Teaching and Technology: Making the Invisible Explicit and Progressive Through Reflection

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Background and Purpose. The scholarship of teaching and learning (SoTL) challenges instructors, regardless of discipline, to consider critically and explicitly how and why an instructional technology is aligned with instructional objectives and anticipated learning outcomes. Individual reflection on experience is useful for making sense of the complex environment of teaching. Interprofessional reflection and dialogue are powerful strategies for stimulating thinking about teaching and learning that extend beyond a single field. This article has 2 purposes: (1) to explore the potential commonalities and disparities existing between 2 professors of different disciplines—physical therapy and chemistry—regarding their experiences using technology in instruction, and (2) to reflect upon and share the reciprocal learning transactions that can occur through "hybrid" interprofessional (and virtual) dialogue.

Method/Model Description and Evaluation. Our method enabled 2 professors to partake in a rich dialogue about their experiences teaching with technology. First, each professor described and reflected individually on the context and rationale for their selection of and teaching experiences with educational technology. Then, a reciprocal analysis transpired where examination of common and divergent themes was identified, which pertained to the implementation, outcomes, impact on student learning, and pitfalls encountered by each professor. Through a virtual dialogue, a learning community dyad was formed that focused on a goal of mutual interest: educational technology. Through concurrent reflection, the 2 professors transcended disciplinary boundaries to learn from each other in ways that were unexpected. A model was developed that describes the SoTL experience that is comparative, divergent, and ultimately progressive.

Discussion and Conclusion. Individual reflection combined with reciprocal analysis and dialogue within a learning community fostered a perspective change for each professor. Reflection illuminated commonalities regarding teaching with technology and collective dialogue provided an opportunity for additional learning to occur. This work supports the benefits of communication about teaching between disciplines to decrease isolation and build intellectual bridges to connect respective professions.

Key Words: Scholarship of teaching and learning, Technology, Learning communities, Reflection.

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INTRODUCTION

Since its introduction in *Scholarship Reconsidered* 15 years ago,[1] the term scholarship of teaching and learning" (SoTL) has emerged as a focal point for discussions of what it might mean operationally to advance our understanding of teaching and learning in higher education. A July 2005 search for the term on www.google.com yields over 50,000 hits, and Boyer's[1] original formulation, "scholarship of teaching," yields another 50,000 hits. The Carnegie Foundation for the Advancement of Teaching has anchored the work on SoTL, and their Web archives are a rich resource for tracking the development of SoTL.[2] Other Web-based resources are equally accessible,[3] as well as a relatively steady, if not increasing, output in various venues.[4]

With all due deference to the work that precedes this article in defining SoTL, the principles presented in *Scholarship Assessed*[5] do a compelling job of defining the general processes of scholarly practice that one would begin with in order to characterize what scholarship of teaching and learning means. In their research on what constituted the way academia defined scholarship, the authors found that when academicians consider a work to be "scholarly," they mean that it conformed, in large part, to the following standards: (1) clear goals, (2) adequate preparation, (3) appropriate methods, (4) significant results, (5) effective presentation, and (6) reflective critique.

Indeed, the scholarship of teaching and learning challenges educators to consider critically and explicitly, based on evidence of student learning, how and why a chosen pedagogy is aligned with instructional objectives and anticipated learning outcomes. Boyer,[1] well known for his work in the area of scholarship within higher education, maintains that scholarship by instructors on the experiences, impact, and outcomes of teaching and learning (SoTL) are inseparable.

BACKGROUND AND PURPOSE

While higher education is facing changes that present faculty members in any discipline with a plethora of research topics, this article examines the use of educational technology by 2 professors—1 in physical therapy and 1 in chemistry. They became a dedicated learning community of faculty committed to intellectually stimulating dialogue leading to new approaches to academic problems and crosspollination of ideas and practices. Participation in the community also provided support for research development and personal development.

Supplements and enhancements to traditional classroom pedagogy are implemented in ways that are strongly connected to the discipline and its subject matter.[6,7] While research on teaching and learning conducted by educators of a single discipline is a necessary and useful strategy for improving instruction, interprofessional dialogue has the potential for creating a perspective shift that transcends professional boundaries and identifies potentially transcendent pedagogies.

Technology Use in Physical Therapist Education

Information literacy is a priority for both higher education and physical therapist education.[7,8] Moreover, current college-aged students are more technologically savvy that those of earlier generations.[9] Perhaps based on this impression more than any other, instructors in many disciplines are exploring learning options that include a technological component.

In physical therapist education, technology can augment learning both during academic and clinical education. Instructors are using computer-assisted, Web-enhanced modules and the Internet to facilitate student learning in many ways. For the purposes of this article, computer-assisted instruction (CAI) refers to the use of CD-ROM and multimedia software programs that supplement traditional instruction with interactive electronic media.[6] CAI is being used to augment anatomical instruction[10-13] and clinical assessment acquisition.[14]

Web-enhanced instruction pertains to the Internet, e-mail, and educational software packages such as Blackboard. One commonly relied on use of Web-enhanced instruction is "Web presence," which refers to placement by instructors of static, paper-based materials such as course syllabi on a course Web site. For example, interactive utilization of Web-enhanced instruction occurs when instruction incorporates synchronous (eg, chat rooms) or asynchronous online discussion boards through a Blackboard course Web site.[15-18]

Distance education learning options enable instruction to occur at locations removed from an institutional setting. One burgeoning use of distance education is the online transitional Doctor of Physical Therapy (t-DPT) program which relies on e-mail, CD-ROM, and Blackboard interactive features, such as discussion boards and virtual chat.[19-21] In addition, some physical therapist clinical education departments are exploring the feasibility of conducting clinical site visits using distance education technology.[22]

Educational technology has many potential benefits. One benefit is that educators can increase participation in classroom discussion and communication between individual students or among students and instructors through discussion boards and virtual chat rooms.[23] In addition, research has demonstrated that online learning opportunities afford wider participation for a diversity of learning styles.[24,25]

However, educational technology has some major disadvantages. One disadvantage concerns the absence of immediate feedback or the nonverbal cues that accompany face-to-face interaction between a student and an instructor.[23,26] Barriers to instruction that relies on technology include lack of familiarity with the computer or the Internet and limited access to either of these elements.[27] Technical flaws such as server problems, gateway disturbances, and viruses resulting in course Web site down-time are inevitable and can affect student attitudes towards online learning environments.[26,28] While the benefits are numerous, educators must also consider the potential barriers and disadvantages of online learning and be prepared for managing these concerns.

Technology Use in Chemistry Education

The use of computer-based technologies in science education is ubiquitous.[29-31] In general, the sciences, engineering, and business have been in the group of early adopters,[32] although a scan of the nearly 100 articles in the first issue of *Journal of Issues Informing Science and Information Technology*[33] reveals a diverse collection of instructional technology world-wide. And while even some things as simple as chat room discussions were immediately exploited to promote and study student learning through student writing,[34] there are now many of what one might call "second-generation" versions of instructional technology. For example, using student writing generated in these electronic discussions as an object of study about student learning has become a formalized, dedicated, and institutionally supported software environment called CPR (Calibrated Peer Review).[35-37] A group of writers and readers—practically unlimited by scale and geography—train themselves through standard samples to give critical feedback and can then access writing that has been submitted by others for peer review. Additionally, the National Science Foundation is facilitating the distribution and access to annotated, user-based, and peer-reviewed instructional technology resources through the education area of the National Digital Science Library[38] and its connection to the disciplinary science education communities.[39]

Every instructional tool, including computer-based technologies, should exploit the medium's instructional strengths ("affordances") and not try to run against the grain of its constraints.[40-42] A healthy debate remains about how to dissect the effects of instructional method from the medium in order to assess the impact of the latter. Clark[43-44] maintains that the data actually favor instructional method, while Kozma[45,46] argues that the intrinsically inseparable nature of method and medium cannot be parsed. Coppola[47] has also argued that curricula (goals) and technologies (methods) should be explicitly linked, exploiting the synergistic relationship, and that activities designed for the use of conventional tools may not necessarily align with the capabilities of computer-based technologies.

Like their counterparts in the field of physical therapy, chemists have adopted commercially available and institutionally supported environments as a way to modify their classroom and course environments. Electronic homework,[48] quizzing,[49] tutorials,[50] and multimedia resources[51] are all easily delivered through WebCT or WWWAssign, and other Blackboard-like environments. Wamser[52] reported using e-mail assignments distributed to large lecture classes to interact with individual students. Faculty members are thinking in flexible ways about what might be possible with even a standard tool such as e-mail, rather than being limited by its standard use.

Science education researchers have examined the impact of instructional technologies; the best results of this research remind us that these tools, like all others, need to be intentionally aligned with instructional goals in order to be effective.[53-56] Otherwise, there are instructional settings in which computer-based technologies result in better learning outcomes than with conventional tools,[57,58] and there are companion studies that reveal no differential impact from computer-based technologies at all.[59,60]

Growing evidence suggests that the use of visual representations supports the development of understanding in science classrooms.[61-66] The role of visual representations has been of particular import to researchers exploring chemistry education,[67-72] a key reason being that the primary phenomena investigated in the discipline—molecules and their interactions—are for all practical purposes unobservable.[73-77] Chemists and chemistry students are forced to understand molecular-level phenomena as they are mediated through a variety of representational forms. These forms include nonlinguistic or visual forms, such as molecular structural drawings and graphs, in addition to verbal descriptions, notational symbols, and the like. Although several studies have shown positive correlations between student use of different types of visualization tools and measures of conceptual learning in chemistry classrooms,[61,62,65,66,78] the mechanisms by which visual representations influence this development are not clear yet.

Theoretical Framework: The Role of Reflective Practice and SoTL

For instructors in any discipline, the classroom is complex and may be compounded by the inclusion of technology. Instructors in higher education often work in isolation without formal mechanisms for receiving feedback on their teaching.[79] Without methods for evaluating teaching and improving instruction, student learning may be compromised.[80] Self-reflection can assist instructors with deciphering the complexity of teaching and can promote professional development.[79,81-84] Reflective inquiry is a goal of physical therapist education and critical for self-directed professional development in students.[8,85-87] In chemistry education, there is a nearly century-old tradition of mainstream faculty members publishing and presenting their pedagogical innovations, and recently, with the inclusion of chemical education research as additional information on which to base their reflective comments.[88]

The idea of reflection on individual experience is not new. Dewey described reflection as critical for "stepping back from a perplexing [incident to] generate a more comprehensive plan of activity" and make meaning of experience.[89(p25)] According to Schön,[85] reflective practice is used by expert professionals to deal with unique or unstable problem situations.

While individual reflection is useful, a powerful strategy for stimulating thinking about teaching and learning that extends beyond a single field can occur through interprofessional reflection and dialogue. Thoughtful consideration is required of faculty who introduce innovative teaching approaches, including technology. The inclusion of technology as a pedagogy should augment instruction in an explicit and measurable fashion. Specifically, an instructor must determine if the chosen technology is aligned with instructional objectives and if desired learning outcomes are achieved in students. Physical therapist educators are "perfectly positioned" to contribute to the evidenced-based literature related to the scholarship of physical therapist education.[90(p2)] Through individual reflection or interprofessional reflection, an instructor can ". . . contribut[e] to the scholarship of teaching by documenting and evaluating early experiences in using Web-based technology in university courses."[91(p585)]

METHOD/MODEL DESCRIPTION AND EVALUATION

The object of inquiry reported in this article concerns the importance of making explicit how the integration of a new pedagogy, educational technology, into existing class formats can facilitate student acquisition of specific learning objectives and skills. Specifically, an instructor must determine if the chosen technology is aligned with instructional objectives and if the technology abets desired learning outcomes in students. In the following sections, 2 examples will be presented that describe how educators in both physical therapist and chemistry education used technology to achieve learning outcomes. A reciprocal analysis will follow where common and divergent themes were identified pertaining to the implementation, impact on student learning, outcomes, and pitfalls encountered by each professor. The content of the concurrent reflection that transpired between the respective interdisciplinary dyads will be shared to illuminate learning that transcends disciplinary boundaries.

Statement of Instructional Goals, Use of Technology—PT Case

Northeastern University (NU) offers a 6-½-year professional (entry-level) Doctor of Physical Therapy (DPT) that includes two 6-month cooperative education or related work experiences in addition to 3 clinical education experiences. Each class within the DPT program contains approximately 70-100 students, making it 1 of the largest programs in the country. Participants were 57 fifth-year physical therapist students enrolled in a 12-week Web-enhanced course entitled "PTH1405 Research for Physical Therapists." PTH1405 introduces students to research design, basic statistics, and analysis of physical therapist literature. Students in PTH1405 met weekly for two 65-minute lecture periods and one 65-minute recitation. For all 57 students, this was their first encounter with a Web-enhanced course.

Instructional Goals

Information literacy is a Professional Practice Expectation for graduates of physical therapist education programs.[8] With the advent of evidenced-based practice, students are required to "use information technology to access sources of information to support clinical decisions."[8(p12)] An additional Professional Practice Expectation is for graduates to possess excellent communication skills. To address these specific guidelines, the instructor of PTH1405 designated 3 of 9 course objectives to technology-based student learning outcomes: (1) demonstrate effective communication skills: verbal, written, presentation, computer, and listening; (2) demonstrate professional behavior while engaged in online communication; and (3) demonstrate computer literacy through the use of Blackboard's virtual chat and discussion thread communication features.

To reach these 3 objectives, the instructor used Blackboard as a Web-enhanced pedagogy to transform PTH1405—a traditional lecture-based course. A goal was to embed Web-enhanced course assignments directly related to course objectives and grading criteria. Another instructional goal was to move beyond using Blackboard to statically house course information incorporating the software's interactive communication features: virtual chat and discussion board.

To do this, the instructor relied on 3 curriculum-based modes of interaction, including a method that was familiar to students: face-to-face method (recitation), virtual chat room, and discussion board. The rationale for including 3 methods of interaction was to increase student familiarity with the interactive features of a widely available educational software package, diversify the opportunities for active student dialogue about research methods and the medical literature, and provide a diversity of communication options to address student learning style differences.[24,25]

Two additional objectives incorporated in the course addressed the Professional Practice Expectations of self-assessment and reflection. As mentioned previously, reflection is a desired skill in physical therapists.[8,85-87]

Instructional Intervention

The instructor posted netiquette guidelines in the "Announcements" section of the Web page to establish expectations for professional online communication and behavior. Also posted were written guidelines for each online assignment that were linked to grading criteria. Throughout the academic term, the instructor interacted with students to continue to guide their online behavior and communication development.

In preparation for recitation, students worked collaboratively in groups of 3-5 individuals to answer questions for critique of peer-reviewed journal articles. The virtual chat room assignment required each small group to collectively brainstorm preparation of the critiques in real time.[6] During the face-to-face format of recitation, students discussed their article critiques as a class or asked questions related to course material.

In a second assignment, the author posted a Web-based newspaper article describing recent health research in the news and questions related to the article on the site. Students posted comments about the article on the discussion board and the entire class could view the postings. Discussion board communication was used to stimulate an online class-wide conversation that could occur at the student's convenience.

Self-assessment was promoted through 4 reflective papers that enabled students to describe their experiences and learning related to the online assignments. Reflective papers were assigned a grade to encourage participation.[6]

Data collected. Data were collected on student learning and experiences 4 times during the academic term via discussion board transcripts, chat room transcripts, and reflective papers. The investigator used a qualitative methodology to iteratively analyze each round of data. Four themes emerged pertaining to: online behavior, communication feature use, students' perspectives—how they learn—and barriers. The instructor used these data to modify future course assignments and pedagogical approaches in PTH1405.

Student Outcomes

Students utilized the online communication features in different ways. Discussion boards allowed students to post individual reactions to assignments, view diverse perspectives of their peers, and post threads leisurely. Students indicated that the threads fostered deeper thinking and critical examination of an assignment, and provided opportunities for students to compare their thinking to that of their peers. By studying student comments in the discussion threads, the instructor was able to note directly a number of positive practices within the student community: application of past knowledge, application of class material, a connection of ideas to therapeutic practice, and an opportunity to build on each others' comments. Online conversations enabled students to learn from reading and thinking about the multiple perspectives of their peers. Generally, individual discussion thread comments were thoughtfully written using professional language, a respectful tone, complete sentences, and few spelling errors.[17]

Chat room behavior reflected a different tenor. Group members joked and had fun while using the technology and often used their cell phones to augment an interaction. Conversations were full of typographical errors and distracting comments. Many conversations were informal and began with welcoming of participants. Then, the emergence of a leader became apparent when an individual posed a question related to the course assignment, which was a deviation from the informal conversation that appeared at the beginning of the chat room session. Groups displayed different approaches when waiting for late individuals to enter the chat room; some groups delayed discussing course material, while others did not. Uniformly, when a late group member entered the virtual environment the ongoing discussion became side-tracked and unorganized.[17] Perhaps because there were so many similarities to the behaviors one sees in any normal group work, the students generally viewed the virtual group meeting as duplicative of times when they could meet in person; in fact, many students expressed a preference for face-to-face interaction.

Table 1. Student Outcomes From Physical Therapy Case

1. Demonstrate professional behavior while using online technology resources.
2. Demonstrate technical competence using online communication features.
3. Engage in self-reflection and critical analysis skills.
4. Read and analyze primary journal sources for evidence as it related to clinical practice.

Barriers to online learning can be either technical or nontechnical. Our participants were affected by 2 major technical impediments: university-wide impact of the Code Red and Nimba viruses, and an unexpected 50% increase in Internet traffic. These impediments together dramatically reduced the performance of Internet-based applications such as Blackboard and limited student ability to access and complete online course assignment at the semester outset. These 2 impediments caused a great deal of distress for the students who could not access course materials. Stress was then passed on to the instructor who had to scramble to prepare and distribute duplicate course materials in class.[17] Table 1 summarizes student outcomes for the physical therapist case study.

Statement of Instructional Goals, Use of Technology: Chemistry Case

The context for developing our use of instructional technology in chemistry is called the Structured Study Group (SSG) program. Since 1994, a cohort of 120-160 first-year university students have earned Honors credit in Supplemental Instruction (SI) sessions attached to the 1,000-student course of standard coursework and examinations in the organic chemistry-based *Structure and Reactivity* courses.[92,93] We developed this modified supplemental instruction option in lieu of a separate Honors section of the course because we felt that first-term students could not judge whether or not an Honors section of organic chemistry would be appropriate.[94] In the second semester of the course, we do offer a separate section of the course where lecture, discussion, laboratory, and SSG work are integrated for a group of approximately 100 self-selected students who wish to take their second term of organic chemistry in a projects and research-based environment.

Students met in teams of 15-20 for 2 hours per week in sessions facilitated by an upper-division student doing generative, literature-based work which they bring to the session for peer review and discussion. SSG leaders were juniors and seniors who demonstrated teaching skills when they were SSG students. Indeed, the SSG assignments permitted students to demonstrate their teaching potential with the idea that they might become SSG leaders. Varma-Nelson and Coppola[95] have outlined the details of team learning-based programs and a proposal for why they work based on 4 well-established areas of educational design and research.

Instructional Goals

One way or the other, a universal educational outcome was that students are able to make meaning from professional writing in our fields. The short version of achieving our particular goal was to give selected journal articles to teams of students and ask them, as a group, to understand and explain the science. In particular, we used technological environments (Web-based multimedia) as the medium for students to complete this task by using the literature to create instructional materials for each other.

Promoting generative work is aligned strongly with constructivist epistemologies.[96] And for all that has been written and said about classroom assessment methods, we think it is useful for instructors to realize that we ask our students to teach us—that is, to generate an explanation—when they answer questions on our examinations.[97] In all cases, whether an exam is in written or oral format, an instructor takes on the student role as questioner and learner, while the student is the one who provides explanations. Yet concrete, explicit opportunities for students to build the skills for this role-reversal are rarely provided. In principle, writing a report, giving a presentation, and taking exams are all capable of doing this job, yet in practice students spend much time delivering answers. In order to emphasize the role that teaching, as well as preparing to teach, can have in the learning process, we have actively promoted ways for students to practice their teaching skills before the examination. These ideas are strongly aligned with the principles of reciprocal teaching,[98-101] and especially with work on the power of explanatory knowledge.[102-105] Learning environments need to include structured opportunities for students to reflect on their learning in ways that specifically develop their interpersonal communication skills, understanding that by doing so they can develop explanatory knowledge. Technologies that enhance the ability for student-generated explanations coupled with pedagogies that promote reflective critique should, in theory, enhance student learning.

Some of the relevant instructional goals for the second-term course were for students to: (1) more fully appreciate the molecular dynamic change in chemical reactions;

(2) learn how to correlate graphic and tabular spectroscopic data with molecular structure; (3) increase confidence in assigning meaning from reading primary writing (eg, journals); (4) promote multirepresentational modes of communication with decision making.

Instructional Intervention

The HTML Project. This was a term-long project that assigned during the special section of the second-term "Structure and Reactivity" course. The class is naturally subdivided into SSG sections of 15-18 students. Within each SSG, smaller study groups) of 3-4 students were created. Each SSG took ownership of a journal article selected by the faculty instructor for the appropriateness of its content to the general subject matter of the course. During the first SSG meetings of the term, students received the following instructions:

> *After using written and oral presentations within your SSGs for each of the items listed below, you will construct a Web site that integrates the hypertext versions of all of the following into a single document for your entire class [the assembly of smaller study groups into the SSGs (larger groups, under a leader), and the collection of SSGs into the whole class]. Both Web and print versions will be required. You will also have the opportunity to burn an archival copy of the Web site on a CD-ROM disk.*
>
> *(1) Describing, in a brief paragraph, the chemistry of your step.*
> - *What kinds of reactions are taking place?*
> - *What is the overall change? What precedents are there for the change?*
> - *What kinds of interesting selectivities or other features were part of your transformation?*
> - *Each smaller study group has a few trigger questions about some of the chemistry represented in their step.*
>
> *(2) Creating an animation for the mechanism of the transformation(s).*
>
> *(3) Creating a correlation between:*
> - *the proton NMR spectrum of the product and its structure (for example: click or mouse-over an absorption signal indicates the hydrogen atom group, and vice versa).*
> - *the carbon NMR spectrum of the product and its structure (click or mouse-over an absorption signal indicates the carbon atom group, and vice versa). the text of the experimental section that described the preparation of the product in your sequence and any terms, procedures or apparatus that are unfamiliar to you and/or your class in general.*

In order for the students to accomplish the goals of this project, they needed to master and combine a number of pieces of software, namely, ChemDraw (to represent molecules in 2-D line formulas), Chem3D (to create 2.5-D or stereoscopic images), CAChe (to create computationally valid molecular structural drawings), Photoshop or other appropriate graphics program (to manipulate the images), GifBuilder (to combine images into animations), in addition to whatever Java and HTML templates might be used by individuals. The students within the smaller study groups were responsible for working through the chemistry that they are assigned so that they could present their understanding, orally and in writing, to their SSG for review and feedback. The groups also had to decide on every aspect of the design in how they were going to represent the work to each other (and the world) at the course Web site.

Why did they study the whole site at all? The site is a complex artifact of student work on sophisticated chemistry explanations. In order to provide more purpose than just another artifact of student learning, the site (and its print version) has significance to the course. From the start, the students knew that the final examination in the course would be based on the student-generated text and hypertext. Furthermore, the instructor used the student work to construct exam questions based on the inevitable, and expected, errors that would remain in the work. This method of testing has been a successful device for transmitting 2 important lessons. First, that one should always have a critical eye when encountering text and hypertext. Second, that true ownership of one's education is possible, even if it means deconstructing 1 of the most central elements in a science course: the textbook.

Student Outcomes

Two of our 4 goals—to more fully appreciate the molecular dynamic change in chemical reactions and to learn how to correlate graphic and tabular spectroscopic data with molecular structure—were explicitly structured in the assignment and made visible by the student work. This site, its accompanying text, and its use constituted an authentic form of student assessment. Indeed, there were many layers of assessment built into the project. One of them was peer-to-peer during the construction of the Web pages. The SSG leaders and the instructor provided another as the pages were examined. In their study for the final examination, these classes spontaneously decided that they needed to meet as a class to rely on each other's expertise as the authors of the work. Interestingly, a group of faculty members from around the United States have told us that they use our students' work as the basis of assignments in their own courses. Well beyond an inquiry into our students' mastery of the chemistry subject matter, this project also allowed the student leaders, through their monitoring of the group work, to assess questions like independence, reliability, and ownership, all of which figured into the evaluation component.

To achieve our third goal, to increase confidence in assigning meaning from reading primary writing in journals, we turned to 2 sources. At least 40%-60% of the chemistry in these journal articles is outside the formal scope of the course, yet semester after semester these students learn how to access and address how to solve the problem of understanding this material. Do they do it perfectly? No. Could they be more systematic? Yes. But the palpable sense of ownership they have of their learning is more than worth a few errors in the final presentation; it's a value judgment. We also turned to our departmental colleagues to report back from their experiences with these students as they entered their research groups. A few years ago, 1 colleague captured his sense of these students as having "naïve courage—they do not know how to do everything, of course, but they are convinced that with a little work and some articles to read they really do think they can do it."

Finally, the fourth goal: to promote multirepresentational modes of communication with concurrent decision making. We are currently developing a methodology based on the tools of discourse analysis that will allow us to analytically assess the drawings of chemical phenomena created by students in order to determine how well their representational skills are mapping toward an expert conception, as indicated by their representational choices. Our method is to create a thematic diagram,[106] which is a metarepresentation that facilitates comparisons of different types of student work. Thematic diagrams can be used to code, and converge, textual or pictorial representations. A thematic diagram of Grant Woods' "American Gothic" would have features (farmer, coveralls, glasses, farmer's wife, pitchfork, cross, tines, etc) whose relationships to each other define them and comprise a theme (eg, the tines of the pitchfork, as opposed to the tines of a dinner fork; the cross on the building

Table 2. Student Outcomes From Chemistry Case

1. Appreciate the molecular dynamic change in chemical reactions.
2. Correlate graphic and tabular spectroscopic data with molecular structure.
3. Increase confidence in assigning meaning from reading primary writing (journals).
4. Use multirepresentational modes of communication.

behind the figures, as opposed to a cross string around the neck of farmer's wife, etc). Once coded, the features and their relationships from different students' representations can be quantitatively compared to each others and to those of experts, enabling us to answer previously unanswerable questions about how well a student's ability to draw chemistry visuals is progressing, or how different interventions might be affecting student learning. While the details of these analyses are beyond the scope of this article, our preliminary results are quite encouraging. Table 2 summarizes the student outcomes for the chemistry case.

Reflective Observations

After creating a somewhat detailed outline for this manuscript, the authors generated their own individual contributions using that rubric. We agreed to write our cases independently, and then to exchange these drafts for mutual commentary only after the drafts were completed, so as not to bias the writing of the author's own case by the reading of the other. In this section, we report the reflections from each author on each other's case.

Physical Therapists' Reflective Observations

Upon reflection, I thought that an amazing number of similarities existed between the 2 cases that significantly outweighed the differences. For example, both instructors embedded technology within an assignment that had a clear educational objective for skill attainment. Also, objectives were stated for both the technological element or desired skill. The professors required students to learn to use a technology (HTML or Blackboard) to complete an assignment. For both disciplines (physical therapy and chemistry), the technology made explicit a student's thinking about an assignment. For example, if a student posted written comments to a discussion board they made their thinking about a topic of interest public for both the instructor and their peers. Another strategy implemented by both instructors was the use of student teams and collaboration to complete an assignment.

A similarity was the use by both professors of multiple communication modes: computer, face-to-face, and written as part of a single assignment. In addition, both instructors relied on multiple layers of grading that related to each assignment. The layers included conducting a critique of a research article using face-to-face, virtual chat, and large group recitation in the physical therapy example. For the chemistry example, the layers of assessment included building a Web site to visualize a chemical property that was peer, and instructor assessed.

One difference between the 2 instructors was that the chemistry professor used peer mentors and peer assessment while the physical therapy professor required self-assessment through reflective journaling on learning and skill acquisition. Another difference noted was the use by the chemistry professor of student work as the basis of examination to promote student ownership of work, and careful examination of work for errors. Yet another concerned the reciprocal learning opportunity provided regarding activities that promoted thinking about the process teaching for the chemistry students, peer, and instructors.

The Chemist's Reflective Observations

I am continually struck by the fundamental similarities that emerged about educational goals when faculty members get the opportunity to share detail about how they design learning environments. Yet, at the same time, our colleagues at the Carnegie Foundation are also examining the differentiating educational practices that Shulman labeled the "signature pedagogies" of the professions (distinctive, pervasive, and found across institutions). Is this a matter of all roads leading to Rome? In identifying and articulating instructional goals, and in seeing their convergence between our clearly different disciplines, I found support for Shulman's original notion of pedagogical content knowledge (PCK). In the context of PCK, distinctive differences in the subject matter might mean that the pedagogical choices a chemist makes for achieving a given instructional goal would not be expected to align with the choices a PT would make for achieving the same goal. On the other hand, the instructional goals themselves were robust and (perhaps) immune to disciplinary differences.

The chemistry and physical therapy populations could not have been more different: a group of first-year, undeclared undergraduates in an introductory chemistry course, nearly none of whom were interested in joining the profession, and a group of fifth-year preprofessionals in a course where, I presume, 100% of them were long-committed to becoming practicing physical therapists. But the goals were nearly the same, and the pedagogical philosophical strategies were more alike than different. The PT education faculty member wanted students to "demonstrate effective communication skills: verbal, written, presentation, computer and listening"; and the chemist wanted to "promote multi-representational modes of communication with decision-making." The PTH1405 course required students to "analyze the medical and scientific literature," and the SSG program had as 2 explicit learning goals related to the literature "to increase confidence in assigning meaning from reading primary writing (journals)" and "to learn how to correlate graphic and tabular spectroscopic data with molecular structure."

Interestingly, there were differences that arose around the expectations of how the technology could be used because the experiences in the student populations appeared to be significantly different. Two of the 3 goals for the PT course involve students' behavior and comfort with learning in such an environment ("For all 57 students, this was a first encounter with a Web-enhanced course."), while (unstated) around 50% of the chemistry students have experience constructing fairly sophisticated Web pages, with nearly all (but not 100%) of the others highly motivated to learn this, in particular. Also unstated, but an important reminder from reading the PTH1405 description, was the goal of having students encounter and debate the etiquette questions when working in these environments. For a full week as the students posted and tested their instructional Web pages, they had open access to all other students' work, and the temptation was high to pull a prank on a friend's Web page, as we once learned the hard way.

I think that both projects drew from a pedagogical content knowledge perspective, that is, what was being proposed in using technology was aligned with explicit instructional goals and derives from a deep understanding of the subject matter. The answers to the question, why is achieving this or that goal best accomplished with these environments and not others, is probably still not explained by either report as well as it could be, but the hints are there. Clearly, when technological literacy is an explicit goal, then using technology is required. In both cases, however, the students also had assignments that were "technology-embedded" rather than "technology-supplemented," and the affordances of the technology permitted the student to make their thinking visible for open review and critique by the community—or even the world.

The push-back from students reported by the physical therapist educator also matched an unreported experience from chemistry. When the technology did not appear to enhance or improve the nontechnology- or alternative technology-based task, students resisted: "Our participants indicated that virtual chat was viewed as duplicative. . . ." In a spin-off project to bring sophisticated Web-based, Web-delivered, student-generated materials comparable to those created in the HTML project, we collaborated with instructional technology experts to develop a "1-stop shopping" software tool called ChemSense, with which students can author pages, construct chemistry animations, and engage in peer review. The students resisted and rebelled in using the aspects of this program that duplicate what can be done with a standard software tool, and so we had to narrowly assign ChemSense to those tasks for which ChemSense is superior to the other choices.

Table 3. A Proposed Set of Transcendent Pedagogical Principles About Instructional Technology

1. Embedding instructional technology as a vehicle for embedding assignments needs to make sense in the context of other methodological choices.
2. Learning an instructional technology and its appended etiquettes should be their own explicit, pedagogical goals when using an instructional technology.
3. Using complex texts, such as the primary literature, creates a high-level challenge for which "open source" discussion and peer commentary is particularly effective because its authority is, in fact, constructed by a community rather than by dogma.
4. The link between using an instructional technology and the instructional goal, which is a statement of pedagogical content knowledge, should be transparent and should make sense. An instructor should be able to explain why X is the best method to accomplish the stated learning goal and why other methods might not be—particularly if there appears to be a simpler, equally effective, or more generally applicable methodology available, because students will see this as a potential distraction.
5. Embedded in the pedagogical approaches were mechanisms for both individual and concurrent reflection stimulated by the opportunity to view the work of others.

DISCUSSION

Our project had 2 purposes. The following sections will present the outcomes for each purpose, an evaluation of goal attainment, and a discussion of the implications for physical therapist and chemist education.

Technology as Pedagogy to Transcendent Pedagogy

Historically, a faculty member in physical therapy/chemistry might never have attended a presentation about instructional design and implementation given by a physical therapist /chemist. Indeed—and we mean this to be a criticism, 1 of the reasons would be "what could I possibly learn that would be relevant to me in my teaching by listening to someone in [X discipline]; they do not have the same issues to deal with," etc? As a comparative process, then, how do we move from highly contextualized details—"signature pedagogies," not only of a profession, but of 2 individuals—to something that might constitute knowledge about instructional technology that can be generalized and that can be taken away from these 2 cases? One proposition would be that such a cross-disciplinary comparison would make clearer the ideas that we could see the general familiarity in each other's work that transcends the discipline—dare we say "transcendent pedagogies"?—precisely because the disciplinary details would be automatically irrelevant as we looked at the cases, leaving the pedagogical principles as a framework on which others might hang their own details.

We constructed our contributions to this article separately yet together. In writing our cases, neither of us read the others in advance of writing our own. We literally had no idea about the nature of the application of instructional technology about which each would write. In commenting on each other's cases, for instance, neither of us read the other person's comments in advance of writing our own. Any convergence in reading and reporting, then, is at least a genuine reflection of what we saw in each other's work rather than what we told each other to think about it.

Table 3 contains a set of transcendent pedagogical principles that we inferred from reading and commenting on our cases.

Model: Disentangling the Pedagogies (Figure 1)

The diversity of instructional needs and objectives creates a familiar tension in formal education between training students in the technical content of the disciplines and the more overarching educational values. One might see this tension as a tangling of 3 highly linked pedagogical objectives.[107] Overarching educational values might be called the *general intellectual* objectives for education. In contrast, *professional intellectual* objectives are the overarching values for a more-specific literacy at the disciplinary level (ie, chemistry, biology, or science). Instructors need to explicitly attend to the connection between the *professional* and *general* intellectual objectives, namely, to answer how learn-

Figure 1. Percent Agreement SOTL Considered as Service in Promotion or Tenure Decisions

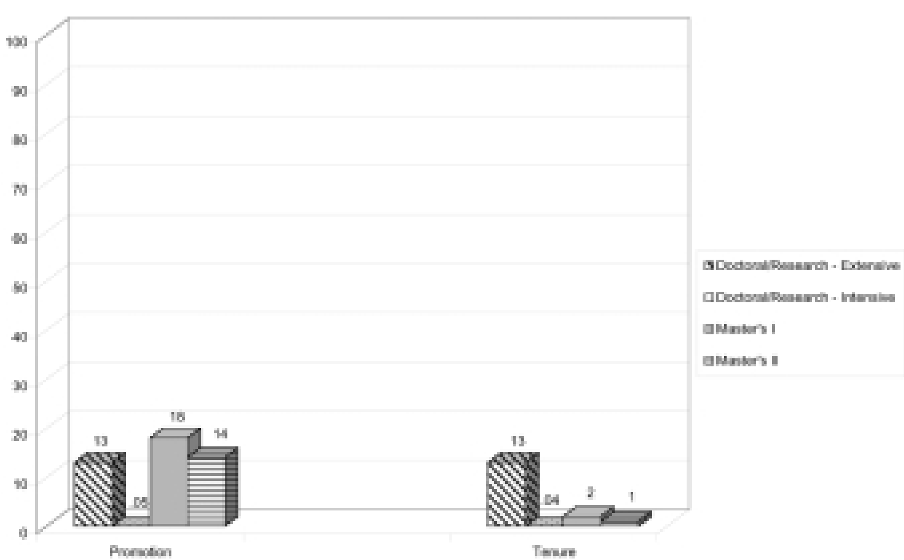

Table 4. Categories for Pedagogical Objectives

General Intellectual Objective	Critical thinking, reflective analysis, effective communication.
Professional Intellectual Objective	Read and transform data-based research reports on (a) natural chemistry phenomena, or (b) the practice of physical therapy. Professional interactions with peers or clients.
Professional Technical Objective	Construct an animation that explains an understanding of the Diels-Alder cycloaddition reaction, or examine the relative merits of manipulation/mobilization therapies in treating LBP.

ing science is connected to a liberal education. Lastly, individual courses are embedded within the richness of *professional technical* objectives, that is, the factual subject matter that typically comprises a written syllabus or table of contents. Technological progress in the disciplines and the detailed articulation of the *professional technical* subject matter should be exploited in order to make clear connections about how learning triple integrals or translating Goethe is not only representative of *professional intellectual* objectives, but also addresses *general intellectual* ones (Table 4).

We propose here that these might not only be 3 categories of pedagogical objectives, but also of pedagogies, and that the process of comparison and reflective reading that we have described here might be a way to disentangle the more general lessons (*general intellectual pedagogies*, or *transcendent pedagogies*) from those more highly embedded in the details of the profession or discipline: *professional intellectual pedagogies* that aim at the epistemological workings of a profession, and the *professional technical pedagogies* that aim at the highly contextualized learning of the subject matter itself, both of which may constitute Shulman's notion of *signature pedagogies*.[108]

Interdisciplinary Community of Practice

The 2 instructors in this article shared their ideas about teaching and assessment regarding the use of educational technology. Through concurrent reflection they became a community of practice dedicated to sharing their challenges arising from teaching with technology.

A learning community involves an active teaching–learning process that promotes the development of "learning relationships."[109] Learning communities are defined by 4 basic traits: Learning is situated among individuals who share meaning and ideas; learning is related to community members' experiences; learning relates to the context of society as well as the groups' collective history; and the content of the learning is valued by members.[109] Members of a learning community, who may have different levels of experience, collectively dialogue, share experiences, and learn about topics of interest.[110] A learning community is organized to reflect a horizontal rather than vertical structure to allow each individual a voice in a discussion.[110] A learning community becomes a community of practice (CoP) when members are interconnected by a future-oriented, shared learning goal. A CoP values "individuality over conformity,"[110(p79)] and recognizes the benefit afforded by a team approach to problem solving.[111] A CoP can occur among members at a designated location or bridge geographic boundaries through Internet technology. Within the physical therapy profession, a CoP enables participants to dialogue from multiple perspectives about clinical practice in its complexity. When dialogue is amplified by reflection that is both individual and collective, shared meaning and understanding develops about a topic of interest.[112] As supported by the literature, this CoP dialogue illustrates a discussion that builds on itself and lends different perspectives on a complex issue of interest.[110]

Limitations

A limitation of our work is that it represented the SoTL experience of 2 professors from 2 disciplines engaged in an interprofessional partnership. These factors may or may not have limited the potential to generalize our findings to a wider audience of disciplines, SoTL experiences, or partnerships. To find commonalities that resonate so strongly in a relatively randomly formed pair might suggests that *transcendent pedagogies* are a robust companion to *signature pedagogies* in describing a more complete picture of instruction. Indeed, valuable information was generated that supports the use of individual and collective reflection buttressed by dialogue about teaching and learning outcomes related to the use of technology to promote student attainment of educational goals. Some challenges that remain include sustainability of the interprofessional collaboration to continue to support peers, who also desire to develop a SoTL program. Opportunities for meaningful interprofessional dialogue are still mainly serendipitous, regardless of how much value one finds in them.

DISCUSSION AND CONCLUSION

Technological literacy is required by employers of students of any discipline. The prevalence of technology options has required that educators consider adding technology to their choices of pedagogy.[6] Moreover, educators have little time to reflect on their teaching and learning experiences. Bringing educators representing different disciplines together to dialogue about teaching–learning approaches may decrease the isolation experienced by professors working alone. Our project was designed to provide opportunities for professors of different disciplines to reflect individually and collectively to learn from each other. Personal reflection on the experience increased educators' awareness of the need for conducting research on their teaching. They became a dedicated learning community of faculty committed to an intellectually stimulating dialogue leading to new approaches to academic problems and to crosspollination of ideas and practices. Participation in the community not only provided support for research development, but also for personal development. Concurrent reflection by more than 1 discipline has the potential to illuminate and expand one's thinking and open new possibilities for the use of technology and innovative pedagogy, irrespective of discipline. More research is indicated to study how faculty of diverse disciplines can share and learn from each other.

REFERENCES

1. Boyer EL. *Scholarship Reconsidered: Priorities of the Professoriate*. Princeton, NJ: Carnegie Foundation for the Advancement of Teaching; 1990.
2. The Carnegie Foundation for the Advancement of Teaching. Available at: www.carnegiefoundation.org. Accessed August 31, 2005.
3. Hakim MA. Navigating the Web of discourse on the scholarship of teaching and learning: an annotated Webliography. *College Res Library News* [serial online]. July/August 2002;63:1. Available at: www.ala.org/ala/acrl/acrlpubs/crlnews/backissues2002/julyaugust/scholarshipteaching.htm. Accessed August 31, 2005.
4. Bernstein D, Bass R. The scholarship of teaching and learning. *Academe* [serial online]. July/August 2005;91(4). Available at: www.aaup.org/publications/Academe/2005/05ja/05jabass.htm. Accessed August 31, 2005.
5. Glassick CE, Huber MJ, Maeroff GI. *Scholarship Assessed: Evaluation of the Professoriate*. San Francisco, Calif: Jossey-Bass; 1997.

6. Palloff RM, Pratt K. *Lessons from the Cyberspace Classroom: The Realities of Online Teaching*. San Francisco, Calif; Jossey-Bass; 2001.
7. Schmoll BJ, Moses YT. Responding to change and forces in higher education. *J Phys Ther Educ*. 2002;16(3):14-22.
8. *A Normative Model of Physical Therapy Professional Education: Version 2004*. Alexandria, Va: American Physical Therapy Association; 2004:112.
9. Fowler K. Motivating and managing the generations. *PT—Magazine of Physical Therapy*. 2004;12(3):34-40.
10. Plack MM. Computer-assisted instruction versus traditional instruction in teaching gross anatomy. *J Phys Ther Educ*. 2000;14(1):38-43.
11. Anderson JC, Conley LK. Retention of anatomic detail. *J Phys Ther Educ*. 2000;14(1): 44-47.
12. Boucher B, Hunter D, Henry J. The effectiveness of computer-assisted instruction in teaching biomechanics of the temporomandibular joint. *J Phys Ther Educ*.1999;13(2):47-51.
13. Berube D, Murray C, Schultze K. Cadaver and computer use in the teaching of gross anatomy in physical therapy education. *J Phys Ther Educ*.1999;13:41-46.
14. Lim HH, Marriott DA, Potter PD, Clayton-Krasinski D. Comparison of two methods of training student physical therapists to score the gross motor function measure. *Pediatr Phys Ther*. 2000;12:127-132.
15. Hayward LM, Kranz TM, Evans SM, DiMarco R. Telementoring an innovative teaching method for stimulating the conversation of practice. *J Phys Ther Educ*. 2001;15(3):57-66.
16. Hayward LM, DiMarco R, Blackmer B, Canali A, Wong K, O'Brien M. Curriculum based electronic peer mentoring: an instructional strategy for integrative learning. *J Phys Ther Educ*. 2001;15(4):14-25.
17. Hayward LM. Integrating Web-enhanced instruction into a research methods course: examination of student experiences and perceived learning. *J Phys Ther Educ*. 2004; 18(2):54-65.
18. Fry-Welch DK. Use of threaded discussion to enhance classroom teaching of critical evaluation of the professional literature. *J Phys Ther Educ*. 2004;18(2):48-53.
19. Coyne C. Electronic education and distance learning: pioneer t-DPT programs report. *PT—Magazine of Physical Therapy*. 2002; 10(5):40-45.
20. English T, Harrison AL, Hart AL. A distance learning model in a physical therapist curriculum. *J Allied Health*. 1998;27:228-232.
21. Cook CE, Merrifield HH. Distance learning outcomes of Texas Tech University's physical therapy program. *J Phys Ther Educ*. 2003; 17(3):74-77.
22. Rodriquez JW. Technology in clinical education: a new method of conducting clinical site visits. *J Phys Ther Educ*. 2002;16(1):69-75.
23. Hiltz SR. The "virtual classroom": using computer-mediated communication for university teaching. *J Commun*. 1986;36:95-104.
24. Dille B, Mezack M. Identifying predictors of high risk among community college telecourse students. *Am J Distance Educ*. 1991; 5:11-19.
25. Becker D, Dwyer M. The impact of student verbal visual learning style preference on implementing groupware in the classroom. *J Asynchronous Learning Networks* [serial online]. September 1998;2(2). Available at: www.sloan-c.org/publications/jaln/v2n2/index.asp.Accessed August 31, 2005.
26. Treadwell TW, Leach EA, Kellar H, Lewis R, Mittan B. Collaborative learning over the Internet. *J Manage Educ*. 1998;22:498-508.
27. Thiele JE, Allen C, Stucky M. Effects of Web-based instruction on learning behaviors of undergraduate and graduate students. *Nurs Health Care Perspect*. 1999;20:199-203.
28. Hayward LM. When technology bites back: A case report describing an instructor's experience with online teaching. *J Phys Ther Educ*. 2003;17(1):48-54.
29. EduCom. Available at: www.educom.com. Accessed August 31, 2005.
30. Pea RD. Augmenting the discourse of learning with computer-based learning environments. In: de Corte E, Linn M, Verschaffel L, eds. *Computer-based Learning Environments and Problem-Solving* (NATO Series, subseries F: Computer and System Sciences). New York, NY: Springer-Verlag GmbH; 1992:313-343.
31. Pea RD. Seeing what we build together: distributed multimedia learning environments for transformative communications. *J Learning Sci*.1994;3(3):283-298.
32. Gillard S. IT educators and IT adoption issues. *J Issues Informing Sci Information Technol*. 2004;1:805-811.
33. *J Issues Informing Sci Information Technol*. Available at: http://iisit.org/vol1.htm. Accessed August 31, 2005.
34. Hein TL. Using student writing as a research and learning tool. *AAPT Announcer*. 1998; 27(4):79.
35. Calibrated Peer Review (CPR). Available at: http://cpr.molsci.ucla.edu. Accessed August 31, 2005.
36. Robinson R. Calibrated Peer Review™: an application to increase student reading and writing skills. *Am Biol Teacher*. 2001; 63(7):474.
37. Russell A, Chapman O, Wegner P. Molecular science: network-deliverable curricula. *J Chem Educ*. 1998;75(5):578-579.
38. National Science Digital Library. Available at: http://nsdl.org. Accessed August 31, 2005.
39. Coleman WF, Fedosky EW. Additions to our open peer-reviewed and open collections *J Chem Educ*. 2003;80(11):1351.
40. Roth WM, Woszczyna C, Smith G. Affordances and constraints of computers in science education. *J Res Sci Teaching*.1996; 33(9): 995-1017.
41. Songer NB, Lee HS, Kam R. Technology-rich inquiry science in urban classrooms: what are the barriers to inquiry pedagogy? *J Res Sci Teaching*, 2002;39(2):128-150.
42. Zhao Y, Pugh K, Sheldon S, Byers J. Conditions for classroom technology innovations. *Teachers Coll Rec*. 2002;104(3):482-515.
43. Clark RE. Reconsidering research on learning from media. *Rev Educ Res*. 1983;5:445-459.
44. Clark RE. Media will never influence learning. *Educ Technol Res Dev*. 1994;42:21-29.
45. Kozma RB Learning with media. *Rev Educ Res*.1991;61:179-211.
46. Kozma RB. Will media influence learning? Reframing the debate. *Educ Technol Res Dev*. 1994;42:7-19.
47. Coppola BP, Kiste AL. Evaluating technologies for student-generated work in a peer-led, peer-reviewed instructional environment. Paper presented at: Proceedings of the 2004 International Conference on Advances in Infrastructure for Electronic Business, Science, and Education on the Internet; 2004; Loreto Aprutina, Italy.
48. Cole RS, Todd JB. Effects of Web-based multimedia homework with immediate rich feedback on student learning in general chemistry. *J Chem Educ*. 2003;80(11):1338-1344.
49. Freasier B, Collins G, Newitt P. A Web-based interactive homework quiz and tutorial package to motivate undergraduate chemistry students and improve learning. *J Chem Educ* 2003;80(11):344-1347.
50. Pienta NJ. A placement examination and mathematics tutorial for general chemistry. *J Chem Educ*. 2003;80(11):1244-1247.
51. Bartholow M. Using chemistry comes alive! in the classroom *J Chem Educ*. 2004;81(7):951.
52. Wamser CC. E-mail molecules—individualizing the large lecture class. *J Chem Educ*. 2003;80(11):1267-1270.
53. Yang EM, Greenbowe TJ, Andre T. The effective use of an interactive software program to reduce students' misconceptions about batteries. *J Chem Educ*. 2004;81(4):587-595.
54. Krajcik J, Marx R, Blumenfeld P, Soloway E, Fishman B. Inquiry based science supported by technology: achievement among urban middle school students. 2000. Available at: http://hi-ce.org/papers/2000/inquiry_based_science_supported/Krajcik_AERA00. pdf#search='Inquiry%20based%20science%20supported%20by%20technology:%20achievement%20among%20urban%20middle%20school%20students'. Accessed August 31, 2005.
55. White BY, Frederiksen JR. Inquiry, modeling, and metacognition: making science accessible to all students. *Cogn Instruction*. 1998; 16(1):3-118.
56. Williams M, Linn MC. WISE inquiry in fifth-grade biology. *Res Sci Educ*. 2002; 32(4):415-436.

57. Ardac D, Akaygun S. Effectiveness of multimedia-based instruction that emphasizes molecular representations on students' understanding of chemical change. *J Res Sci Teaching.* 2004;41(4):317-337.

58. Barnea N, Dori Y J. Computerized molecular modeling as a tool to improve chemistry teaching. *J Chem Information Comput Sci.* 1996; 36(4):629-636.

59. Lewalter D. Cognitive strategies for learning from static and dynamic visuals. *Learning and Instruction.* 2003;13:177-189.

60. Triona LM, Klahr D. Point and click or grab and heft: comparing the influence of physical and virtual instructional materials on elementary school students' ability to design experiments. *Cogn Instruction.* 2003;21(2):149-173.

61. Barnea N, Dori YJ. High-school chemistry students' performance and gender differences in a computerized molecular modeling learning environment. *J Sci Educ Technol.* 1999; 8(4):257-271.

62. Burke KA, Greenbowe TJ, Windschitl MA. Developing and using conceptual computer animations for chemistry instruction. *J Chem Educ.* 1998;75(12):1658-1661.

63. Roth WM. Affordances and constraints of computers in science. *J Res Sci Teaching.* 1996;33(9):995-1017.

64. Roth WM, Bowen GM. Of cannibals, missionaries, and converts: graphing competencies from grade 8 to professional science inside (classrooms) and outside (field/laboratory). *Sci, Technol, Hum Values.* 1999;24(2):179-212.

65. Sanger MJ, Greenbowe TJ. Addressing student misconceptions concerning electron flow in aqueous solutions with instruction including computer animations and conceptual change strategies. *Int J Sci Educ.* 2000; 22(5):521-537.

66. Wu HK, Krajcik JS, Soloway E. Promoting conceptual understanding of chemical representations: students' use of a visualization tool in the classroom. *J Res Sci Teaching.* 2001; 38(7):821-842.

67. Beall H, Prescott S. Concepts and calculations in chemistry teaching and learning. *J Chem Educ.* 1994;71:111-112.

68. Francisco JS, Nakhleh MB, Nurrenbern SC, Miller ML. Assessing student understanding of general chemistry with concept mapping. *J Chem Educ.* 2002;79(2):248-257.

69. Nakhleh MB, Mitchell RC. Concept learning versus problem solving. *J Chem Educ.* 1993; 70:190-192.

70. Nurrenburn S, Pickering M. Concept learning versus problem solving: is there a difference? *J Chem Educ.* 1987;64:508-510.

71. Pickering M. Further studies on concept learning versus problem solving. *J Chem Educ.* 1990;67:254-255.

72. Sawrey BA. Concept learning versus problem solving: revisited. *J Chem Educ.* 1990;67: 253-254.

73. Ben-Zvi R, Eylon B, Silberstein J. Theories, principles and laws. *Education in Chemistry.* May 1988;25:89-92.

74. Gabel D. The complexity of chemistry and implications for teaching. In: Fraser BJ, Tobin KG, eds. *International Handbook of Science Education.* Great Britain: Klewer Academic Press; 1998:233-249.

75. Keig PF, Rubba PA. Translation of representations of the structure of matter and its relationship to reasoning, gender, spatial reasoning, and specific prior knowledge. *J Res Sci Teaching.* 1993;30(8):83-903.

76. Kozma RB. The use of multiple representations and the social construction of understanding in chemistry. In: Jacobson MJ, Kozma RB, eds. *Innovations in Science and Mathematics Education.* Mahwah, NJ: Lawrence Erlbaum; 2000:11-46.

77. Kozma RB, Chin E, Russell J, Marx N. The roles of representations and tools in the chemistry laboratory and their implications for chemistry instruction. *J Learning Sci.* 2000; 9(2):105-143.

78. Copolo CF, Hounshell PB. Using three-dimensional models to teach molecular structures in high school chemistry. *J Sci Educ Technol.* 1995;4(4):295-305.

79. Hayward L. Becoming a self-reflective teacher: a meaningful research approach. *J Phys Ther Educ.* 2000;14(10):21-30.

80. Guillaume AM, Rudney GL. Student teachers' growth toward independence: an analysis of their changing concerns. *Teaching & Teacher Educ.* February 1993;9(1):65-80.

81. Adler AL. Teacher education: research as reflective practice. *Teaching & Teacher Educ.* April 1993;9(2):159-167.

82. Osterman KF. Reflective practice: a new agenda for education. *Educ Urban Soc.* February 1990;22(2):133-152.

83. Lytle SL, Cochran-Smith M. Teacher research as a way of knowing. *Harvard Educ Rev.* 1992;62:447-474.

84. Brodkey JJ. Learning while teaching: possibilities and problems. *Teacher Educ Q.* 1993;20: (1)63-70.

85. Schön DA. *The Reflective Practitioner: How Professionals Think in Action.* New York, NY: Basic Books Inc; 1983.

86. Shepard KF, Jensen GM. Physical therapist curricula for the 1990s: educating the reflective practitioner. *Phys Ther.* 1990;70:566-577.

87. Jensen G, Denton B. Teaching physical therapy students to reflect: a suggestion for clinical education. *J Phys Ther Educ.* 1991;5(1):33-38.

88. Coppola BP, Jacobs D. Is the scholarship of teaching and learning new to chemistry? In: Huber M T, Morreale S, eds. *Disciplinary Styles in the Scholarship of Teaching and Learning. A Conversation.* Washington, DC: American Association of Higher Education and The Carnegie Foundation for the Advancement of Teaching; 2002:197-216.

89. Dewey J. *How We Think: A Restatement of the Relation of Reflective Thinking to the Educative Process.* Chicago: DC Heath and Co; 1933.

90. Mostrom E. Reconsidering scholarship in physical therapy education [editorial]. *J Phys Ther Educ.* 2003;17(2):2-3.

91. Human SE, Kilbourne LM, Clark TD, Shriberg A, Cummingham B. Using Web-enhanced instruction in an interpersonal skills course. *J Manage Educ.* 1999;23 (5):584-606.

92. Ege SN, Coppola BP, Lawton RG. The University of Michigan undergraduate chemistry curriculum 1. philosophy, curriculum, and the nature of change. *J Chem Educ.* 1997; 74(1):74-83.

93. Coppola BP, Ege SN, Lawton RG. The University of Michigan undergraduate chemistry curriculum 2. instructional strategies and assessment. *J Chem Educ.* 1997;74(1):84-94.

94. Coppola BP, Daniels DS, Pontrello JK. Using structured study groups to create chemistry honors sections In: Miller J, Groccia J E, DiBiasio D, eds. *Student Assisted Teaching and Learning.* New York, NY: Anker; 2001:116-122.

95. Varma-Nelson P, Coppola BP. Team learning. In: Pienta N, Cooper MM, Greenbowe T, eds. *A Chemist's Guide to Effective Teaching.* Saddle River, NJ: Pearson; 2005:155-169.

96. Wittrock M. Generative learning processes of the brain. *Educ Psychol.* 1992;27(4):531-451.

97. Coppola BP. Reaction to the symptoms versus reaction to the disease. In: Millar SS, ed. *Proceedings From Indicators of Success in Postsecondary SMET Education: Shapes of the Future.* National Institute for Science Education: Madison, Wisc; 1998. Available at: www. wcer.wisc.edu/archive/nise/Publications. Accessed August 31, 2005.

98. Palincsar AS, Brown AL. Reciprocal teaching of comprehension-fostering and comprehension-monitoring activities. *Cogn Instruction.* 1984;1(2):117-175.

99. Palincsar AS. Reciprocal teaching. In: *Teaching Reading as Thinking.* Oak Brook, Ill: North Central Regional Educational Laboratory; 1986.

100. Brown AL, Palincsar AS. Guided, cooperative learning and individual knowledge acquisition. In: Resnick LB, ed. *Knowing, Learning, and Instruction: Essays in Honor of Robert Glaser.* Hillsdale, NJ: Lawrence Erlbaum Associates; 1989:393-451.

101. Palincsar AS, Klenk LJ. Dialogues promoting reading comprehension. In: Means B, Chelemer C, Knapp MS, eds. *Teaching Advanced Skills to At-Risk Students.* San Francisco, Calif: Jossey Bass; 1991.

102. Brown AL. Design experiments: theoretical and methodological challenges in creating complex interventions in classroom settings. *J Learning Sci.* 1992;2(2):141-178.

103. Coleman EB. Learning by explaining: fostering collaborative progressive discourse in science. In: Beun RJ, Baker MJ, Reiner M, eds. *Natural Dialogue and Interactive Student Modelling*. Berlin, Germany: Springer-Verlag; 1995:123-135.

104. Coleman EB, Brown AL, Rivkin I. The effect of instructional explanations on learning from scientific texts. *J Learning Sci*. 1997; 6(4):347-365.

105. Coleman EB. Using explanatory knowledge during collaborative problem solving in science. *J Learning Sci*. 1998;7(3&4):387-427.

106. Lemke JL. *Talking Science: Language, Learning, and Values*. Norwood, NJ: Ablex Publishing; 1990.

107. Kovac J, Coppola BP. Universities as moral communities. *Soundings: An Interdisciplinary J*. 2000;83:765-779.

108. Shulman L. The signature pedagogies of the professions of law, medicine, engineering, and the clergy: potential lessons for the education of teacher. paper presented at: "Teacher Education for Effective Teaching and Learning" workshop hosted by the National Research Council Center for Education, February 8, 2005. Available at: http://hub.mspnet.org/index.cfm/11172. Accessed August 31, 2005.

109. Oakes J, Lipton M. *Teaching to Change the World*. New York, NY: McGraw Hill; 1999.

110. Howard A, Kennedy-England E S. Transgressing boundaries through learning communities. *J Cooperative Educ*. 2001;36(1): 76-82.

111. Doty EA. Organizing to learn: recognizing and cultivating learning communities. *Semin Nurse Managers*. 2002;10(3):196-205.

112. Lave J, Wenger E. *Situated Learning: Legitimate Peripheral Participation*. Cambridge, UK: Cambridge University Press; 1991.