Educational research

Use of a multimedia DVD for Physical Chemistry: analysis of its effectiveness for teaching content and applications to current research and its impact on student views of physical chemistry

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Abstract: In this study, a new multimedia learning tool for physical chemistry was implemented in a class setting, and students' attitudes and learning gains examined. The *Physical Chemistry in Practice* (PCIP) DVD contains multimedia modules that provide an in-depth description of the research of eight different scientists. Each module contains a documentary style video program of the researcher and their laboratory, HTML-based background information about the topic, problems for students to work on, and links to related information. The DVD was implemented in a physical chemistry laboratory course where students worked through a module on surface-enhanced Raman spectroscopy (SERS). Data was collected in the form of pre- and post-tests of content knowledge and surveys about attitudes and academic career choices. Students showed statistically significant learning gains after using the DVD and showed an increase in their recognition of the applications of physical chemistry to real problems. Students also showed an increased interest in further study of physical chemistry. [*Chem. Educ. Res. Pract.*, 2007, **8** (3), 308-326.]

Keywords: physical chemistry, multimedia, surface-enhanced Raman spectroscopy (SERS), DVD, attitudes, learning gains

Introduction

Great strides have been made in the field of physical chemistry that are not included in traditional college courses, such as: nanotechnology, novel materials, advances in laser techniques, and photolithography. Exposure to these topics may give students a more complete view of the field and the value of research in it. Without students being introduced to applications or current work, physical chemistry may continue to seem overly abstract to them. Many educators called for inclusion of new physical chemistry research and applications in undergraduate curricula (Moore and Schwenz, 1992; Schwenz and Moore, 1993; Zielinski and Schwenz, 2004). Others have adapted teaching and learning advances used in other courses for physical chemistry (Moog et al., 2004a; Moog et al., 2004b).

In a different area of educational research, instructional technologies have begun to see increased use and support. Using Mayer's Theory of Multimedia Learning (Mayer, 2001, 2002) and other related work (Atkins, 1993) as a basis, multimedia instruments can be developed that will allow students to learn in a learner-controlled environment. However, in order for the technology to contribute to a rich and effective learning experience, research must be done to determine how students learn from technological tools, and how the technology can be designed to benefit the student best. In this article, we examine student use of a multimedia learning tool designed for the physical chemistry course, and look at aspects of that tool that assist with student learning and student views of physical chemistry.

Physical chemistry curriculum reform

Physical chemistry has traditionally been taught as a very mathematics-intensive, conceptually abstract course. Many innovations in the field of physical chemistry have been omitted from the curriculum, and other traditional topics – electrochemistry, pressure-volume work, phase diagrams – remain. Researchers and physical chemistry educators have advocated modernizing the physical chemistry curriculum and making the undergraduate courses more relevant to the work that current physical chemists practice (Zielinski and Schwenz, 2004). It is clear that not all important topics in the area can be given in-depth coverage in a one-year course, which is the time allotted at many institutions in the US. Refocusing educational goals will ensure that the students will learn the basic information necessary for them to succeed in industry or graduate school, as well as be exposed to current topics of physical chemistry research. Topics that Zielinski and Schwenz felt were important for inclusion in the new physical chemistry curriculum included polymer chemistry, materials science, nanomaterials, Bose-Einstein condensates, computer visualization, molecular modeling and computational programs, Raman spectroscopy, atomic force microscopy, photolithography, and atmospheric chemistry.

In 1992, the decline in the number of physical chemistry students was partially attributed to the fact that the immense progress of physical chemistry was not being communicated to students (Moore and Schwenz, 1992). Moore and Schwenz wrote that if the teachers of physical chemistry informed undergraduate students about the cutting-edge topics and opportunities in research, more students might pursue physical chemistry in graduate school. The authors believed that the traditional method of focusing on the mathematics and not utilizing microscopic explanations of chemistry makes the physical chemistry course appear, from the students' point of view, to not be chemistry.

Research has also been done on what factors influence student success in physical chemistry, as well as what factors make physical chemistry a difficult course. A qualitative study was conducted at two universities in Turkey to find what undergraduate students and lecturers felt made physical chemistry a difficult course, and what solutions they would propose to lessen these difficulties (Sozbilir, 2004). Students and lecturers both agreed that difficulties in physical chemistry arose from the abstract nature of the concepts covered, an overload of the amount of course content, teacher-centered teaching, and lack of student motivation. Students overwhelmingly said that they wished physical chemistry instruction would make more links between course content and everyday life, because they believed this would make the topics easier to learn.

Based on documented difficulties that students face in the physical chemistry course (Nicoll and Francisco, 2001; Derrick and Derrick, 2002; Sozbilir, 2004), several different types of innovations for the physical chemistry curriculum have been proposed. Pentecost and James (2000) moved towards a more student-centered classroom, using small-group discussions and problem packets. Group and individual interviews showed that students felt the system forced them to study in a new and more useful manner. Two books have been written (Moog et al., 2004a; Moog et al., 2004b) for teaching physical chemistry classes based on the Process Oriented Guided Inquiry Learning (POGIL) model (Hanson and Wolfskill, 1998; Farrell et al., 1999). A group of colleges and universities implemented Physical Chemistry Online (PCOL). In PCOL activities, students grappled with authentic context-rich problems while working in cooperative groups within their institution. They collaborated with students at other institutions via a list server available on the Internet, which allowed small (ten students or fewer) physical chemistry classes to discuss problem solving strategies within a larger group (Long et al., 1996; Stout et al., 1997; Towns et al., 1998; Sauder et al., 2000; Towns et.al., 2001; Slocum et al., 2004). The richness of the on-line discussion allowed the group to generate faculty facilitation guidelines (Slocum et al., 2004). Other than this use of the internet, however, relatively little work has resulted in the development or use of instructional technologies specifically for the physical chemistry course.

Multimedia development and implementation

An early overview of multimedia educational tools revealed a disparity between current theories of learning and the format in which most multimedia tools are created (Atkins, 1993). Atkins stated that the design of multimedia educational tools followed a behaviorist approach, whereas cognitive theory had already made a shift to a constructivist view of learning. Atkins referenced cognitive theory, by which he was referring to a broad swath of theories in learning and psychology, mainly information processing and social constructivism. He argued that the design of multimedia tools should draw from the current findings of this cognitive theory.

Richard Mayer elaborated on the cognitive approach to multimedia design (Mayer, 2002, 2005; Robinson, 2004). In order for multimedia instructional tools to be most effective in promoting understanding, Mayer stated that the developers must take into consideration three assumptions about the way people learn and process information in a multimedia setting: the dual channel assumption, the limited capacity assumption, and the active processing assumption. Mayer called this the "Cognitive Theory of Multimedia Processing". Using these assumptions to describe how the human mind receives and constructs information, Mayer proposed eight principles of multimedia learning that can be used to ensure that multimedia instructional tools are designed to promote meaningful learning (Mayer and Anderson, 1991, 1992; Mayer and Sims, 1994;; Mayer and Moreno, 1998; Mayer et. al., 1999; Moreno and Mayer, 1999, 2000; Mayer et al., 2001; Mayer and Chandler, 2001; Mayer, 2001, 2002, 2005). These were used as guiding principles to design the multimedia instructional tool for the physical chemistry course that we present in this paper.

Purpose of this study

The *Physical Chemistry in Practice* Digital Video Disk (PCIP DVD) was developed specifically to utilize new technology to inform students about physical chemistry and its applications in modern research. This study investigated the effects of the DVD on student learning of the physical chemistry content covered in the DVD and on student perceptions about the subject. In order to determine if the PCIP DVD is an effective educational tool, three research questions were posed:

1. How do students perceive the usefulness of the PCIP DVD as an assignment in a physical chemistry laboratory course?
2. How does student understanding of a physical chemistry topic differ before and after using the PCIP DVD?
3. How does the DVD affect student views on the applicability and connections of physical chemistry to life?

In this article we report on one approach to including topics from current research and incorporating the use of multimedia in the physical chemistry course. As was described above, these are issues that have been discussed among educators for some time. However, what has not been resolved is how the methods and tools for doing that will work. Therefore, this work represents one aspect of a project in which we are beginning to assess the impact of a tool to accomplish just this. The results are useful to inform us not only about this tool, but about the design and use of future tools of a similar nature.

The Physical Chemistry in Practice DVD

The Physical Chemistry in Practice (PCIP) DVD was created as a supplement for physical chemistry courses with the goals of introducing the topics of interest that curriculum reformers suggested (Moore and Schwenz, 1992; Zielinski and Schwenz, 2004), as well as helping students understand real-world applications of physical chemistry theory. The DVD comprises eight modules, each of which is based on actual research being carried out by scientists nationwide in academia or industry, and relates to some fundamental topic in physical chemistry. Each module explores the research project being carried out with respect to both the fundamental theories involved and broader applications of the work. Topics include surface enhanced Raman spectroscopy, atomic force microscopy, thin-film kinetics of photolithography, Bose-Einstein condensates, electronic structure of corrinoids and Vitamin B_{12}, single molecule thermodynamics of DNA, hydrogen fuel cells, and magnetic resonance imaging. At the time of writing this, several modules are still in development.

The PCIP DVD is different from traditional educational videos, which are designed for passive watching (see, for example, videotapes and videodiscs at JCE Online). The PCIP DVD uses a relatively new interface that allows it to be interactive and show additional information along with the video. A hybrid interface was used that allows for simultaneous and synchronized display of full-featured DVD video along with web content. The program can be used to automatically cue particular content at specific times during the video, which is useful for providing definitions or links that correspond to topics in the video. An internet connection is not necessary, as the interface uses all the files (both HTML and DVD video format) from the disc itself. (Additional information about the DVD is provided in the Appendix.)

This interface allows the DVD to contain video of the scientists explaining and showing their research, as well as textual explanations of background theory, equations and a glossary of terms. Multiple formats of graphical information can be included either embedded as part of the videos, or in the HTML-based files, including high-quality three dimensional animations of molecular-level visualizations or simulations of the internal working of instruments. Each module also contains problems for students to work on that are related to the content of the video. In some cases, they are asked to analyze authentic data from the research. A text transcription (script) of each video is also provided. The sections of the DVD are summarized in Table 1.

Table 1. Sections of the PCIP DVD.

Section of PCIP DVD	Information Contained in this Section	Format
Video	Multi-chapter video including scientists explaining their research, three dimensional animations, graphs, and footage of research being conducted	DVD video
Theory	Text book-like explanations of equations and theory necessary to understand the research	HTML
Glossary	Listing of terms and definitions, hyperlinked from theory pages	HTML
Animations	Animations from the video available to be viewed separately	DVD video
Problems	Homework or project-like questions, based on actual research shown in the video, including authentic data to be analyzed by the student	HTML
Script	Transcription of narration in the video segments	HTML
Timed links	Interactive links cued to specific parts of the video, allowing connection to glossary, theory, or external web pages for additional information	HTML
References and credits	List of literature references and production credits for the video	HTML

The interface design of the DVD allows students the freedom to navigate the material in myriad ways. Figures 1 through 3 show screen shots of the menu and content pages (these are discussed in greater detail in the Appendix). The video content is divided into chapters, along with the corresponding theory and glossary information. Students could choose to view the video chapters in order, then view the additional theory information later, or the video and information for each chapter can be viewed together. The format of the DVD allows students to control the way they access the material, including when and how often they view particular parts of the content, giving them the capability of interacting with and participating in their learning environment.

Figure 1. Main menu of the DVD interface, showing a link to each module. In this image, the user has rolled over the menu button for the SERS module, which becomes enlarged and outlined.

Figure 2. The module menu, showing the main components of the module (on the left) and a list of individual chapters within this module (on the right).

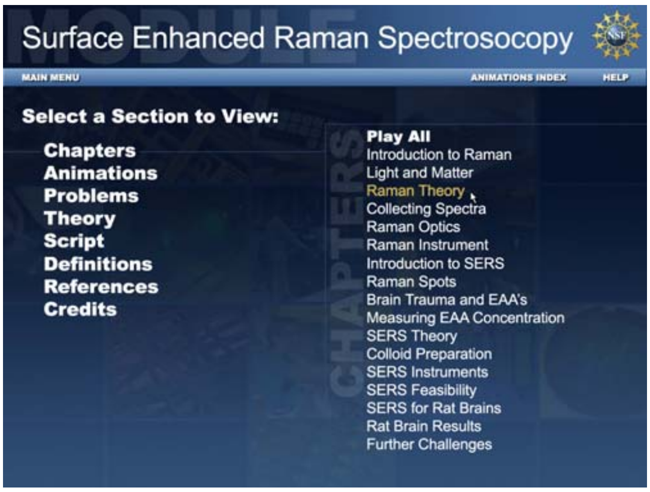
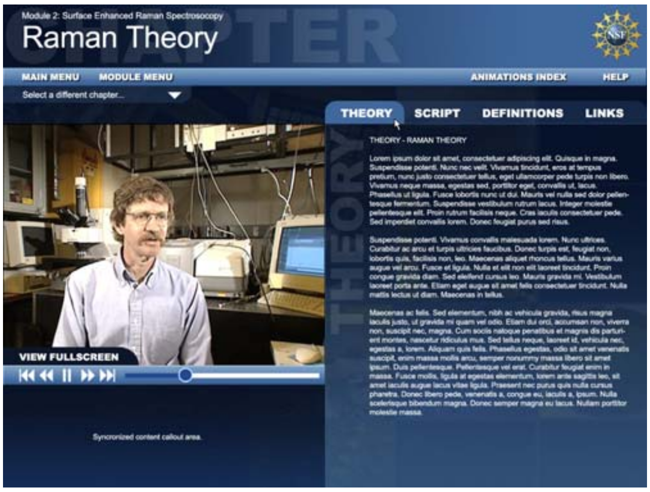


Figure 3. The main viewing screen for a module chapter. The video can be viewed here in a split-screen fashion that also simultaneously displays the theory, script, or definitions in separate tabs. The video can also be expanded to full screen view.



The PCIP DVD was designed using several of Mayer's multimedia design principles. Both the multimedia principle, which encourages the use both words and images, and the contiguity principle which suggests they should be present simultaneously (Mayer and Anderson, 1991; 1992), are evident in the design of the main chapter viewing area in which words (in both audible and written form) are present with images (either video or animations). The modality principle states that animations are more effective with narrated rather than written text (Mayer and Moreno, 1998; Moreno and Mayer, 1999). Since the PCIP DVD animations are integrated into the video, the video narration is used in explaining them. The interactivity principle suggests that students should be able to control the pace and order in which material is received in order to maximize learning (Mayer and Chandler, 2001). In the PCIP DVD, students can access any part of the material in any order that they choose. They can watch videos as often as they would like, and can scan through them using the slider bar.

Background to the present study

One of the main educational goals of the PCIP DVD is to show students the connections between the abstract, mathematical content of physical chemistry courses and real-world applications. With information about concrete applications of the concepts, students may be able to better understand the physical chemistry course. Three DVD modules (Atomic Force Microscopy, Surface Enhanced Raman Spectroscopy, and Thin-Film Kinetics) were previously implemented in courses and evaluated between Fall 2002 and Spring 2005 at two universities (Dyer, 2005; Dyer et al., 2007). In that study, students' attitudes and content learning were evaluated. Dyer found that students' content knowledge increased with the viewing of the DVD, and that the majority of students had positive attitudes about the usefulness of the DVD for their learning and showed excitement about using similar technology to learn other topics. However, in the Dyer studies the students used the DVD individually outside of a class setting, and there was no impact on their grade. All the students in that study were chemistry majors. The user interface in that study was very rudimentary, and many of the findings from that work helped us to revise the user interface into its current form. In this study, we looked at the DVD as a replacement for a laboratory activity in a course where students have a combination of majors. The first was essentially a pilot study and this study represents a step toward a more authentic use of the disc.

The module used in this study, Surface-Enhanced Raman Spectroscopy (SERS), is based on the work of Gerard Coté (O'Neal et al., 1999, 2000; O'Neal et al., 2003) at Texas A&M University. Their work explores the use of SERS as an alternative for analyzing excitatory amino acids in patients suffering from brain trauma. In some forms of head injuries, the presence of elevated levels of glutamate and aspartate in the cerebrospinal fluid indicates a need for pharmaceutical intervention. However, the interventions would be dangerous if these elevated levels are not present. The current method used for detection is often too slow to allow for effective treatment, while SERS could allow for accurate analysis in minutes. The module contains background information on the fundamentals of Raman, SERS, and metal colloid surfaces, as well as specifics about the medical applications of SERS. A comparative study is shown, in which the current method of analysis (HPLC separation, chemical tagging, and either IR or UV/visible spectroscopy) is compared to SERS. SERS requires much less time to perform the analysis, and has a slightly higher sensitivity than the current method. There is some disparity between the methods as to the quantitation of the highest excitatory amino acid concentration, which is presented to students as a data analysis problem for them to work on.

Methodology

Participants and setting

Data were collected during the spring 2006 semester at Purdue University. All participants were undergraduate students in the physical chemistry laboratory course. This course is populated by chemistry and chemical engineering students, who also take one of several physical chemistry lecture courses available. The laboratory course consists of one 50-minute lecture period per week and one 3-hour lab period per week. Two lab sessions are used to complete each experiment; the first week is used to collect most of the data, the second week is used for additional data collection, data analysis, and write-up. The 2006 spring semester course consisted of eight lab sections with three to ten students in each.

Table 2. Demographics of student participants; total number of students is 58.

Sex		**Race/Ethnicity**	
Male	33	White	46
Female	25	Asian	7
Age		Hispanic/Latino	1
19	2	African American	2
20	7	No Answer	2
21	30		
22	15	**Major**	
23	3	Chemical Engineer	25
≥24	1	Chemistry	16
Mean age	21.3 years	Chemistry Education	2
Year in school		Dual Chem/ChemE	1
2nd/sophomore	3	Biochemistry	8
3rd/junior	21	Dual Chem/Biochem	5
4th/senior	30	Other	1
5th	4		

The demographic information for those who participated in this study is detailed in Table 2. The course has a majority of male students, but has a typical distribution for a third/fourth year course with respect to age. Typical of the institution itself, the students in this course are predominantly White, non-Hispanic. The majority of the students are in major fields that are strongly allied with chemistry, which will have an impact on how they perceive and use the DVD.

SERS module implementation

During week 14 of the semester, the SERS module of the DVD was used by students during the laboratory period in place of a 'wet' laboratory experiment. Each student had individual access to a Macintosh G5 desktop computer on which the DVD had been loaded before class by the researchers. Headphones were provided so the students could listen to the narration on the video without disturbing other students. Students were able to view the DVD in any order they chose for the full laboratory period, and could take notes on the material. No printing capabilities were available to the students.

Survey data collection

Three surveys, developed by the author, were given during Weeks 2, 9, and 15 of a 16-week semester. The surveys consisted mainly of free response questions. The free response questions of Survey 1 asked students what they expected to learn in the course, what they had heard from peers about the course, and what difficulties they expected. Demographic information was also collected in Survey 1. Survey 2 asked the students what they had learned thus far in the course, what they expected to learn during the remainder of the semester, and what connections they saw between physical chemistry and real-world issues or their other coursework. On Survey 3, students were asked to compare the DVD module to other laboratory activities and to describe what aspects of the DVD were useful and not useful for their learning. This survey also asked them, again, about connections they saw between physical chemistry and other experiments. Two questions, "*would you pursue a career in physical chemistry?*" and "*would you take additional courses in physical chemistry beyond those required?*" appeared on all three surveys and consisted of a 5-part Likert-scale response ("definitely not" to "definitely"), followed by a free response explanation.

Learning gains data collection

In addition to the surveys described above, at the beginning of the laboratory period of week 14, students were given a pre-test consisting of twelve questions covering SERS and Raman spectroscopy. The students had been given a lecture earlier in the semester about Raman spectroscopy (week 12) and had performed a laboratory activity using conventional Raman spectroscopy (weeks 12 and 13). The pre-test was administered by the researchers before students were given access to view or use the DVD. If unsure of an answer, students were directed to write "*I don't know*" rather than leave the answer area blank. After completing the DVD, during the same laboratory period, they were given the post-test, which was identical to the pre-test. The students were allowed to go back to the DVD if there were questions that they could not answer based on their recollection or notes. The students were advised that their notes would be useful for studying for the final exam as well. The questions for the pre- and post-test are shown in Table 3.

Table 3. Questions for the pre- and post-test.

Questions
1. Explain how the photon/molecule interaction in the Raman process results in a signal.
2. Describe the signal enhancement process in Surface Enhanced Raman Spectroscopy (SERS).
3. Why does Raman spectroscopy require a high intensity light source?
4a. Place the following analysis methods in the order of largest detection limit to smallest detection limit: Conventional Raman, Conventional IR, and SERS
4b. For each of the analysis methods in 4a above, please include the improvement (order of magnitude) in detection limit over the previous one.
5. Of the 20 naturally occurring amino acids, what is special about aspartic acid and glutamic acid?
6a. Clinically, what is the single greatest advantage of the SERS method detection of excitatory amino acids (EAA's) over the conventional high performance liquid chromatography (HPLC)/infrared spectroscopy method?
6b. Why is that advantageous?
7. Using Raman spectroscopy, how are the two EAA's glutamate and aspartate distinguished?
8. Explain the variables that could complicate the experiment described in this module?
9. SERS might be a feasible technique to observe events other than brain trauma. What other kinds of events could be included in this list?
10. In relation to the Raman effect demonstration, explain the problem solving process involved in using Raman spectroscopy to distinguish between two samples, for example benzene and toluene.

Anonymity and scoring of student data

Students were given randomly assigned three-digit code numbers in order to keep their responses confidential. Students used their code numbers on the surveys so that each student's responses could be followed throughout all three surveys. Each survey and pre-test was worth a minimal number of points based only on completion of the instrument, and these counted towards the students' final grade. No staff associated with the course or with the assignment of grades were allowed to see the surveys. The post-test content questions were graded by the course teaching assistants and were included as a laboratory assignment score. All surveys and content tests were then scored independently by the researchers for the purpose of this study.

Data analysis

Survey responses were transcribed verbatim and coded using QSR N-VIVO® software. Each student's responses to Question 7 (Would you pursue a career in physical chemistry?) and Question 8 (Would you take additional courses in physical chemistry beyond those required?) were also analyzed for any changes in responses over the semester.

The data from the pre- and post-tests were scored in the same manner as previous DVD evaluations (Dyer, 2005; Dyer et al., 2007), based on the work of Abraham (Abraham, 1992; Abraham and Williamson, 1994). This system uses a scale of 0-5, where 0 is assigned a 'no response' answer, and 5 is assigned a fully correct answer. The scoring scheme is shown in Table 4.

Inter-rater reliability was established by having the researchers independently score three students' pre- and post-tests and then compare results. Scoring was conducted on three sets of data until 90% agreement (100% within 1) was reached. After scoring, each set of data was analyzed using Statistical Package for the Social Sciences (SPSS) for Windows®.

Table 4. Scoring scheme for pre- and post-tests.

Numeric Score	Degree of Understanding	Criteria for Score
0	No Response	Blank, "I don't know"
1	No Understanding	Irrelevant or unclear response
2	Specific Misconception	Responses that include illogical or incorrect information
3	Partial Understanding with Specific Misconception	Responses show understanding of concept, but also make statements which demonstrate a misunderstanding
4	Partial Understanding	Responses that include at least one component of the validated response, but not all the components
5	Sound Understanding	Responses that include all components of the validated response.

Results and discussion

Connections between the laboratory course and other areas

Throughout all three surveys, several trends became apparent about what students want from this laboratory course. Students' belief that there should be an explicit connection between laboratory and lecture material was very evident. Even though the laboratory course is designed to be a stand-alone course that students with varied physical chemistry backgrounds take, students seem to want parallels drawn for them between the thermodynamics or quantum mechanical concepts taught in their physical chemistry lecture courses. Most of these students are in their third or fourth year of undergraduate study and are beginning to consider a position in industry or attending graduate or professional school. Having a chance to see how theory applies to problem-solving situations they may be faced with in their career is important to them.

> *In this class I expect to finally see how the concepts and equations I learned in [physical chemistry lecture courses, I and II] work in practice. This includes any number of concepts in thermodynamics and quantum mechanics (Student 607).*

Students stated that they either wanted to learn or expected to enjoy learning how physical chemistry related to 'the real world'. This phrase, or a variation of it, was often used; however, the students rarely defined it, so we do not know whether they were speaking of the world of chemical problems, everyday issues that all people face, larger societal issues, or many other possible meanings. For example, one student stated:

> *Real life stuff. Yes I might have learned what an RTD [resistance temperature detector] is but now let me use it for something real. And I guess a big problem is I am a CHE [chemical engineer], I don't want to do research, but in a lab, so I like real things (Student 406).*

An interesting aspect of this desire is that rarely, if ever, do the students say which 'real world' problems they would like to solve, or how they think it should apply. Also, some students say that they can apply physical chemistry to 'real life', but they never specifically say what concepts they can apply or to what aspect of 'real life' the concept can be applied.

On Survey 2 and Survey 3, after the students had some experience with the physical chemistry laboratory course and any other physical chemistry courses in which they were enrolled during the semester, the students were asked what connections they could see between physical chemistry and their lives or the world around them. For this question on Survey 2, the most common answer was included in the coding scheme as "generic connection". Many students (15 students, 25.9%) responded with what seemed to be a very ambiguous, uninformative general statement, such as:

It seems like PChem is used in every aspect of everyday life (Student 307).

Some of these vague responses were very elaborate, but still did not explain what connections the student saw.

Physical chemistry has taken my satisfaction and amazement of this universe to a new level (Student 429).

Other students responded with very specific situations and topics such as refrigeration (3 students, 5.2%), engines, fluorescence, medicine, meteorology, nanotechnology, and phase changes (1 student each, 1.7%). None of these students provided any details, but because of the specific nature of their responses, it would seem as though they had been exposed to these applications in other situations. A large number of students (19 students, 32.8%) stated that they saw no connection between physical chemistry and their lives.

On Survey 3, there were still a large number of students (15 students, 25.9%) who responded with a generic physical chemistry connection. A much larger group of students mentioned a connection between physical chemistry and the medical field (15 students, 25.9%). This increase was most likely due to the use of the DVD the week previous to the survey, where the module specifically showed the use of Surface Enhanced Raman in a medical setting. Eleven students (19.0%) still said they saw no connection. The increase in the number of students who see a connection between physical chemistry and the world around them supports the use of an approach, such as the one facilitated by this DVD, which makes explicit connections between physical chemistry theory and its research and 'real world' applications. The fact that students made connections to topics that were explicitly described in the DVD suggests that this tool is effective for this purpose.

Physical Chemistry as a career or field of study

The responses to the 5-point Likert-scale questions asking "*would you pursue a career in physical chemistry?*" and "*would you take additional courses in physical chemistry beyond those required?*" were tallied and a paired samples t-test was conducted to examine if there was a significant difference between the answers from Survey 1 and Survey 3. Both the physical chemistry career question ($n=58$, $t=-3.446$, $p=0.001$) and physical chemistry course question ($n=58$, $t=-6.343$, $p<0.001$) showed a significant change in the distribution. For both questions, the results were consistently weighted toward 'definitely not', with a shift occurring toward the positive end of the scale in Survey 3. These results can be seen in Tables 5 and 6. Overall, from Survey 1 to Survey 3, there is a decrease in the number of 'definitely not' responses. On the physical chemistry course question, there is an increase in the number of 'maybe' and 'likely' responses. These shifts are statistically significant, indicating that students had a less negative attitude toward physical chemistry by the end of the semester. Furthermore, the shift was not statistically significant until after the students viewed the DVD, indicating that this multimedia tool may have had an impact on student attitudes toward the course.

Table 5. Results for question "*would you pursue a career in physical chemistry?*"

	Survey 1	Survey 2	Survey 3
Definitely not	20	19	15
Unlikely	26	26	29
Maybe	12	9	11
Likely	0	4	3
Definitely	0	0	0

Table 6. Results for question "*would you take additional courses in physical chemistry beyond those required?*"

	Survey 1	Survey 2	Survey 3
Definitely not	30	20	19
Unlikely	16	23	17
Maybe	10	9	17
Likely	1	6	4
Definitely	1	0	1

The most common explanation for the large number of 'definitely not' responses was that the students had no interest in physical chemistry.

Definitely not. Subject matter does not interest me at all (Student 674).

Another common reason that appeared was that these students did not want a career based in research and laboratory bench work.

Definitely not. It's interesting, but I don't want to spend my life locked in a lab with a chalkboard assembling a laser or a math proof (Student 527).

Students also had plans for other careers in which they had more interest, even if physical chemistry held their interest.

Unlikely. I have other plans lined up, and while PChem is interesting, I do not know that I would make a life of it (Student 953).

The students who showed interest in pursuing a career in physical chemistry (those who responded as 'maybe' or 'likely') explained their choice mainly in terms of their interest in the topic.

Maybe. I have so far found it [physical chemistry] very interesting, prior to this course the answer would have been definitely not (Student 906).

Some students also described their interest in physical chemistry in terms of the value of the field itself.

Likely. It's [physical chemistry] a good blend of theory and practice, yet seems fundamental to the rest of chemistry (Student 685).

The students who showed some interest in taking additional physical chemistry courses (those who responded as 'maybe', 'likely', or 'definitely') explained their position primarily in terms of the course content capturing their interest.

Maybe. PChem is very interesting to me (Student 355).
Likely. I like the discussions and the new topics that I haven't heard of before (Student 116).
Definitely. It's a very exciting topic and field (Student 685).

Questions about the usefulness of the PCIP DVD

On Survey 3, students were asked to list the aspect or aspects of the DVD that were the most useful for their learning. The response given by the largest number of students to this question (15 students, 25.8%) was that the video component of the DVD was the most useful. Eleven students (19.0%) stated that the animations were the most useful.

> *Several of the diagrams/charts/visual aids proved quite useful to enabling better understanding of the concepts (Student 914).*

Ten students (17.2%) said the script was the most useful. One student who felt the script was useful said,

> *The end [was the most useful] where you can navigate through each different chapter and look at what they talked about in words [the script]. I learned a lot better by reading what they said (Student 766).*

Since reading the script is much like reading a textbook, it was surprising that such a large proportion of students found it more useful than the video, which includes animations and visual examples. Mayer (2002) suggested that the combination of visual and audio should help create the most useful multimedia learning situation, but these students did not take advantage of this multimedia learning, choosing instead to use the more traditional, written materials.

Six students (10.3%) said the navigational abilities of repetition and control over the flow of information were the most useful. Having both video and script allowed the students to control the format through which they could obtain information, enabling them to interact with the information to best suit their learning styles. A student described why this was his preference:

> *The ability to go back and see things a couple of times to make sure I understood the material (Student 719).*

Five students (8.62%) said the use of the script and the video together was the most useful.

Aspects of the DVD perceived not to be useful

Students were also asked to state which aspect or aspects of the DVD they did not find useful. Rather than identify a section or component of the DVD, the students instead said the scientists on the video (14 students, 24.1%) and their monotone voices (6 students, 10.3%) were not useful for their learning. The scientists in the videos had been reading a teleprompter. This tended to make their dialog seem non-conversational. One student's response was characteristic of all responses:

> *Staring at the monotonous emotionless boring speakers talk during the video (Student 363).*

Eleven students (19.0%) said that all parts of the DVD were useful for them. This shows that this group of students was open to the use of the DVD as a learning tool, even though a number of students (17 students, 29.3%) said that while it provided them with new information, it was not a good substitute for a hands-on laboratory activity. Rather than identifying certain aspects as not useful, many students gave suggestions as to what they would prefer, such as:

> *I felt disorganized going through it. I would have rather seen all Ch 1 (movies, theory, figures, etc) then move on. I know I could have done this, but I wanted to simply click next and have that occur (Student 251).*

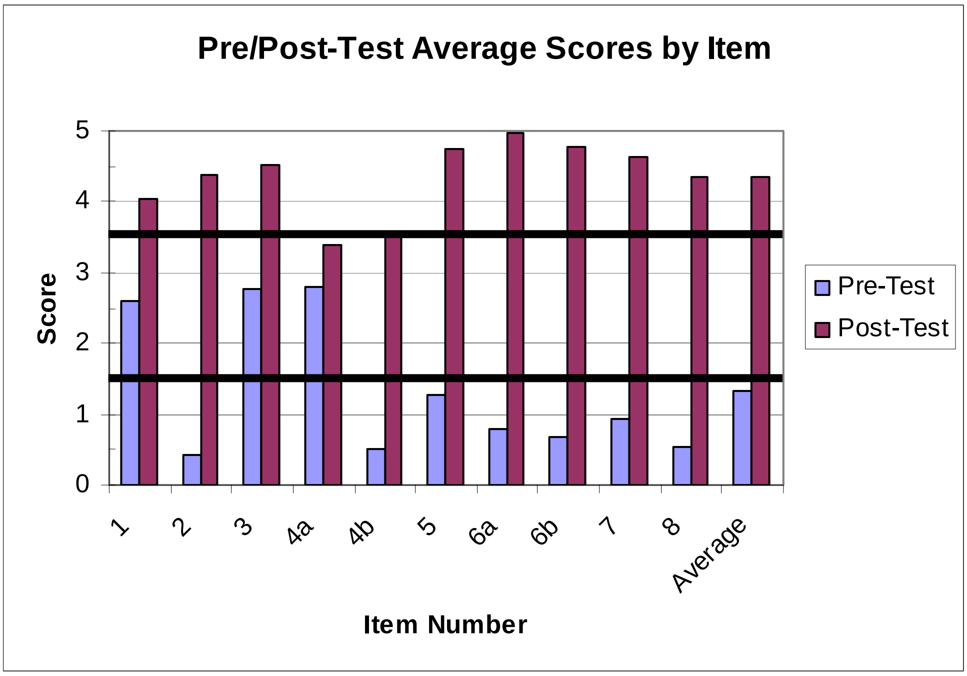
This student's quote is interesting, in that s/he did not want the level of navigational freedom that our interface provided, which contradicts much of the research in multimedia design. While providing flexibility in navigation allows the material to be used in different ways by different students in order to suit their learning needs, certain individual students may desire a prescribed order for viewing the material.

Learning gains data

Students' responses on both the pre- and post-test forms were scored on the 0-5 point scale described earlier. Even though each form had twelve questions, only the first ten were scored (1-8 in Table 3). Two questions were not scored because they could be answered in a much broader manner and still be considered correct; there was no single correct answer. The scores for the remaining questions were tallied for all participants (N=58). The overall pre-test average was 1.3, and the overall post-test average was 4.3. Each question had a positive gain average, and the average gain for all questions was 3.0.

The numerical range can be described in three broad ranges, in order to simplify interpretation and illuminate patterns within the data. These ranges are shown with horizontal lines in Figure 4, such that the general level of understanding increases from the bottom to the top. The figure shows that every question except 4a shows a major change in the level of understanding, and there is an overall trend in the student responses toward the 'understanding' level on the post-test.

Figure 4. Graph of pre- and post-test average scores for each question and overall. Regions separated by the thick horizontal lines denote a rough demarcation from lower levels of understanding (bottom) to higher levels of understanding.



Statistical analysis

In order to determine if any of the gains on these questions were statistically significant, the Wilcoxon Matched-Pairs Signed Ranks Test was performed on the data. The Wilcoxon test is designed as a nonparametric alternative to a repeated measures t-test. The data presented here is considered nonparametric because the 0-5 values do not represent an even interval scale. For example, a score of 4 on this scale does not mean the response is twice as correct as a response scored as a 2. Instead of comparing means, scores are converted to ranks and compared at two different times (Pallant, 2001). All Z-scores are greater in magnitude than 1.96 standard deviations and all p-values are below 0.05. This means that the gain for every item is statistically significant.

Question analysis

For some questions, this shift to the 'understanding' level is more dramatic than for others. Questions 5-8 all show a major shift in category from a majority of the responses being categorized as 'no understanding' to 'understanding'. The answers to all the question numbers 5-8 were rather explicitly stated in the DVD material about the application of SERS to brain trauma analysis. Thus, these represent rote memorization learning. Questions 1 and 2 focus on the theory behind Raman and SERS, respectively. Since the students had performed a Raman experiment during the two weeks prior, many responses to question 1 were in the 'partial understanding' category, showing that the students remembered some of what they had learned previously about Raman spectroscopy. Question 2 shows a dramatic shift, showing that the students have learned about the process of signal enhancement in SERS, which is not something they were exposed to as part of their conventional Raman experiment. Questions 4a and 4b do not show as much of a shift in responses. These two questions (4a and 4b) required the most synthesis of any of the questions. The information about the sensitivities of different instruments necessary to answer these questions was distributed throughout several chapters of the DVD, and students had to find all the information, compare the sensitivities, and rank the instruments. This was obviously difficult for the students, as shown by the much smaller shift in response categories as compared to the other questions

Conclusions

Overall, the DVD can be considered to have been an effective multimedia tool for teaching concepts and research applications of physical chemistry, especially those that are not usually included in the curriculum. Students showed positive learning gains for the information contained in the DVD module. Because there was no other method of instruction provided between the pre and post tests, the learning gains are attributable to the use of the DVD and, to some degree, to the short amount of time that elapsed between the two tests. Because the learning gains described here were measured very soon after the students viewed the DVD, the information was still fresh in their minds. It will be necessary to perform a longitudinal learning study to find out how much of the information they will retain.

The number of students identifying specific applications of physical chemistry also increased. This cannot be completely attributed to the DVD, because students experienced other instruction between the surveys that asked them about applications. The same is true for shifts in students' interest in the field of physical chemistry. However, the interview data indicate that the DVD contributed to these positive shifts. Also, students stated that they felt the DVD was useful for their learning. Of the students who said the DVD was not completely useful for their learning, the overwhelming reason given was that the speaking style of the scientists interviewed in the video was monotonous. In newer modules, this issue has been addressed, and a much more conversational tone is used by the speakers, as well as much shorter time on camera ('talking head') interspersed with video, graphics and animations to help explain concepts.

The DVD in its current form does show promise as a tool for including new topics in the physical chemistry curriculum, as recommended by Zielinski and Schwenz (2004). It is a tool that is designed to be a supplement to a course, which allows for the inclusion of techniques, experiments or demonstrations that are not possible or feasible to be performed by students in the classroom or undergraduate lab. A good example of this is magnetic resonance imaging, which is carried out in specialized facilities with very expensive equipment, but which can be shown to students easily with the DVD module that covers NMR and MRI. The DVD was designed to serve as a supplement to the lecture and laboratory course, and this study demonstrates that it can be a useful tool when used in that way. Additional studies are planned that will examine the effects of using other modules on the DVD and will attempt to distinguish the effect of learning with the DVD from that of other educational interventions.

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Appendix

Figure A1. Main menu of the PCIP DVD.

The DVD can be used either in a computer that has a DVD player, or in a set-top DVD player connected to a television monitor. If used in a computer, the DVD will launch automatically using the NetBlender player. This is a file that is resident on the DVD and does not require any software to be loaded onto the computer. The player is designed to incorporate both HTML content and DVD video into the same interface. The opening screen is a graphical menu of the available modules, as well as links to the help pages and animations index (discussed below). Selecting and item from the main menu brings the user to the module menu, as show in Figure A2.

Each module contains five main components, which are accessible through the module menu: video chapters, animations, problems, theory and script. When the 'chapters' link is selected, the screen gives a list of the chapters for that module on the right side of the screen (see Figure A2). Each chapter will open with a 'tabbed' view that shows the DVD video in a small window, along with the theory, script, definitions and links available as tabs next to it (Figure A3). The video can also be viewed full screen, and has all of the capabilities of standard DVD video with respect to resolution, flexibility in sizing, and random access to different time points in the program.

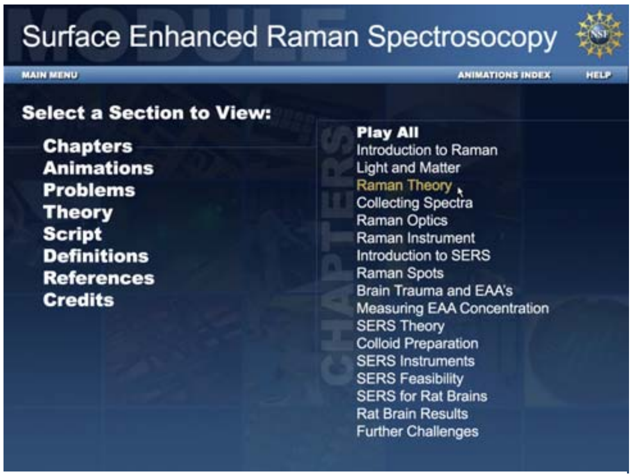

Figure A2. A typical module menu.

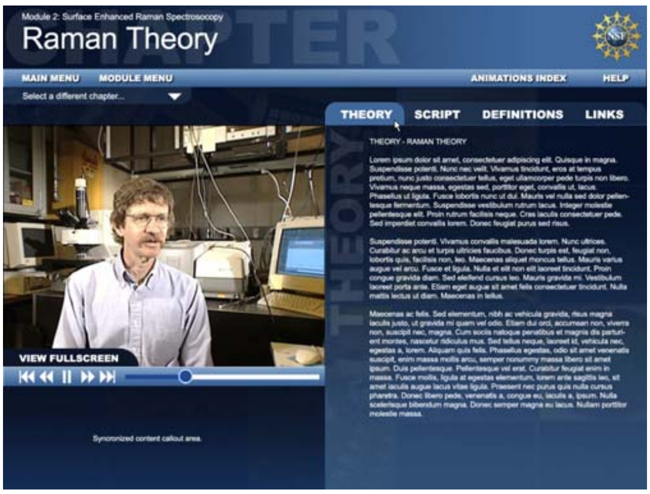

Figure A3. Chapter window with tabbed view.

Animations that are associated with each module are integrated into the video content itself. However, these animations can also be accessed individually from the module menu or from the animations index link on the main menu. The animations index allows animations to be played '*à la carte*' either for students to review them or for demonstration purposes in the classroom.

The theory section of each module includes information about each section of the DVD module. These are linked to the curriculum materials that students will be learning in the classroom. The problems section of each module includes problems for students to work on that are related to the material in each module. The problems progress from fundamental concept problems up to data analysis problems that utilize the actual data collected by the scientists in the module. For example, for the AFM module, students are asked to calculate the force that will be felt by an AFM tip. In a later problem, they are provided with AFM images of an arsenic covered surface at different temperatures and asked to analyze the size distribution of the arsenic islands.

In addition to the main content continued in the chapters, the disc also contains a list of references, definitions and production credits for each module. The video component of this disc is a standard DVD video that can be accessed through any standard DVD player on a computer or on a television set-top player. If accessed in this way, only the video components will be available, along with a searchable menu. None of the ancillary information (script, theory, definitions, etc.) will be available when viewed in a standard DVD player.

List of modules

1. Atomic Force Microscopy to Examine Growth of Germanium Layers on Silicon. This video features the work of Prof. Stephen R. Leone, who was at the University of Colorado of Boulder at the time the video was created and is currently at UC-Berkeley.
2. Surface Enhanced Raman Spectroscopy to Examine Amino Acids in the Cerebral Spinal Fluid after Brain Trauma. This video features the work of Gerard Coté at Texas A&M University.
3. Kinetics of Photolithographic Polymers. This video features the work of Frances Houle and William Hinsberg at the IBM-Almaden Research Laboratories.
4. NMR and MRI applications. This module features the work of Jack Roberts at the California Institute of Technology and William Bradley at the University of California, San Diego.
5. Hydrogen Fuel Cells and Solid Acid Electrolyte Research. This module features the work of Sossina Haile at the California Institute of Technology.
6. Bose-Einstein Condensation. This module features the work of Eric Cornell at the University of Colorado at Boulder.
7. Spectroscopy of Vitamin B_{12} Cofactors. This module features the work of Thomas Brunold at the University of Wisconsin – Madison.
8. Thermodynamics of DNA and RNA single molecules using optical tweezers. This module features the work of Carlos Bustamante at the University of California, Berkeley.