3] Leanne A. Hoeffler,[1] Rochelle D. Schwartz-Bloom[1]†

Many teachers say that their most difficult task is getting students' attention. What does get students' attention? Sex, drugs, and rock-n-roll, of course.

U.S. high-school students rank relatively low in science achievement compared with their international peers (*1*). Factors that may contribute to poor science achievement include (but are not limited to) inadequate teacher training, lack of inquiry-based teaching, insufficient hands-on student activities, and students' views of science as boring or too hard (*2*, *3*). A positive relation exists between student interest and student learning: Topics and approaches that arouse student interest can help motivate students to learn and increase achievement (*4*). Theories of constructivism (that learners formulate new understandings by building on their own prior ideas) from cognitive psychology also indicate that learning improves when information is embedded within meaningful contexts (*5*).

When high-school students are asked to indicate their interest in learning about various topics in their science classes, they choose topics such as disease (cancer and HIV/AIDS), drugs (therapeutic and recreational), biological and chemical weapons, the ozone layer, and greenhouse gases (*6*). Yet, the usual high-school science curriculum does not address these topics.

Pharmacology Education Partnership

Given the interest of students in drugs and their bodies, we hypothesized that science instruction in the context of drug-related topics (i.e., pharmacology) could improve student learning of standard high-school biology and chemistry concepts. To study this issue, we developed the Pharmacology Education Partnership (PEP), a partnership between Duke University faculty and high-school teachers across the United States. The PEP project comprised three major components: (i) development of pharmacology content modules, (ii) professional development for teachers of high-school biology and chemistry, and (iii) assessment of students' knowledge of basic biology and chemistry concepts.

Each pharmacology module was designed in an inquiry-based format. Details of the contents of the module and the teachers' guide are found in the supporting online material (SOM) and on the PEP Web site (*7*). The modules focused on a pharmacological topic that integrated basic science principles in biology and chemistry with issues from other relevant disciplines such as mathematics, public policy, psychology, and social sciences. Topics (see figure, right) were chosen with an expectation that students would identify with the subject matter on the basis of personal experience or interest generated from popular culture and the media.

High-school biology and chemistry teachers were recruited nationally to take part in the PEP study (see demographics in SOM). The process began when 116 teachers attended day-long professional development workshops at one of three conferences, including the Conference on Science Education for the National Science Teachers Association (NSTA) and the North Carolina Science Teachers Association (NCSTA) in 2003 (SOM). The workshops showed how biology and chemistry concepts support the pharmacology topics in the modules. Teachers discussed how to bring these topics into their already crowded curriculum. After the workshop, teachers collaborated to develop classroom and laboratory activities to support each module (activities are available on the PEP Web site). Assessment of teacher knowledge one year after the workshops indicated gains in knowledge of biology and chemistry (SOM).

The following year after the workshops, 95 of those teachers field-tested the program in their classes (21 teachers dropped out during the year for unknown reasons). Because teachers often modify use of instructional materials according to their own style (*8*), we invited that flexibility; we requested only that teachers use as many modules as possible and report what they did. Of the teachers who used modules in their classes, the most commonly reported method was to incorporate the content in their normal lesson plans, without "piling on additional material" (SOM). The most commonly reported reason for not using the modules was lack of time (SOM), suggesting that priority was given to preexisting curricula.

MODULE TOPICS

- Acids, Bases, and Cocaine Addicts
- Drug Testing: A Hair-Brained Idea
- How Drugs Kill Neurons: It's Radical!
- Military Pharmacology: It Takes Nerves
- Why Do Plants Make Drugs for Humans?
- Steroids and Athletes: Genes Work Overtime

Student Assessment

With input from an advisory group of five high-school teachers (independent of our testing group), we developed a testing instrument to determine students' knowledge of standards-based biology and chemistry concepts. The test consisted of two parts (see SOM for sample questions). The "basic knowledge" questions were similar to those found in standard high-school biology and chemistry textbooks. The "advanced knowledge" questions tested specifically for knowledge about drugs, assessing concepts not normally taught in the standard curriculum. To obtain control data, 65 of the 95 teachers had the workshop soon enough that they were able to administer the tests to a separate group of students in the year before they used (field-

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tested) the modules as a teaching component. The other 30 teachers joined the study later and thus did not generate control data.

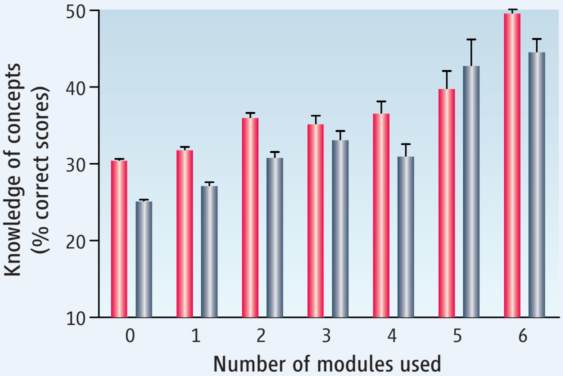
During the field-testing year, 47 of the 95 teachers used the modules in their classes. Then, all 95 teachers administered the same test (unannounced) to their students. Although the control data were derived from different students than those who used the modules, the demographic profiles were the same. A total of 7210 students provided data for the study. Student achievement demonstrated a dose-response relation: As the number of modules experienced increased, the students' performance increased (see figure, right).

We used a logistic regression model to adjust for differences in students' demographic characteristics (gender, race/ethnicity, course type, and level) with the use of random effects to control for teacher effects (*9*, *10*) (SOM). For both basic and advanced knowledge questions, the logistic regression indicates that the probability of students answering any question correctly increases significantly as teachers use more modules (SOM). Students exposed to all six different modules are more likely than students with zero exposure to answer a basic knowledge question correctly. This corresponds to about a 16–percentage point increase (compared with zero modules) in the chance of a white female in Biology One (the baseline, SOM) answering correctly. When our analysis includes only the students from the 65 teachers who served as their own controls, the modules still have significant positive effects, providing assurance that the module effects are not likely confounded by teacher and student effects (e.g., only the best teachers used the modules).

Relevance, Repetition, Integration

The PEP topics such as drugs of abuse and chemical warfare carry personal, societal, and global relevance, which may have supported the successful outcome of this educational intervention. Similar attention to the students' interests may improve effectiveness of science education reform initiatives in other disciplines as well. Alternatively, consistent with educational research findings, the student-learning gains may have been strengthened by repetition of important principles among modules (*11*). Although we cannot state with certainty whether the use of socially relevant topics or repetition of scientific principles is responsible for the educational gains, at the very least the pharmacology topics can support repetition without boring students.

The teacher-training workshops, crucial to this program, fulfilled several elements of the National Science Education Standards (*12*). In particular, the teachers learned new information (in this case, basic pharmacology principles) into which they could integrate biology and chemistry concepts. This sort of cross-connective experience is rare for secondary school teachers (*13*). Although we did not test for the effect of integrating disciplines on student achievement, the pharmacology topics supported improved student performance in both biology and chemistry. Such integration across science disciplines is a proposed goal of science education reform efforts (*14*).



Student improvement with exposure to modules. Performance of all students on questions of basic (red) and advanced (blue) knowledge depending on the number of PEP modules they experienced. Data are the mean ± SEM scores from students in both biology and chemistry courses (n = 7210). Binomial regression revealed that the use of at least one module was a significant predictor of higher student scores for both tests.

Reproducibility

Our results for both teacher and student content knowledge are similar to another study in which we provided the professional development over 5 days at Duke University and used a wait-listed randomized control design (*15*). The 6-hour workshop content was the same as that provided in the present study, although teachers had some "hands-on" time and interactions in small groups during the longer format. Regardless, both forms of professional development are associated with a significant increase in student achievement in biology and chemistry. From a practical standpoint, a full-day professional development experience is efficient and cost-friendly; its design allows more teachers to participate (compared with a residential 5-day workshop), eventually affecting a much larger student population.

A prevailing goal of science education is to encourage students to use science to think critically when making decisions about their daily lives (*2*). Although preventing drug abuse was not a goal of the present study, more knowledge about street drug pharmacology may help students make better decisions concerning illicit drugs.

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Supporting Online Material

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Supporting Online Material for:

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SOM
Analytical and Statistical Methods

Raw student test data were obtained from participating teachers' classes. Inspection from the demographic representation of students indicates that the students among different classrooms have nonequivalent demographic characteristics. Since these could be related to performance on the tests, it was appropriate to control for those differences in order to compare the groups' average test scores.

To do so, we adjusted for differences in demographic characteristics among classrooms using random effects logistic regression models, which are a type of multi-level model (*1*, *2*). The outcome variables are the number of correct answers out of 20 questions (as a percentage) for the basic knowledge portion and the number of correct answers out of 10 questions (as a percentage) for the advanced knowledge portion of the student testing instrument. For simplicity, we analyze each outcome independently. The random effects account for the correlations among outcomes of students who have the same teacher.

Specifically, let Y_{1ij} be the number of correct answers on the basic knowledge test for student *ij*, where *i* indexes the student and *j* indexes the student's teacher. We assume the Y_{1ij} follow binomial distributions such that each student has probability p_{1ij} of answering a question correctly, i.e. $Y_{1ij} \sim Bin(20, p_{1ij})$. The p_{1ij} are linked to the vector of covariates X_{ij} (indicator variables for the student's class type, race, sex, and treatment group) with the logistic function, $\log(\frac{p_{1ij}}{1-p_{1ij}}) = X_{ij}\beta_1 + \lambda_{1ij}$. The λ_{1ij} are student effects that account for heterogeneity in students' abilities that is not captured by the X_{ij}. They are modeled as random effects that follow normal distributions, $\lambda_{1ij} \sim N(\alpha_{1j}, \sigma_1^{\ 2})$, where the α_{1j} are teacher effects and the σ_1^2 is the variance of the student effects. Finally, the α_{1j} are modeled as random effects that follow the normal distribution, $\alpha_{1j} \sim N(0, \tau_1^{\ 2})$, where τ_1^2 is the variance of the teacher effects. The model used for the advanced knowledge scores is similar, with the exception that $Y_{2ij} \sim Bin(10, p_{2ij})$.

All parameters in this model are estimated; only the data (X_{ij}, Y_{1ij}) are known. We obtain inferences about the unknown parameters using Bayesian model-fitting techniques. Following typical practice, we assume vague proper prior distributions on all parameters so that the data dominate the inferences. We fit the models using the software package WinBUGS, which implements Markov Chain Monte Carlo sampling. We checked convergence to the posterior distribution by examining trace plots and the Gelman-Rubin-Brooks statistic (*3*) for all parameters. After the chains converged, we generated 10,000 draws of the parameters from their posterior distributions. These drawn values were used to summarize the posterior distributions.

We checked the models using posterior predictive checks and sensitivity analyses (*1*), which are typical diagnostics in Bayesian modeling. The posterior predictive checks involve (i) simulating new outcomes for the students in the dataset based on the fitted model, and (ii) comparing the simulated outcomes to the Y_{1ij}. Discrepancies in the simulated and actual outcomes indicate inadequate model fit. The sensitivity analyses involve fitting the model with other reasonable prior distributions and comparing the resulting inferences. Substantial differences indicate the model is sensitive to the prior assumptions. The posterior predictive checks did not reveal any lack of fit, suggesting that the models are reasonable. In contrast, when we excluded the λ_{1ij} or the α_{1j}, the models under-predicted small and large outcomes and over-predicted typical outcomes. We also found that assuming the Y_{1ij} or Y_{2ij} follow normal distributions led to inferior model-fit, with many negative predicted scores. The sensitivity analyses confirmed that our prior distribution did not substantially impact inferences.

We compared the test scores of all students whose teachers chose to use zero modules and all students whose teachers were not yet allowed to use the modules (i.e., when the teachers were controls). There were no significant differences among these students' average test scores (means 30.5% and 30.5% correct on the basic knowledge test or 25.5% and 24.3% correct on the advanced knowledge test, respectively). Thus, we combined all student data with zero modules in one group for the analyses.

We repeated the analyses using only the 65 teachers who served as their own controls. The results are very similar; increased module use by teachers resulted in strongly significant positive and increasing gains in student knowledge. This is expected since roughly 70% of the students were taught by teachers who served as their own controls. Assuming teacher and student quality does not change radically from class to class, this similarity provides some assurance that the significant positive effects associated with the modules do not result primarily for selection bias (e.g., only the best teachers use the modules).

The logistic regression results are valid under the assumptions that, for any given student, (i) the probability of answering correctly is the same for all basic or all advanced knowledge questions, and (ii) each question is independent of others. The second assumption is reasonable, since the questions are designed to test different concepts (e.g., specific concepts in both biology and chemistry). We made the first assumption out of convenience; the dataset comprised total scores rather than individual item scores. Prior to the study an advisory panel of 5 teachers rated each question for relevance and appropriate level of difficulty. Four of the 5 teachers rated 19 of the 20 basic knowledge questions as relevant and of appropriate difficulty. One of the 20 questions was rated by 3 of the 5 teachers as relevant and of appropriate difficulty. Although the dataset used for analysis only had total scores, we subsequently reviewed performance on individual questions for students in the zero module group. Most questions were answered correctly by 15% to 45% of the students (basic knowledge mean = 30% with SD = 15%, and advanced knowledge mean = 25% with SD = 13%). One question in each test was answered by more than 50% of the students (62% and 53%, respectively). Thus, although there are no "easy" questions on either test, the assumption of equal item difficulty may not be precisely true. We tried normal and Poisson distributions in place of binomial distributions, since these do not assume constant probability; however, these models did not fit the data as well as the binomial model.

Given the strong effects of the modules, and since all students took the same test, we are optimistic that the general conclusions would not change substantially if we controlled for item difficulty. In our model checks, we did not see any evidence of over-dispersion or lack of fit, which suggests that the binomial model yields reasonable inferences for the overall effects of the modules. Nevertheless, building an item-level dataset allows one to account explicitly for variation in item difficulty with a more complex statistical model, as is done in item response models. Thus, one can evaluate the properties of the individual questions and ascertain if the effects of the modules differ by question. Future studies can be performed to explore these relationships.

Module Content

(Complete content is available online at www.thepepproject.net)

- **Each PEP module comprised:**
  - A set of learning objectives
  - An inquiry-directed student handout (problem-based learning approach)
  - A teacher's guide with background science content (containing answers to student questions) and illustrative graphics
  - A glossary of terms
  - A resource list
  - Student hands-on or minds-on activities
  - Assessment strategies

- **The biology and chemistry principles highlighted in the modules include:**

  - *Acids, Bases and Cocaine Addicts*
    - Acid-base chemistry, molecular structure, circulatory system, membrane transport, cocaine formulations, addiction biology

  - *Drug Testing: A Hair-Brained Idea*
    - Acid-base chemistry, molecular structure, cellular structure, anatomy, biology & chemistry of hair, nicotine, cocaine, heroin, racial ethics

  - *How Drugs Kill Neurons: It's Radical!*
    - Oxidation-reduction, oxygen radicals, neuron structure, neurochemistry, cell death, methamphetamine, neurodegenerative diseases

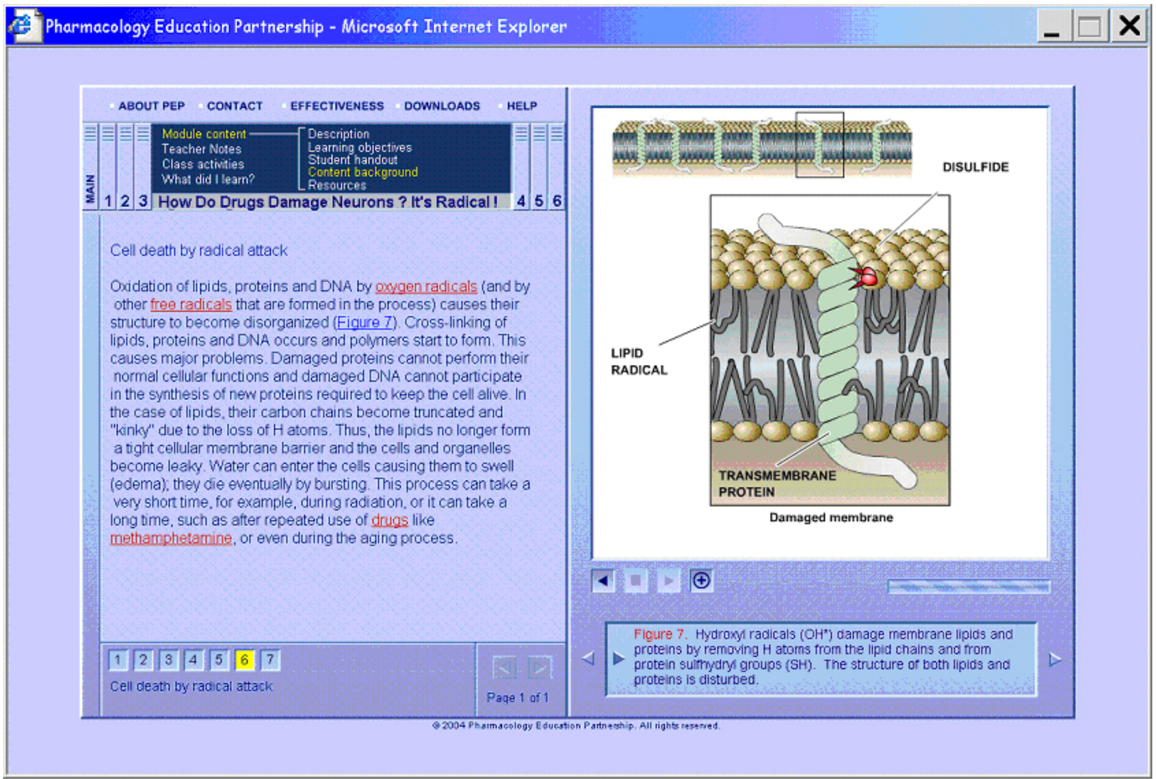
  - *Military Pharmacology: It Takes Nerves*
    - Covalent bonding, enzyme action, autonomic nervous system, physiology, behavior of gases, chemical warfare, Middle East & Japan current events/history

  - *Why Do Plants Make Drugs for Humans?*
    - Plant cell structure and classification, acid-base chemistry, molecular structure, polarity, membrane transport, tobacco industry chemical "tricks

  - *Steroids and Athletes: Genes Work Overtime*
    - Steroid biology, molecular structure, muscle cell anatomy and physiology, lipophilicity, diffusion, DNA structure, gene transcription, protein synthesis, drug testing

Sample Page from Module 3 at www.thepeproject.net

How do Drugs Kill Neurons? It's Radical!



During the PEP study, there were 556 teacher visits and 4,659 student visits to the website online (this does not include offline usage; all teachers had a CD Rom version of the website that did not require internet access). Since opening the PEP website to the public in 2004, there have been 14,411 teacher visits and 31,779 student visits to the website online (as of August, 2007). The online usage underestimates the curriculum usage, as the entire content is downloadable in pdf format.

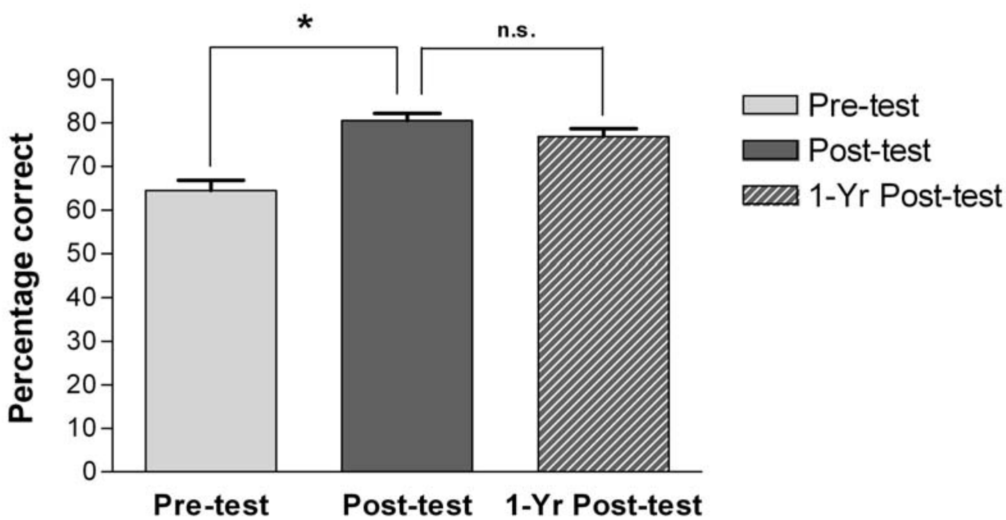
Demographics of Teachers Attending the Workshops

Category	Total number
Subject	
Biology	56
Chemistry	38
Biology & Chemistry	22
School Type	
Public	104
Private	10
Parochial	2
School Size	
< 500	12
501-1000	36
1001-2000	50
>2000	18
School Minority Population	
< 10%	30
10-39%	42
40-79%	26
> 80%	18
School Locale	
Urban	34
Suburban	53
Rural	29
US Location	
Northeast	52
Southeast	49
Midwest	5
West	10

Teachers attended either the workshop at the National Science Teachers Association Conference in Science Education in 2003 (Philadelphia, PA) or the North Carolina Science Teachers Association Conference in Science Education in 2002 and 2003 (Greensboro, NC). Of the 116 teachers attending the workshops, 95 teachers participated in field-testing. Of these, 30 teachers matriculated too late to provide control data from their students. Thus, 65 teachers served as their own controls.

Teacher Knowledge, Pre- and Post-Workshop Training

To assess the effect of the workshops on teacher knowledge, teachers were administered pre- and posttests without prior warning. The tests consisted of 20 true/false questions of basic biology, chemistry, and pharmacology principles. The post-test given at the workshop indicated a significant gain in knowledge (65 % vs 81% correct, pre- and post-test respectively). To assess the impact of the workshop long-term, teachers were tested again 1 year later. Teachers maintained their knowledge gain for at least 1 year after they completed the workshop.



Data are the mean +/- SEM percent correct scores from a 20-item test of biology, chemistry, and pharmacology principles taken prior to the workshop (pre-test), immediately after the workshop (post-test), and 1 year after the workshop (1-yr post-test). Significant knowledge gains were achieved as assessed by both post-tests (*p<0.001, ANOVA and Neuman Keul's Multiple Comparisons Test (n = 45 paired comparisons)).

Teacher Feedback Concerning Module Implementation

We collected teacher feedback concerning module implementation and lack of implementation. Of the teachers who provided us with this information, they used modules in 85 classes. Teachers did not use modules in 50 classes. The methods or reasons for using or not using the modules in these classes are summarized below:

Method for implementation of the PEP modules	**Percentage of classes** *(n = 85)*
Incorporated module content into lesson plans throughout semester	47
Presented module material in a single class period	33
Presented module material over 2 or more class periods	13
Modules used as supplementary exercise(s) out of class (e.g., homework, student projects)	5
Other	2

Reasons for not using the PEP modules	**Percentage of classes** *(n = 50)*
No time due to course requirements	22
No time (no reason given)	30
Material too advanced	14
Other	34

Sample questions from the PEP testing instruments

*Correct answers are indicated in bold.

Basic knowledge assessment

A drug injected into a vein travels throughout the circulation in the following order to reach the brain:

A. Left side of the heart, lungs, right side of the heart, arteries, brain
B. Right side of the heart, lungs, left side of the heart, arteries, brain
C. Left side of the heart, lungs, right side of the heart, veins, brain
D. Right side of the heart, lungs, left side of the heart, veins, brain
E. don't know

Which one of the following types of compounds is most volatile?

A. molecular compounds
B. ionic salts
C. network solids
D. macromolecular compounds
E. don't know

Plant cells store compounds within the cytoplasm in watery sacs called:

A. lysosomes
B. ribosomes
C. vacuoles
D. mitochondria
E. don't know

Protein synthesis proceeds in the following order:

A. DNA is translated to mRNA, mRNA carries out transcription to a protein
B. DNA is transcribed to mRNA, mRNA carries out translation to a protein
C. RNA is transcribed to DNA, DNA carries out translation to a protein
D. RNA is translated to DNA, DNA carries out transcription to a protein
E. Don't know

Aspirin, HASA, ionizes in solution, indicated by

$$HASA \Leftrightarrow H^{+} + ASA^{-}$$

When adding the following to the aspirin solution, which will produce the greatest concentration of ASA^{-}?

A. water
B. a molecular liquid such as cyclohexane or benzene
C. sodium bicarbonate of the same pH as the intestines
D. hydrochloric acid of the same pH as the stomach
E. don't know

Advanced knowledge assessment

Methamphetamine (speed or ice) causes destruction of neurons by:

A. inhibiting cell metabolism
B. increasing dopamine oxidation
C. decreasing ATP levels
D. increasing dopamine hydrolysis
E. don't know

Nerve gas poisoning causes salivation, vomiting, urination, diarrhea, convulsions and death due to:

A. destruction of the central nervous system
B. inhibition of the parasympathetic nervous system
C. stimulation of the parasympathetic nervous system
D. inhibition of the sympathetic nervous system
E. don't know

Highly lipophilic compounds such as THC or anabolic steroids accumulate in the body after repeated use. Where do these drugs accumulate?

A. fat
B. skin
C. stomach
D. bone
E. don't know

Why do plants store compounds such as nicotine and cocaine in their leaves?

A. to increase photosensitive chemical reactions
B. to enhance exposure of the compound to air
C. to provide a natural insecticide
D. to stimulate leaf growth
E. don't know

Drugs like nicotine and morphine accumulate in hair because they are:

A. highly metabolized
B. poorly metabolized
C. strong bases and bind to keratin
D. weak bases and bind to melanin
E. don't know

Demographics of Students in Classes of Participating Teachers

Demographic	Percent of students (*n* = *7210*)
Male	47
White	69
Asian	6
Black	17
Native American	2
Hispanic/Latino	6
First year	15
Sophomore	35
Junior	38
Senior	12
Biology 1	40
Chemistry 1	40
Biology 2/AP	14
Chemistry 2/AP	6

AP = Advanced placement

Logistic Regression for the Basic Knowledge Assessment

Predictor	Mean	Standard Error	95% interval	Mean probability of a correct answer (95% interval)
Intercept	-1.001	.056	(-1.127, -0.901)	.27 (.24, .29)
Male	0.087	.015	(0.058, 0.117)	
Asian	0.005	.033	(-0.060, 0.070)	
Black	-0.122	.027	(-0.177, -0.070)	
Hispanic	-0.078	.033	(-0.141, -0.012)	
Native American	-0.176	.052	(-0.278, -0.073)	
Chemistry 1	-0.024	.037	(-0.093, 0.050)	
Chemistry 2	0.322	.051	(0.222, 0.421)	
Biology 2	0.564	.032	(0.505, 0.628)	
1 Module	0.073	.030	(0.016, 0.133)	.28 (.26, .31)
2 Modules	0.311	.036	(0.239, 0.383)	.33 (.32, .35)
3 Modules	0.212	.059	(0.094, 0.328)	.31 (.29, .34)
4 Modules	0.686	.078	(0.535, 0.844)	.42 (.39, .46)
5 Modules	0.448	.117	(0.225, 0.684)	.37 (.32, .42)
6 Modules	0.732	.064	(0.606, 0.858)	.43 (.40, .46)

Note: The reported probabilities of a correct answer are indicated for a white female student in Biology 1 (the baseline condition). Significance for the use of modules is indicated by the 95% intervals for the coefficients that do not contain zero. The probabilities in the row for the intercept represent zero modules. Interpretations of the coefficients as odds ratios are obtained by exponentiation of the point estimates and confidence interval limits. For example, a student whose teacher uses six modules has $e^{.732}$ = 2.07 higher odds of answering a question correctly than a student whose teacher uses zero modules. The 95% interval for the odds ratio is $e^{.606}$ = 1.83 to $e^{.858}$ = 2.36

Logistic Regression for the Advanced Knowledge Assessment

Predictor	Mean	Standard Error	95% interval	Mean probability of a correct answer (95% interval)
Intercept	-1.196	.036	(-1.267, -1.127)	.23
Male	0.054	.020	(0.014, 0.094)	
Asian	-0.085	.044	(-0.174, 0.001)	
Black	-0.194	.036	(-0.266, -0.123)	
Hispanic	-0.029	.045	(-0.117, 0.060)	
Native American	-0.141	.071	(-0.281, -0.001)	
Chemistry 1	0.003	.043	(-0.085, 0.085)	
Chemistry 2	0.157	.065	(0.034, 0.285)	
Biology 2	0.297	.040	(0.220, 0.374)	
1 Module	0.159	.039	(0.083, 0.236)	.26 (.24, .28)
2 Modules	0.322	.048	(0.231, 0.417)	.29 (.27, .32)
3 Modules	0.383	.076	(0.232, 0.538)	.31 (.27, .34)
4 Modules	0.709	.109	(0.491, 0.916)	.38 (.33, .43)
5 Modules	1.082	.159	(0.773, 1.392)	.47 (.39, .55)
6 Modules	0.707	.080	(0.557, 0.868)	.38 (.34, .42)

Note: The reported probabilities of a correct answer are indicated for a white female student in Biology 1 (the baseline condition). Significance for the use of modules is indicated by the 95% intervals for the coefficients that do not contain zero. The probabilities in the row for the intercept represent zero modules. Interpretations of the coefficients as odds ratios are obtained by exponentiation of the point estimates and confidence interval limits. For example, a student whose teacher uses six modules has $e^{.707} = 2.03$ higher odds of answering a question correctly than a student whose teacher uses zero modules. The 95% interval for the odds ratio is $e^{.557} = 1.75$ to $e^{.868} = 2.38$.

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