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Teaching High School Chemistry in the Context of Pharmacology Helps Both Teachers and Students Learn

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S *Supporting Information*

ABSTRACT: Few studies demonstrate the impact of teaching chemistry embedded in a context that has relevance to high school students. We build upon our prior work showing that pharmacology topics (i.e., drugs), which are inherently interesting to high school students, provide a useful context for teaching chemistry and biology. In those studies, teachers were provided professional development for the Pharmacology Education Partnership (PEP) in an onsite venue (either five-day or one-day workshop). Given financial difficulties to travel, teachers have asked for alternatives for professional development. Thus, we developed the same PEP training workshop using a distance learning (DL) (two-way live video) approach. In this way, 121 chemistry and biology teachers participated in the DL workshops to learn how to incorporate the PEP modules into their teaching. They field-tested the modules over the year in high school chemistry and biology classes. Teacher knowledge of chemistry and biology increased significantly after the workshop and was maintained for at least a year. Their students (N = 2309) demonstrated a significant increase in knowledge of chemistry and biology concepts, with higher scores as the number of modules used increased. The increase in both teacher and student knowledge in these subjects was similar to that found previously when teachers were provided with onsite professional development.

KEYWORDS: High School/Introductory Chemistry, Chemical Education Research, Interdisciplinary/Multidisciplinary, Distance Learning/Self Instruction, Inquiry-Based/Discovery Learning, Testing/Assessment, Acids/Bases, Drugs/Pharmaceuticals, Enzymes, Oxidation/Reduction

It has been known for many years that promoting interest is an important factor in helping motivate students to learn and increase achievement.[1] One way to promote interest is to use topics that are relevant to students' lives, especially for teenagers. Not surprisingly, when high school students are asked what topics would be interesting to them during science class, they indicate topics such as disease, drugs, and the environment.[2] Additionally, when students with relatively low expectations for success in science are asked to connect the relevance of their science topics in class to their lives, they display more interest and perform better in science.[3] While there is a paucity of studies that assess how specific topics affect student achievement in chemistry, there are a few that have provided some evidence of impact. For instance, the Chemcom Chemistry in the Community curriculum developed by the American Chemical Society[4] includes chemistry-based units that are focused in areas such as the environment, industry, food, and health. When implemented in the high school chemistry class, the Chemcom Chemistry in the Community curriculum has resulted in a significant increase in student achievement.[5]

To address the issue of relevance, we have conducted several studies demonstrating increased knowledge in chemistry and biology when students are taught these subjects in the context of pharmacology (i.e., drugs).[6−8] Pharmacology is a science that integrates basic principles of chemistry and biology to uncover the mechanisms by which drugs and chemicals affect organisms. Such integration addresses an important component of the National Science Education Standards.[9] A brief description of these studies is presented below, as they provide the rationale for the study presented here.

THE PHARMACOLOGY EDUCATION PARTNERSHIP FOR HIGH SCHOOL CHEMISTRY AND BIOLOGY

Several years ago, we developed the Pharmacology Education Partnership (PEP-I), a program to help high school teachers teach chemistry and biology in the context of pharmacology.[6] PEP-I was a randomly assigned, wait-listed control intervention[6] of 50 chemistry and biology teachers across the United States. The teachers attended an intensive five-day workshop at Duke University to learn principles of pharmacology and how pharmacology could be used to teach basic concepts in chemistry and biology. The workshop included content provided by university faculty (in five, 1-h lectures), small group discussions with university faculty, and participation in inquiry-based activities. In the months following the workshop, teachers worked in teams to develop activities to accompany the PEP-I modules that they could use in their own classrooms. The following year, teachers field-tested four PEP-I modules in their classrooms (4038 students). We found that teacher subject-matter specific content knowledge improved significantly after the workshop and it was maintained for at least a year.[6] Second, students in classrooms

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using the PEP-I modules had significantly greater understanding of basic chemistry and biology concepts compared to students in classrooms receiving the standard education.[6]

While the results obtained in the PEP-I study were very encouraging, we concluded that the five-day professional development workshop format has limited utility; it is quite expensive and therefore it is unlikely to reach a wide population. Thus, we determined whether implementation of the PEP program could improve student achievement when teachers received a less intensive professional development workshop format delivered onsite at the National Science Teachers Association (NSTA) Science Education Conference (PEP-II).[7] The 6-h workshop included the same content as that delivered in the PEP-I study; teachers continued to work together over the next 2 months to develop activities to supplement the PEP-II modules, which included two additional modules compared to PEP-I. Similar to the PEP-I study, there were significant gains in student (N = 7120) achievement compared to classes that did not use the PEP-ll modules and teacher knowledge gains were maintained for at least a year.[7]

A recurring comment by teachers who attended the PEP-I and PEP-II workshops was that the time commitment and cost of travel was a deterrent to many of their colleagues who wished to obtain professional development in chemistry and biology. Research has shown that quality distance education courses can provide an effective alternative to onsite training.[10] Moreover, a live two-way video distance learning (DL) approach can enhance teacher science learning better than teleconferencing or Web-based training.[11] Therefore, we were interested in determining whether a similar workshop with the same content could be delivered using a live DL approach and provide the same benefits that we observed in PEP-I and PEP-II. Thus, we designed another study, presented here, in which we provided the same 6 h of professional development to teachers across the United States using DL technology. We partnered with the North Carolina School of Science and Mathematics (NCSSM) to deliver the DL broadcasts; NCSSM is a pioneer in North Carolina for bringing distance education to all corners of the state. We assessed both teacher content knowledge gains and student achievement over the next year, and compared the findings to those obtained in PEP-I and PEP-II.

METHODOLOGY

The Participants

High school chemistry and biology teachers were recruited nationally; participation required that the teacher had access to a DL broadcast site, typically within their school, school district educational center, public library, or community college. The workshop was broadcast to 22 sites in 14 states across the United States. Most of the 121 teachers who participated came from public high schools, with 50% teaching chemistry. A complete listing of broadcast locations and teacher demographics can be found in Tables 1 and 2 of the online Supporting Information. The teachers' students (N = 2309) who participated in the study were enrolled in chemistry or biology classes in grades 9−12 (see Table 1 for the complete demographics). We note that a wait-listed randomized controlled design was not possible in this study owing to the complexities of reserving DL broadcast sites. However, 9 of the 121 teachers did agree to participate in testing a year before the workshop, serving as their own controls as a comparison.

Table 1. Demographics of Students in Classes of Participating Teachers

Demographic Variable	Distribution of Students, % (N = 2309)
Male	42
Female	58
First year	15
Sophomore	43
Junior	31
Senior	11
Caucasian	66
Asian	13
Black	9
Native American	2
Hispanic	10
Chemistry 1	45
Biology 1	42
Chemistry 2/AP[a]	6
Biology 2/AP[a]	7

[a] AP is advanced placement.

The Distance Learning Workshop

The DL workshop consisted of three, 2-h sessions (once a week for three weeks) conducted at the beginning of the school year. The 6 h of content covered in the DL workshop were identical to the 6 h of content delivered in the onsite teacher workshop in our previous study.[7] The sessions were conducted using two-way live video and audio to locations (e.g., schools, libraries) throughout the U.S. to allow video-interaction with the instructors (as well as with teachers at other sites). The technical specifications concerning the broadcasts are found in the online Supporting Information. A video of each broadcast was made available to teachers via a URL address so they could review the workshop presentations online at any time during the year. The DL workshops were led by the authors, a professor of pharmacology and science educator, and a chemistry instructor at NCSSM, who had 10 years of experience in distance education broadcasting.

A major goal of the DL workshop was to provide teachers with a context (i.e., pharmacology) to teach subject-specific concepts in chemistry and biology, such as acid−base chemistry, molecule polarity, oxidation−reduction reactions, enzymes, cell structure−function, molecular transport across biomembranes, DNA structure, function, and the circulatory system. The pharmacologic context for these chemistry and biology concepts was provided within the group of six modules developed previously for the PEP-I and PEP-II studies (see below). (The workshop syllabus can be found in Table 3 of the online Supporting Information.) During the workshop, teachers discussed

1. How the topics aligned with specific National Science Education Standards for Science Content[9] (see Table 4 in the online Supporting Information)
2. How they would incorporate the PEP modules into their teaching, especially given tight schedules
3. Preliminary ideas for activities that they would develop (over the next 2 months) to accompany the PEP modules (summarized in Table 2)Activities addressed the specific content covered in a module; they were later reviewed and edited by the PEP instructors before disseminating to all participating teachers. Activities can be accessed online at the PEP Web site.[12]

Table 2. PEP Module Chemistry and Biology Content

Module Title	Chemistry Content	Biology Content	Other Content
Acids, Bases, and Cocaine Addicts	Acid−base chemistry, equilibrium, molecular structure, polarity, ions	Membrane transport, circulatory system, cell types	Addiction biology
Drug Testing: A Hair-Brained Idea	Acid−base chemistry, molecular structure, polymers, oxidation, reactions, enzymes	Membrane transport, circulatory system cellular structure, anatomy	Nicotine, cocaine, heroin, racial ethics
How Drugs Kill Neurons: It is Radical!	Oxidation−reduction, oxygen radicals, reactions, enzymes	Proteins, lipids, DNA, neuron structure, cell membranes, cell death, brain anatomy	Methamphetamine, neurodegenerative diseases
Military Pharmacology: It Takes Nerves	Behavior of gases, covalent bonding, enzymes, solubility, hydrolysis, reactions	Autonomic nervous system, physiology	Chemical warfare, Middle East and Japan current events/history
Why Plants Make Drugs for Humans	Intermolecular bonding, acid−base chemistry, alkaloids, hydrocarbons, polarity, molecular structure, equilibrium, enzymes	Plant cell structure, membrane transport, neuron receptors, vacuoles	Nicotine, THC, cocaine, tobacco industry chemical "tricks", economics
Steroids and Athletes: Genes Work Overtime	Chemistry of testosterone, steroids, acids/bases, polarity, DNA structure, ions, molecular structure	Muscle cell anatomy and physiology, DNA, transcription, protein synthesis, steroid action, hypothalamus	Drug testing, addiction biology

The PEP Module Field Test

After the workshop, teachers were instructed to field-test the six PEP modules in their classrooms over the year. The six PEP modules were the same as those used in our previous study.[7] Each of the PEP modules is inquiry-based, opening with a story, and followed by a series of questions for students to answer. The modules focus on a pharmacologic topic that integrates chemical and biological concepts provided during the workshop (described above). A summary of the six module topics and the chemistry and biology content is provided in Table 2. The PEP modules can be accessed online free of charge for interactive use or downloaded as PDFs directly from our Web site.[13]

The modules were designed so that teachers could incorporate the content into their standard curriculum in a way that fit their own teaching style and time constraints. Because many teachers tend to modify the use of instructional materials according to personal teaching style,[14] we did not prescribe rigid instructions for module implementation but requested that teachers use as many modules as possible. We also asked the teachers to report to us how they used the modules.

Assessments

We addressed two questions: (i) Does a 6-h professional development experience provided in a DL format increase teacher knowledge of subject-matter specific science content (i.e., chemistry, biology, and pharmacology concepts) long-term? (ii) Does the use of pharmacology as a context to teach subject-matter specific science content lead to increased student achievement in chemistry and biology? To answer these questions, we carried out assessments of both the teachers and their students.

Teacher Assessment. We conducted a summative evaluation to determine the attitudes of teachers about the quality of the workshop. There were three strands within the survey—content, teaching approaches, and format of the workshop. The nine items were assessed using a five-point Likert Scale (see Table 3), followed by several open-ended questions pertaining to what they liked most and least about the workshop.

To determine the effectiveness of the workshop on teacher knowledge gain and retention long-term, we administered a short test consisting of 20 true−false questions that addressed the chemistry and biology subjects listed above. The questions were devised by both authors and reviewed by high school chemistry and biology teachers at NCSSM. The test was administered to the teachers at the beginning of the workshop ("pretest"), at the end of the workshop ("posttest"), and at the end of the year, we mailed the posttest to teachers, without prior notification.[a] Data were analyzed by a repeated-measures ANOVA and Tukey's multiple comparison test. Sample items are included in the online Supporting Information. The assessments were the same as those used previously in the one-day workshop.[7]

Student Assessment. At the end of the school year after field-testing the PEP modules, we sent the teachers a multiple-choice "PEP" test previously established for reliability and validity[6,7] to give to their students (the tests were unannounced). The nine teachers serving as their own controls also administered the test to their students a year before the DL workshop. The tests were constructed by the authors, with input from high school chemistry and biology teachers at the NCSSM. The test comprised two parts, a basic knowledge and an advanced knowledge section. The basic test consisted of 20 questions (11 chemistry and 9 biology), similar to those found in first-year chemistry and biology textbooks (see the online Supporting Information for examples). The multiple-choice questions assessed student knowledge of concepts in chemistry and biology as well as reasoning skills, according to the framework provided by the 1996 National Assessment of Educational Progress science test.[15] Validation of the content relevance and appropriate difficulty of the questions was made by a separate group of high school chemistry and biology teachers at the NCSSM. Following the 20 "basic knowledge" questions, 10 questions specifically addressed the new knowledge about drugs in the context of chemistry and biology ("advanced knowledge"). These questions assessed concepts not normally taught in the standard curriculum (see the online Supporting Information for examples).

We posited that several factors might affect the students' scores on the PEP tests. Therefore, we obtained demographic information from the students regarding:

1. Students' gender
2. Students' race or ethnicity
3. Students' year in high school ("student year"—i.e., 9th−12th grade)
4. The course type (i.e., chemistry or biology)
5. The course level (i.e., first-year or second-year chemistry or biology; AP)The demographic representation of students within classes of teachers who administered the PEP tests is presented in Table 2.

Data Analysis: Statistics Analytical Model

The percentage correct scores on the tests were obtained from 2309 students in the teachers' classes. We adjusted for the differences in demographic characteristics (see Table 1) using

Table 3. Teacher Evaluation of PEP Distance-Learning Workshops

Evaluation Item (Strongly Agree = 5; Strongly Disagree = 1)	Mean Score (N = 116)	Respondents Answering 4 or 5, %
I learned something new in biology.	4.4	88.9
I learned something new in chemistry.	4.2	79.5
I learned something new in pharmacology.	4.8	97.4
I learned something new about integrating biology and chemistry through pharmacology.	4.6	92.3
This workshop stimulated my thinking about new ways of teaching my subject.	4.4	87.2
This workshop stimulated my thinking about new ways to integrate biology and chemistry.	4.3	88.0
I found the DL approach effective.	3.9	64.1
I had no trouble following the lectures delivered via television.	4.0	72.6
I prefer the DL approach to traveling overnight to a workshop.	4.0	71.8

random effects logistic regression models, which are a type of multilevel model.[16,17] The outcome variables are the number of correct answers out of 20 questions (as a percentage) on the "basic" test and the number of correct answers out of 10 questions (as a percentage) on the "advanced" test. For simplicity, we analyzed each outcome independently. The random effects account for the correlations among outcomes of students in the same class. Details about the equations and models can be found in the online Supporting Information.

RESULTS

Teacher Evaluation of the Distance Learning Workshop

At the conclusion of the workshop, teachers provided an evaluation of the workshop approach and content delivery. A summary of their evaluation scores is provided in Table 3. The teachers felt that they learned new material in their own disciplines as well as in pharmacology (content). Second, they reported that the workshop helped them learn how to integrate chemistry and biology in their teaching, and learn new ways of teaching their subjects (teaching approaches). Third, they felt that the DL workshop format was effective in helping them learn the content and teaching approaches (format).

Teachers also provided comments about aspects of the workshop that they really enjoyed, which included the convenience to home, interactivity with DL, and access to the recorded sessions via computer. A few DL sites had technical problems (beyond our control), and not surprisingly, teachers from those sites indicated some frustration such as a choppy connection, time delays for voice transmission, and loss of interactivity with the instructors and other sites (some did resort to using the streaming video alternative).

Teacher Content Knowledge

To assess the effect of providing the pharmacology-based professional development workshop on teacher knowledge of basic chemistry and biology principles, teachers were administered a 20-item pretest and 2 posttests. The posttest given at the conclusion of the workshop indicated a significant gain in knowledge ($P < 0.01$) (Figure 1). On average, teachers maintained their knowledge gain when tested again at the end of the school year ($P < 0.01$). However, the teachers who actually used the PEP modules in their classes gained 8.5 ± 4.3 percentage points at the end of the school year compared to the first posttest. In contrast, teachers who did not use any modules lost 9.3 ± 5.0 percentage points compared to the first posttest.

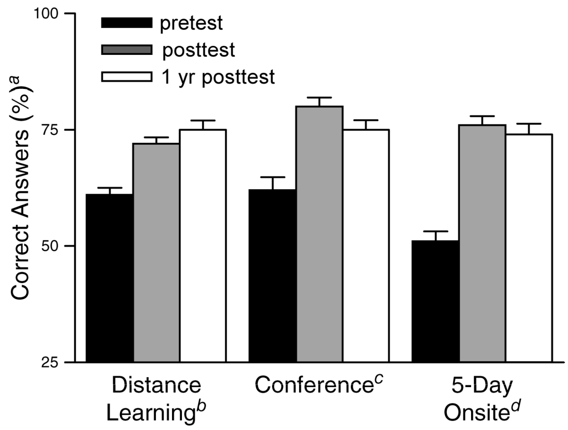

Figure 1. Teacher gain in chemistry and biology knowledge is maintained for at least one year, regardless of workshop format. [a]Mean ± SEM; [b]$P < 0.01$, ANOVA, and Tukey's multiple comparisons test ($N = 40$); [c]see ref 7; [d]see ref 6.

Finally, the long-term knowledge gains by teachers who participated in the DL workshop were similar to those by teachers who attended the 6-h onsite conference workshop[7] (PEP-II): see Figure 1. (Although a larger gain was found in the teachers attending the five-day onsite workshop, PEP-I,[6] this was due to lower pretest scores. Because a few of the chemistry assessment questions in PEP-I were considered too advanced for biology teachers, the assessment instrument was modified for PEP-II,[7] bringing up the pretest scores appropriately.)

Student Achievement in Chemistry and Biology

Teachers participating in the workshop were instructed to use as many PEP modules as possible (i.e., six) in their classes throughout the year. During the workshop, teachers discussed ways in which they could incorporate the PEP modules into their already crowded teaching schedule. Not surprisingly, only 48% of the teachers attending the workshops continued with the study over the following year. Of these, 59% (N = 34) used the PEP modules in their classes during the year of field-testing. They used the modules in a variety of ways: 37% used the PEP modules by incorporating the content throughout their entire course; 28% covered the PEP content in a single class period; and 11% used several class periods to cover the PEP content. Classes in which no PEP modules were used (i.e., not the control classrooms) (41%) served as a baseline for comparison to student performance in classes using the PEP modules.

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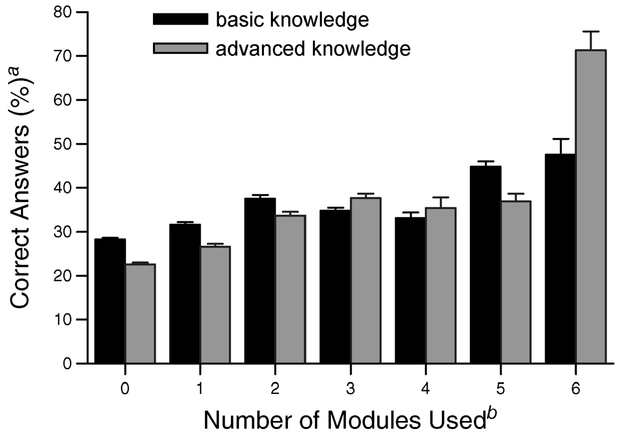

Figure 2. Student knowledge of chemistry and biology concepts improves as teachers use more PEP modules. [a]Mean ± SEM; [b]use of modules is a significant predictor of increased scores (logistic regression; N = 2903 students; see the online Supporting Information, Tables 5 and 6).

Teachers administered the tests, unannounced, at the end of their courses. The results of the regression analyses revealed that the use of the PEP modules was a significant predictor of increased student achievement on both the basic and advanced tests, controlling for other demographic factors such as gender, race or ethnicity, and type of course (see Tables 5 and 6 in the online Supporting Information for the complete regression results). The average student scores on both the basic knowledge and advanced knowledge tests are shown in Figure 2. The group using zero modules scored on average the same (28.2 ± 14.7% and 22.6 ± 15.3% correct for basic and advanced knowledge, respectively) as a separate group of students (N = 813) tested in classes from the 9 control teachers who had not yet attended the workshop (and used no modules) (25.2 ± 13.9% and 21.3 ± 15.3% correct for basic and advanced knowledge, respectively).

The use of all six modules produced robust results: students scored on average 19 and 49 percentage points higher on the basic and advanced tests in chemistry and biology, respectively, than students not using any modules. Even the use of only one module was a significant predictor of increased scores on the basic knowledge test, while the use of at least two modules was a significant predictor of increased scores on the advanced test (see the online Supporting Information, Tables 5 and 6). These findings are very similar to those reported in our previous studies in which teachers attended either the five-day onsite workshop[6] or the 6-h onsite conference workshop.[7]

The logistic regression analysis also revealed some other significant differences, controlling for all demographic factors identified (see Tables 5 and 6 in the online Supporting Information). On the basic knowledge assessment, students in Chemistry 2 and Biology 2 outperformed students in Chemistry 1 and Biology 1. Black students scored slightly lower than White students and male students scored slightly higher than female students, although the effect was very small. The assessment of advanced knowledge revealed a slightly different picture. Students in Chemistry 1 and Biology 2 scored the highest, and of the minority students, the Hispanic and Native American students scored slightly lower than White students. Gender was not a significant predictor of improved scores.

■ DISCUSSION

In this study, we demonstrate that professional development in pharmacology improves teacher knowledge content in chemistry and biology long-term. In addition, when teachers use the pharmacology modules to teach chemistry and biology concepts, their students' performance in these subjects improves. The extent of these two learning outcomes when teachers are trained using a DL approach is similar to that observed when teachers are trained in an onsite workshop either in a limited (i.e., 6-h) or extended (i.e., five-day) format.[6,7]

Sustained Teacher Learning

The DL workshop incorporated several of the key elements that have been discussed as essential to effective professional development, including a focus on specific subject-matter knowledge and content, pedagogy, and development of inquiry-based activities.[18,19] While teachers' self-reports revealed "high marks" for the quality of the workshop format, a subset of teachers indicated that improving technology connections could enhance teacher satisfaction. In the sites with connection problems, the interactivity was lost, as well as the face-to-face nature of the interaction. The importance of interactivity as a salient contributor to teacher satisfaction with DL training is not surprising, as it has been shown to be a key factor in successful DL training.[11,20]

The teachers' self-reports that they learned something new in chemistry and biology during the workshop were supported by the more quantitative assessment of content knowledge gains after the third week of the DL sessions. Moreover, the content knowledge gains were maintained by the end of the school year and were similar to the gains by teachers attending professional development workshops onsite in an extended (i.e., five-day) or limited (i.e., 6-h) format.[6,7] It is possible that the long-term knowledge retention was due to teachers' use of the PEP modules in their classes because those who actually used the modules had additional knowledge gains, and those who did not use the modules lost some of the initial knowledge gains. The connection between content knowledge and implementation of inquiry-based teaching in the chemistry classroom has been discussed by Roehrig and Luft.[21] They conclude that teacher content knowledge in chemistry and presence of appropriate curricular materials may be critical ingredients for teachers (especially new teachers) to successfully implement inquiry-based lessons designed to build student content knowledge. Finally, regardless of how teachers acquire their content knowledge, it appears that teachers must incorporate the lessons gained from professional development into their teaching in order to sustain their knowledge gain.

However, the teacher knowledge gain after the professional development in pharmacology was not sufficient to improve student scores. If teachers who attended the workshop did not use any of the PEP modules, their students scored no better than students of teachers who had not yet attended the workshop. Thus, implementation of the PEP modules was necessary for improvement in student achievement (discussed below). We do not know whether implementation of the PEP modules is sufficient for student improvement because we did not have a "no professional development" control group using modules. From a practical standpoint, this would be useful information, as most teachers who decide to use the PEP modules available online will not have any prior training in pharmacology. Nevertheless, we continue to provide professional development at science teachers' annual professional meetings (e.g., National Science Teachers Association or International ChemEd) for teachers interested in using the PEP modules.

Student Achievement

The implementation of the PEP modules in chemistry and biology classes was associated with increased student performance in these subjects. Teachers implemented the modules in a variety of ways that fit their own teaching styles and time constraints, although we do not know whether any one style is more effective than another. It is possible that the beneficial effects associated with using increased number of modules by teachers reflect the influence of confounding variables. For example, perhaps teachers with high achieving students use more modules than those with low achieving students, so that the effects are mainly attributable to differences in student quality. However, the "dose−response" relationship between number of modules and students' performance is similar to the relationship that we found in previous studies.[6,7] Those studies minimized the potential of confounding by including controls, for example, students assessed before their teachers were permitted to use the modules (as was the case with nine teachers in this study). Thus, we believe that the results presented here similarly reflect the effect of module usage by teachers who attended onsite professional development workshops.

There are several factors (e.g., relevant context, inquiry- or case-based lessons, interdisciplinary content) that may have contributed to the success of this program, although we did not systematically test which of these individual factors may have been most important. Relevance and context-based science education have been discussed as positive influences on student engagement and their interest in science.[22] The PEP modules include topics such as drugs of abuse and chemical warfare that have personal, societal, and global relevance—especially for high school students. In fact, we monitored the online use of specific modules at our Web site during the study.[13] Teacher and student traffic rose considerably on certain modules during the months when the topic was in the news. For example, use of Module 1, Acids, Bases, and Cocaine Addicts, increased concomitant with news reports of celebrities arrested for cocaine possession, and use of Module 4, Military Pharmacology: It Takes Nerves (all about nerve gas), increased when news reports of chemical warfare were broadcast. It is possible that some teachers may have decided to use these modules because of their own or their students' interest in the subject generated by the news stories. Having access to curricular resources that address interests, either expected or expressed by students, may be an effective means of motivating student learning in science.[23] Finally, the PEP topics provide an interdisciplinary approach for teaching chemistry (as well as biology). Disciplines outside conventional science are addressed as well, including politics, ethics, business, and psychology. The use of contexts with an interdisciplinary character can provide a more "holistic and balanced approach to the underlying science", helping students to demonstrate science competence in context-based assessments (e.g., PISA 2006).[22,24]

CONCLUSION

In this third of three studies, we reproduce the results from our previous work,[6,7] totaling more than 17,000 students who have participated in the PEP project nationwide. We find that student achievement in chemistry and biology can improve when teachers use an engaging and relevant context, such as drugs, to teach these subjects. Moreover, providing professional development to help teachers embrace this program does not have to involve an intensive onsite format; a DL approach, which is now becoming feasible in most school districts, is just as effective in terms of teacher learning. Future studies will be performed to determine whether use of PEP modules by teachers obtaining online professional development in pharmacology can enhance student performance in chemistry and biology similarly to that demonstrated in the three studies to date.

ASSOCIATED CONTENT

Supporting Information

Tables; analytical and statistical methods; technical broadcast specifications; sample teacher and assessment items. This material is available via the Internet at http://pubs.acs.org.

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ADDITIONAL NOTE

[a] Although teachers were told that posttests would be sent to them, they were not told when. Instructions to the teachers requested that they answer on their "honor" without consulting any materials. They were told that the validity of the study was dependent on their cooperation to honor our request.

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