Creating the Paradigm Portfolio:

A new exercise in web-based curriculum documentation

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Introduction:

In the last twenty years, there has been tremendous growth in the field of science education research. Researchers are discovering how students learn and how teaching affects student learning. It now falls to the professoriate to apply this new research to their students' classroom experience.

Before the recent research, the "straight" lecture had been the generally accepted method of teaching upper division physics. Those students who could innately grasp the material would (as long as they worked hard enough); the "weaker" students would find other fields where they were happier. However, new research is showing more effective ways to communicate with all types of learners.

The Paradigms in Physics program at Oregon State University seeks to apply the advances in education research by utilizing small-group classroom activities and focusing on connecting concepts. Recently, some of the instructors at Oregon State University (OSU) have undertaken to record the teaching and learning that takes place in the paradigms.

Until the 1990's, there was little precedent for recording the teaching and learning that took place in a course except for the textbook, or a detailed report published in some of the journals of social science. In 1992 William Cerbin sought to approach the idea of recording classroom interactions in a new way. He wanted to create a document to collect a body of information about the teaching and learning that took place in a single class. This type of document is now called a course portfolio, and the goals, nature, and construction of the course portfolio were the topic of a scientific study published in 1996. (Hutchings, 1996)

focus

In the years since then, there have been many attempts to create useful course portfolios for documenting many types of student learning or teaching questions. However, there still exist two main drawbacks of the course portfolio. First and foremost, it was not created to address the teaching community, but the education research community. Its usefulness, then, is limited to research and not application. Secondly, there is no defined and effective organizational structure. In studying the existing course portfolios, the interested reader finds a wealth of information in very dense and difficult packages.

Just as the Paradigms sought to implement the latest in physics education research in their teaching, breaking barriers and claiming new territory, now the Paradigms documentation group seeks to create a way to record what happens in the Paradigms that creates a valuable resource for other professors. This is being accomplished by using a focus upon activities, a multi-layered approach, and an html-based format.

Traditionally, textbooks have fundamentally focused upon content, and course portfolios upon overarching themes or questions. Neither of these are particularly useful to teaching professors seeking new teaching methods. The Paradigm Portfolio intends to focus upon the individual activities that take place in class, themselves. This will provide other instructors with the resources they need to borrow from the paradigms anything they find useful.

These individual activities, lectures, whiteboard questions, and other resources will only be a small part of the structure of the Paradigm portfolio. However they will serve as the base. Built on top of that will be the structure that ties together these “snapshots” (term coined by the Carnegie Foundation), connecting them into units, classes, and overarching themes of the Paradigms Program. The upper levels of the structure will be occupied by short articles about different types of small group activities, or other overarching themes that can connect to the snapshots.

The html format of the Paradigm Portfolio allows these connections to take organizational roles. By creating hyperlinks that are vertical in the structure to augment the horizontal links that will exist naturally will allow a browser great ease of use and access to information. The final benefit to using the html format is how simple the publication becomes when it is possible to post it on the World Wide Web.

This paper is broken into three main sections. In the first, I will discuss the background necessary to understand the Paradigms Documentation Project, including recent advances in education research, the nature of the Paradigms in Physics program, and the call for shared teaching knowledge exemplified in Ernest L. Boyer’s work in the late 1980’s. The second section will discuss how the Paradigms in Physics program seeks to answer that call, and the unique methods being used to document the unique curriculum. Finally the last section will discuss the impact of the Paradigm Portfolio, and opportunities for further research.

Section 1: Background

Recent Education Research

In April of 1983, the National Commission on Excellence in Education released the report, “A Nation at Risk: The Imperative for Educational Reform.” The opening of the report makes these statements:

> Our Nation is at risk. Our once unchallenged preeminence in commerce, industry, science, and technological innovation is being overtaken by competitors throughout the world… the educational foundations of our society are presently being eroded by a rising tide of mediocrity that threatens our very future as a Nation and a people.
>
> If an unfriendly foreign power had attempted to impose on America the mediocre educational performance that exists today, we might well have viewed it as an act of war. As it stands, we have allowed this to happen to ourselves… We have, in effect, been committing an act of unthinking, unilateral educational disarmament.
>
> …This report, the result of 18 months of study, seeks to generate reform of our educational system in fundamental ways and to renew the Nation's commitment to

> schools and colleges of high quality throughout the length and breadth of our land.

The nation did move into action. The House Science Education Bill 1310 and Senate Bill 1285, "Education for Economic Security" created the funding that allowed the "new" research in science education as a whole, and physics education specifically.

By 1985, researchers at Arizona State University developed a method of testing students' knowledge of basic physics concepts. When they applied this to university students in an introductory course, they found that the course had impressively little effect upon the students' conception of the physical world. Students retained many basic misconceptions about physics despite intentional instruction on those topics (Halloun & Hestenes, 1985). To correct this problem, the physics teaching community focused much of its energy on improving introductory physics courses, considering teaching methods and the new tools offered by technology.

The loudest response to this problem has been the justification, evaluation and implementation of "active engagement" or "interactive engagement" teaching. The idea is that the students are expected to be involved in the lecture, recitation, or laboratory. Significant evidence has been given to show the benefits of implementing interactive engagement (Hake, 1988).

As the technology available to instructors increases, the question of how to use technology for instruction often falls to commercial developers. However, the value of active-engagement computer-based laboratories for physics instruction has been confirmed by independent studies. (Redish, Saul, & Steinberg, 1996).

The perennial problem for students in introductory physics has been the practice of problem solving. Significant research into student problem solving was done already in 1980, identifying the difference between the way experts and novices solve physics problems (Larkin, McDermott, Simon, & Simon, 1980). The difference between how experts and novices solve problems is fundamentally based upon how they organize and access their knowledge about the relevant subject (van Heuvelen, 1991). Alan van Heuvlen suggests that active engagement using cooperative groups, including immediate feedback from the professor, will help students to structure their knowledge in a physically useful fashion. The Physics Education Research group at the University of Minnesota made student problem solving a focus of their research, and in 1991 published, "Teaching problem solving through cooperative grouping," a two-part article in the American Journal of Physics that showed the effectiveness of cooperative learning in building students' problem solving abilities (Heller, P, Keith, R, & Anderson, S.; Heller, P & Hollabaugh, M.).

The Paradigms in Physics Program

In 1996 the physics faculty at Oregon State University voted to develop a new program for their upper-division undergraduate curriculum. The curriculum reform group identified six goals for their new curriculum: (Manogue, 2003)

- be flexible enough to accommodate students with a wide range of career goals in industry as well as in academia.
- introduce quantum mechanics in the junior year to prepare students for the GRE and/or to take specialty classes in the senior year.
- emphasize the connections between the fields of physics.
- promote the development of problem-solving and mathematical skills.
- accommodate the growing number of non-traditional students entering the physics and engineering physics programs.
- incorporate modern pedagogical techniques and information gained from physics education research.

Structuring the curriculum as physics professionals structure their understanding of the concepts led to a curriculum broken up into ten small, concept-based junior-level classes (called paradigms) and six standard-sized senior-level classes called capstones. This constitutes a re-ordering of the upper-division content that is unique, with its own benefits and challenges. The concepts covered in these courses are diagrammed in the article, "Paradigms in Physics: A new upper-division curriculum" (Manogue, Siemens, Tate, & Browne, 2001).

The focus in the paradigms is not merely communicating concepts, but fostering student learning. Education research tells us that clearly communicated concepts are not sufficient for the synthesis of student understanding. The student must build connections between those concepts. In-class group exercises, explicit discussion of problem-solving techniques, and research-guided learning are some of the best ways of enabling students to build those connections.

Active Engagement

Though most physics education research today is done at the introductory physics level, many results can be transferred to teaching at a junior level. There is no stronger example than active engagement. Though the size of most introductory classes requires technological advancement to use active engagement, at the junior level, much of the class can be in a "raise your hand to ask a question" style with no detriment to student engagement.

However, the Paradigms use an additional active engagement technique that is now common among K-12 classrooms: white board questions. White boards allow students to answer questions by expressing themselves easily in multiple representations. Pictures, formulae, and question marks can be extremely useful in communicating student understanding to the teacher, and allowing an instructor to tailor their presentation to the needs of their students.

In addition, the Paradigms employ many small-group activities. Collaborative learning in small groups is one of the most successful teaching techniques to be developed as a result of recent research (Heller, Keith, et al, 1992), and these activities constitute a vital part of the paradigms curriculum.

Problem-Solving

There have been many studies that investigate student problem solving ability, starting with “Understanding and teaching problem solving in physics,” (Larkin & Reif, 1979). The paradigms use cooperative student groups to address student problem solving strategies. Asking individual group members to take on specific tasks in the group is one method that is occasionally used. Also, the Bridge Vector Calculus (Dray & Manogue, 2003) material is used in math classes at OSU, and focuses heavily on developing student problem solving through collaborative learning

Research-Guided Learning

The hope of our research-guided learning is that the learner will be able to think like a professional physicist as a result of the education. The paradigms have attempted to mimic this organization of knowledge by the structure of the paradigms classes.

One of the largest differences between the way students and professional physicists think is their use and interpretation of different types of information. Therefore, the paradigms also employ visualization methods, requiring students to draw pictures often, and convert between multiple representations of information. This research area was first opened from the mathematics perspective (Janvier, 1987), and later approached in physics (van Heuvelen, 1991).

The Documentation Challenge

The Scholarship of Teaching and the Teaching Commons

In 1990, Ernest L. Boyer, the president of the Carnegie Foundation for the Advancement of Teaching, authored a book entitled *Scholarship Reconsidered* that sought to redefine the way American higher education viewed scholarship. He saw American universities focusing the majority of their evaluation of professors on their ability to conduct and publish research. He encouraged the professoriate to shift to a view of scholarship that includes four distinct features: the scholarship of discovery, the scholarship of integration, the scholarship of application, and the scholarship of teaching.

The scholarship of discovery is what has been regarded as scholarship for the last century: discovering new things about humankind and the universe. The scholarship of integration embodies drawing on pertinent discovery scholarship to create useful bodies of knowledge. Those bodies are then used in the scholarship of application to take part in the mission of benefiting the universe and humankind. Finally, the scholarship of teaching involves teachers thinking critically about their teaching methods and sharing that information with the entire teaching community.

As the current president of the Carnegie Foundation, Lee S. Shulman, says in his preface to *The Advancement of Learning*, “As many of you know, the scholarship of teaching and learning is a major theme of the Carnegie Foundation, one that has been central to our work for some time… I see it as one of the Foundation's most important continuing legacies" (Huber & Hutchings, 2005). Shortly thereafter, he defines the vision that he has for the scholarship of teaching…

> The scholarship of teaching and learning invites faculty at all these levels [K-12 and graduate/professional education] to take teaching seriously as intellectual work, ask good questions about their students' learning, seek evidence in their classrooms that can be used to improve practice, and make this work public so that others can critique it, build on it, and contribute to the wider teaching commons. (v-vi)

This describes the current movement towards the creation of a "teaching commons" where the exchange of ideas about teaching and learning are shared between not only education researchers and psychometricians, but practicing educators in K-16 education. While the endeavor has been shared by National Science Foundation-sponsored digital libraries (http://www.nsdl.org) and individuals like those in the University of Nebraska-Lincoln's Peer Review of Teaching Project (http://www.courseportfolio.org), I am most aware of the efforts of the Carnegie Foundation (http://carnegiefoundation.org). Their efforts to build the Knowledge Media Library (KML) and the Carnegie Academy for the Scholarship of Teaching and Learning (CASTL) as well as their publication of numerous works on the topic are evidence of their continuing commitment to Boyer's vision of scholarship.

A New Form of Peer Review

One characteristic of scholarship that has been central throughout this reform is the necessity of peer review. In 1995, in an effort to create guidelines for all forms of scholarship, the Oregon State University faculty Senate approved a new definition of scholarship to be used as a basis in promotion and tenure proceedings. "Scholarship is creative intellectual work that is validated by peers and communicated – including creative artistry and the discovery, integration, and development of knowledge." (Weiser, & Houglam, 1998). The teaching commons provides a forum for the communication and peer review of teaching methods, curriculum development, et cetera.

The problem now stands: how does the teaching community build a method of recording the teaching and learning that they want to submit before the teaching community? This is partially answered by the practice of documentation and dissemination. The terms "documentation" and "dissemination" are used in an education research context to mean collecting and composing documents and data representing a teaching/learning program or scheme, and sharing those methods and results with the teaching community.

It is my opinion that for the last few hundred years, science and mathematics professionals have been focused upon discovering new concepts. Consequently, the conventional method of documenting teaching is the writing of textbooks (works that organize their information based upon concepts), and the conventional method of dissemination has been publishing through a private publishing company. In the last half of the twentieth century, education research repeatedly asserted the impact of teaching methods upon student learning. This created a desire for evaluating teachers and professors based upon their teaching methodology, as well as their content knowledge. As a result, documenting teaching and learning has been a growing topic for the last few decades.

A traditionally taught curriculum focuses upon the concepts the students need to learn, and the documentation usually takes the form of a new text. If the traditional choice were made for the paradigms documentation, it would involve ordering the concepts in a new way to make a single text that incorporates all the ideas discussed in the junior year at Oregon State University, using consistent nomenclature. In contrast, the focus in the paradigms is not merely communicating concepts, but fostering student learning.

The paradigms documentation group has the goal of documenting the paradigms program (specifically the junior-level classes), with a vision for dissemination. The unique features of the curriculum, namely its organization and the integration of recent education research, are what the group is most interested in conveying.

Answering the Challenge

In order to address the problem of documenting the paradigms, we will first describe current methods of documentation, including course portfolios and digital libraries.

The Course Portfolio

The first response to the need to evaluate teachers was the development of the "teaching portfolio" or dossier in the 1980's (Urbach, 1992). However, their purpose is evaluating the teacher as an instructor, not describing the relationship between teaching and student learning. In order to describe that relationship, William Cerbin attempted something new: what is now called a course portfolio. As a professor of psychology at the University of Wisconsin-La Crosse, he wrote this about his thinking surrounding his portfolio, composed in 1992 (Hutchings, 1996):

> Ernest Boyer's *Scholarship Reconsidered* appeared, and I was very struck by his notion of the scholarship of teaching – and how that notion might take us beyond the old saw that teaching is based on scholarly acumen in one's field, brought to bear in the classroom. I wanted to explore what it was that's scholarly about the teaching I do… I was familiar with teaching portfolios… But thinking about teaching as a scholarly inquiry began to lead me in the direction of something I had not seen anyone else doing: a portfolio that focused on the course rather than on all of one's teaching. Being a social scientist, I began to think of each course… as a kind of laboratory – not as a truly controlled experiment, of course, but as a setting in which you start out with goals for student learning, then you adopt teaching practices that you think will accomplish these, and along the way you can watch and see if your practices are helping to accomplish your goals, collecting evidence about effects and impact. (52-53)

In 1994, the American Association for Higher Education (AAHE) launched a four-year project entitled From Idea to Prototype: The Peer Review of Teaching." The concept of course portfolios and the potential of their use in the peer review of teaching led a dozen faculty to experiment with course portfolios, forming the AAHE Course Portfolio Working Group. In 1996, the AAHE and Carnegie Foundation published the book *The Course Portfolio: How faculty can examine their teaching to advance practice and improve student learning*, (Hutchings, 1996) as a synthesis of many of the results of the AAHE project.

"Early on in its work, the Working Group identified three basic purposes a course portfolio might serve: personal growth, contribution to the field, and rewards" (p. 47). The choice of purpose will affect the focus and format of the rest of the portfolio.

Curtis Bennett, professor at Michigan State University and author of a course portfolio there, identifies five purposes of a course portfolio as defined by the AAHE and Carnegie publication: "(1) A vision of the possible, (2) an aid to memory, (3) an occasion to investigate student learning, (4) an escape route from the isolation of the classroom, and (5) a way of bringing recognition and reward to teaching excellence" (2000, para. 1).

These historical models for course portfolios served as a very useful guideline for the group working to document the Paradigms. However, observing the course portfolios that have been generated under that model, the Paradigms Group decided to investigate how to create a portfolio that would be useful to people who did not know about the class or the unique structure of the curriculum surrounding it, and that would be relevant to the audience of educated peers. Perhaps later studies may call this a curriculum portfolio; I have decided to simply call it the Paradigm Portfolio.

The Digital Library

In the last 15 years, the ability of technology to store and make available information has motivated private organizations as well as the National Science Foundation to invest in developing "digital libraries." The goals of these digital libraries are usually to make available successful teaching materials. The idea is that hundreds of teachers across the United States develop new Van De Graff generator demonstrations or laboratories every year. If the most effective of those could be collected into a free resource for teachers, they would not have to duplicate their efforts.

The operation of a digital library is simple. The users of the library will get a free account with the server. When they develop new teaching material that they would like to share, they submit it to the library for review and posting. When they would like to borrow material from someone else, they search for it, and try it in their classroom. Most libraries have an area for teachers who have used the material to comment on its usefulness, or modifications that they employed. In this way, the library serves two purposes; it serves as a resource for instructors looking for activities as well as a forum for the communication or review of educational tools and strategies.

The biggest problem with large-scale digital libraries is the issue of context. When teachers create an activity for their class, ideally it is carefully tuned to their students' level of knowledge about all the related subjects, as well as how they learn best, emphasizing the most recent lessons, and assuming the earlier ones. Because there are many different ways of organizing a teaching unit, and countless reasons for each organization, the teachers who desire to use an activity will probably not have the same class context as the original author.

The Carnegie-MERLOT Template

It was this problem that the Carnegie-MERLOT template sought to solve (The Knowledge Media Library (KML) is the digital library of the Carnegie Foundation, and the KEEP Toolkit is an easy web editor used for creating resource pages and the Multimedia Educational Resource for Learning and Online Teaching (MERLOT) is a pioneering digital library established in 1997): (http://www.carnegiefoundation.org/master/sub.asp?key=38&subkey=512)

> The KEEP Toolkit is being integrated into MERLOT to address two main issues. At the moment, MERLOT provides users with information about each online resource through its peer review, assignments, user comments and personal collections features. These features however, tend to be more context free and focused on their potential uses. A challenge for members of the MERLOT community, specifically users wishing to use one of the learning objects available, is to gain access the author's knowledge and experience in designing and using the materials as well as being able to share their challenges and successes in using the learning object. With these two features provided, members of the MERLOT community would be better equipped to learn from each other's work, continue improving these learning objects and build on each other's pedagogical innovations. The pilot effort between the KML and MERLOT hopes to tackle these challenges using the KEEP Toolkit.

The template created by this joint effort contained information about the activity, but did so in a context-rich environment, including the motivation for the activity, thus allowing the user a much broader understanding of the most useful application of the resource. This is the type of documentation we felt necessary to use in creating the Paradigm Portfolio.

Section 2: Creating the Paradigm Portfolio

The Problem

The Paradigms in Physics program was implemented at Oregon State University to research the confusion about the subject matter for the upper-division physics curriculum. Because OSU's former curriculum was typical for an American university, the solution should be common as well. How, then, can we offer our curricular change to other institutions?

The expected course of action for a research academic is to publish. Indeed, members of the Paradigms group have published four articles in Physics Today and The American Journal of Physics relating to the program. Though these articles highlight the main features of the curriculum or case studies on specific examples, they do not provide the readers with the tools to implement a program like the Paradigms. If any university agrees with us that they should, "do as we do", then the onus is upon us, as the suggesting party, to give them the resources we have for implementing the program (The question "how can our documentation benefit our implementation" will be addressed later).

One way to provide implementation resources would be to write an "Intermediate Undergraduate Physics" text. It would offer a singular, comprehensive description of this organization of the content. This idea is immediately attractive, because new organization of the content seems to be the most distinctive feature of the Paradigms curriculum. However, what then happens to the wealth of applied education research? How can a text communicate the necessity of active engagement, the method for constructing a peer working group, or how to problem-solve like a professional physicist?

After spending the time describing course portfolios, the reader may recognize the usefulness of that type of documentation for individual paradigms classes. However, there is a wealth of deliberate organization in the large-scale structure that would be missed if the paradigms were only documented as individual classes. Indeed, at least half of the "Paradigms in Physics" article that appeared in the American Journal of Physics dealt with the desired and unexpected results of the new organization. Therefore Paradigm Portfolio must document curricular structure at a level higher than the individual course

A New Approach

Because none of the natural solutions seemed sufficient, the Paradigms Documentation Group decided to create a method of documenting the teaching and learning in the Paradigms. Because we were creating a documentation style focused towards dissemination, the first thing we focused upon was our audience.

Audience

There are two fields that, at the current time, are quite separate: the fields of Physics and Physics Education Research. The large majority of Americans holding PhD degrees in physics have a very specific theoretical area of study, like superfluids, quantum field theory, nuclear physics, or a more specific experimental area of study, like condensed matter physics, femptosecond spectroscopy, or magnetic anisotropy in transition metals. After spending 6 or more years studying a specific question in one of these areas, a physicist will receive his or her PhD. They will also have found the fulfillment that comes from dedicating oneself to a fundamental question of physics until an answer is found. These are the individuals often hired as instructor/researchers at universities. It is perhaps entirely unrealistic to ask a person who is dedicating so much of themselves to specific advances in the world of physical understanding to keep up on the advances in science education research and implement them into their teaching. In addition, the reward structure for professors is generally based upon research or scholarship, not teaching.

There have been many advances in PER, but for many reasons, there is a large gap between the "ideal" classroom of an education researcher and the actual experience of a professor. One reason that may not be obvious is that the bulk of PER has taken place at the level of the introductory physics courses, where the researchers are interested in how different students access the concepts offered by the course. The material and academic challenges are very different in upper-division courses, where the venue has often moved from a lecture hall of over 100 students to a classroom seating twenty.

Understandably, the majority of course or activity documentation has taken place in the language and forums of the science education specialists. However, the need for the information lies at the feet of the physics professor who has to construct an upper-division electrodynamics course by next fall. Therefore, it should be the goal of the Paradigms Group to address the needs of this professor in a method that will be accessible to that individual. Teaching professors balance between two stereotypical extremes: the reformed (instructors who focus upon how things should be taught) and traditional (instructors who focus upon what things should be taught).

"And so I think that I have messages that I want to convey: different messages to different people. To the traditional faculty, I want to convey the understanding that students don't just miraculously learn to think in particular ways, and so they need to think about the ways in which they want to convey this content that they care about so strongly. … For the reform oriented faculty member, I need to help them understand that it's important to think about the content as well as to think about "are you helping students learn how to think and learn how to reason for themselves?" … these shouldn't be polar opposites. True education is about doing both at the same time." (Corinne Manogue, 4/24/2006, private discourse)

Focus Upon Activities

In late 2005, the Paradigms Documentation Group was researching course documentation designs on the website of the Carnegie Foundation. Their Knowledge Media Laboratory (KML) offered a new perspective for documentation, using web-based design. The basic building block of KML documentation is a single web page called a "snapshot" that captures a certain education question or activity. When we came across the template created by MERLOT (http://www.carnegiefoundation.org/master/sub.asp?key=38&subkey=512), we found their attempt to solve the same problem that we were facing in a different context.

The Group decided to pursue documenting the courses from the bottom up, using the Carnegie-MERLOT template to document individual classroom activities. Instead of starting with the class structure, and creating links to interesting lectures and activities, we decided to start by documenting the activities, then creating records about interesting aspects of the class structure. The reasoning behind this resides in the fact that the majority of the innovations employed in the paradigms are manifested in the individual activities. For a typical physics professor looking for materials, or ways to implement reformed teaching methods, the activities are probably the most informative, useful, and easily adopted element of reform in the paradigms.

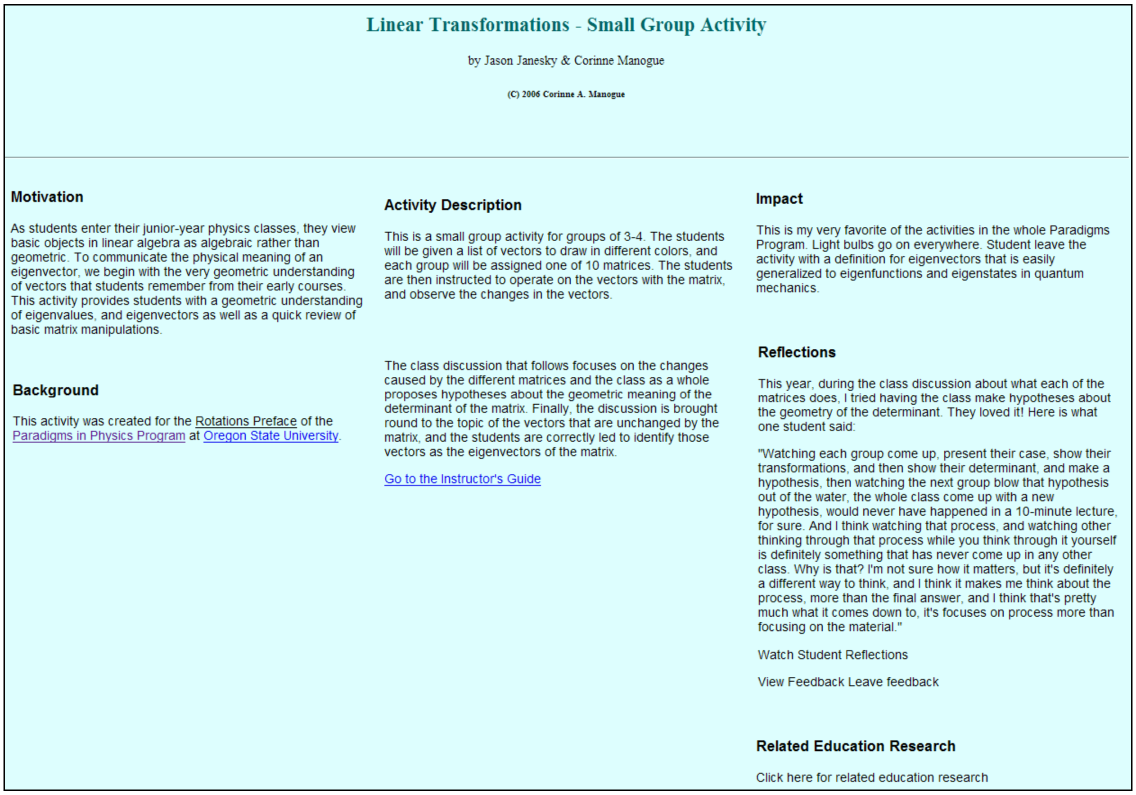
Multi-Layered Approach

Another benefit to focusing upon individual activities is that those are most likely the most interesting pages to both education researchers and potential adopters. After they review that page, they may be more inclined to read further. Thus, it becomes necessary to create a structure that allows freedom of motion throughout related topics.

The structure that we have adopted is a hierarchical structure that is focused not on the content, like a text would be, nor on student learning, like a course portfolio would be, but upon the teaching strategies and activities. This is the most useful form for potential adopters, so it is the form that meets our goals best.

Level 1: Activities, Lectures, Artifacts, and White Board Questions

The activities in the Paradigms are usually performed by the students in small groups. Each group of three or four will address a particular problem or set of problems. Each activity is designed to fit in a particular gap of understanding that exists in students after learning material in lectures. The activity ‘splash” (The first page the browser sees when the activity is accessed) seeks to present the motivation behind the activity, its context in the curriculum, the impact it has on student learning, teacher reflections on the activity, and links to related education research. Beyond this, the page will contain video of the activity as well as the description of the activity itself (Figure 1).



Linear Transformations - Small Group Activity

by Jason Janesky & Corinne Manogue

(C) 2006 Corinne A. Manogue

Motivation

As students enter their junior-year physics classes, they view basic objects in linear algebra as algebraic rather than geometric. To communicate the physical meaning of an eigenvector, we begin with the very geometric understanding of vectors that students remember from their early courses. This activity provides students with a geometric understanding of eigenvalues, and eigenvectors as well as a quick review of basic matrix manipulations.

Background

This activity was created for the Rotations Preface of the Paradigms in Physics Program at Oregon State University.

Activity Description

This is a small group activity for groups of 3-4. The students will be given a list of vectors to draw in different colors, and each group will be assigned one of 10 matrices. The students are then instructed to operate on the vectors with the matrix, and observe the changes in the vectors.

The class discussion that follows focuses on the changes caused by the different matrices and the class as a whole proposes hypotheses about the geometric meaning of the determinant of the matrix. Finally, the discussion is brought round to the topic of the vectors that are unchanged by the matrix, and the students are correctly led to identify those vectors as the eigenvectors of the matrix.

Go to the Instructor's Guide

Impact

This is my very favorite of the activities in the whole Paradigms Program. Light bulbs go on everywhere. Student leave the activity with a definition for eigenvectors that is easily generalized to eigenfunctions and eigenstates in quantum mechanics.

Reflections

This year, during the class discussion about what each of the matrices does, I tried having the class make hypotheses about the geometry of the determinant. They loved it! Here is what one student said:

"Watching each group come up, present their case, show their transformations, and then show their determinant, and make a hypothesis, then watching the next group blow that hypothesis out of the water, the whole class come up with a new hypothesis, would never have happened in a 10-minute lecture, for sure. And I think watching that process, and watching other thinking through that process while you think through it yourself is definitely something that has never come up in any other class. Why is that? I'm not sure how it matters, but it's definitely a different way to think, and I think it makes me think about the process, more than the final answer, and I think that's pretty much what it comes down to, it's focuses on process more than focusing on the material."

Watch Student Reflections

View Feedback Leave feedback

Related Education Research

Click here for related education research

Figure 1. An example Small Group Activity page.

The goal of providing this mass of information is to contextualize the activity, so that instructors will be able to implement the activity if their students are having the same problems in understanding that students had at Oregon State. The motivation and impact sections will be most useful to other teachers who might want to use the material, and the reflections section will be useful to anyone who actually tries to use it. Education researchers will be interested in the same things that the teachers are, but for very different reasons. They will be interested in the nature of the activity and the student impact. These will enable them to understand how the Paradigms are attempting to reach their goals.

Instructor's Guide: Linear Transformations - Small Group Activity

Click Here for Handout

Click Here for Handout with Teaching Comments

Learning Activities (Process):

1. Students should perform the activity (in groups of 3) as directed on the handout.
2. One matrix should be assigned to each group.
3. As each group finishes, they should also draw their transformed vectors on the board. Groups that finish early can be given another matrix.
4. The teacher should complete any remaining examples.

Materials Needed:

- Linear Transformations handout LinTrans.pdf (1 per student)
- Graph paper (1 per student)
- Colored pens/pencils [red, green, blue, yellow, purple] (1 per group of 3)
- Colored chalk [red, green, blue, yellow, purple] (several sets)
- White Boards and Dry erase markers(1 per group of 3)

Tips for Teaching

Prerequisites:

The students will have to be familiar with matrix multiplication.

Warmup:

Depending upon the students' linear algebra background, it may be necessary to do a short recap of the relationship between vectors and matrices.

Wrapup:

Each group should report what their transformation did, the determinant of their matrix, and any unchanged vectors. Make sure to bring out the following points as they occur in a natural way:

1. det A = 1: ----> rotation
2. det A = -1: ---> reflection in line
3. |det A| > 1: ---> stretching
4. det A = 0: ----> projection

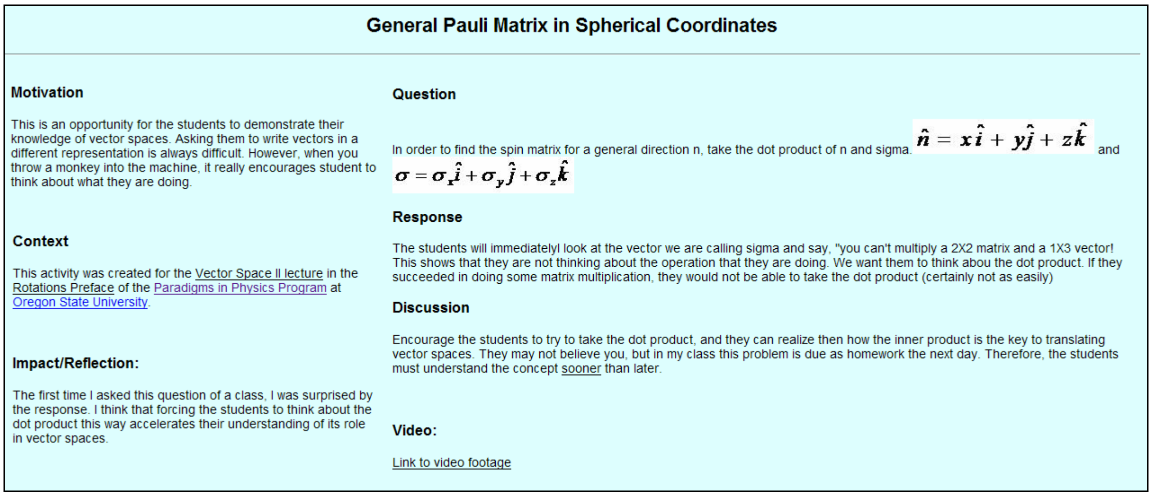
Conclusion: Eigenvectors are "held fixed" by transformation in the sense that direction is unchanged. May be stretched and/or multiplied by -1

Figure 2. An example Activity page Instructors Guide.

Also linked to the activities splash page will be the Instructors Guide (Figure 2). This page contains information necessary for the utilization of the activity, like a materials list, procedure, guide to discussion, etc. This page is very similar to the instructor's notes for leading the activity, and is created in a format that will be easy to print out, should the instructor desire to use it.

Lectures in the paradigms are very typical of instruction at other universities, except for the presence of white board questions, which will be discussed presently. The documentation of the lectures will be the construction online of a page very similar to the instructor's notes on the subject, with a title that gives a clear impression of the content covered in the lecture. The main goals in documenting the lectures are to give the context for white board questions, and to create a record that would be useful for future teachers at OSU and elsewhere. The lectures are still the place where the majority of the content is presented, and any attempt to implement the class without a clear understanding of the sequence of lectures would prove very time-consuming for the implementing teacher. The lectures form the substrate upon which all of the unique features of the Paradigms are affixed.

During the lectures, the instructor will often ask a "white board question". That means that they address a question to the class, but instead of some students raising their hands, all students write something on their personal white board. Then, they pick up the whiteboards and show them to the instructor. An example might be the instructor turning to the class in the middle of a discussion of Fourier series and saying, "Draw me a picture of a function with period of three pi." The class would then participate in a discussion of how to approximate some of the functions using Fourier series. White board questions are the basis of a large part of the active engagement in the Paradigms, so the reason for desiring documentation for these questions is clear. However, the construction of a white board documentation scheme proved troubling. It is vital to include the context of the white board question in great detail, but it seems cumbersome to do this on the page itself. Therefore, we decided to place the main link to the white board question in the lecture page itself (Figure 3). By doing so, we hope to give the browser an ability to contextualize the white board question themselves, without us trying to tell them how it fits into the lecture.



General Pauli Matrix in Spherical Coordinates

Motivation

This is an opportunity for the students to demonstrate their knowledge of vector spaces. Asking them to write vectors in a different representation is always difficult. However, when you throw a monkey into the machine, it really encourages student to think about what they are doing.

Context

This activity was created for the Vector Space II lecture in the Rotations Preface of the Paradigms in Physics Program at Oregon State University.

Impact/Reflection:

The first time I asked this question of a class, I was surprised by the response. I think that forcing the students to think about the dot product this way accelerates their understanding of its role in vector spaces.

Question

In order to find the spin matrix for a general direction n, take the dot product of n and sigma. $\hat{n} = x\hat{i} + y\hat{j} + z\hat{k}$ and $\sigma = \sigma_x\hat{i} + \sigma_y\hat{j} + \sigma_z\hat{k}$

Response

The students will immediatelyl look at the vector we are calling sigma and say, "you can't multiply a 2X2 matrix and a 1X3 vector! This shows that they are not thinking about the operation that they are doing. We want them to think abou the dot product. If they succeeded in doing some matrix multiplication, they would not be able to take the dot product (certainly not as easily)

Discussion

Encourage the students to try to take the dot product, and they can realize then how the inner product is the key to translating vector spaces. They may not believe you, but in my class this problem is due as homework the next day. Therefore, the students must understand the concept sooner than later.

Video:

Link to video footage

Figure 3. An example White Board Question page.

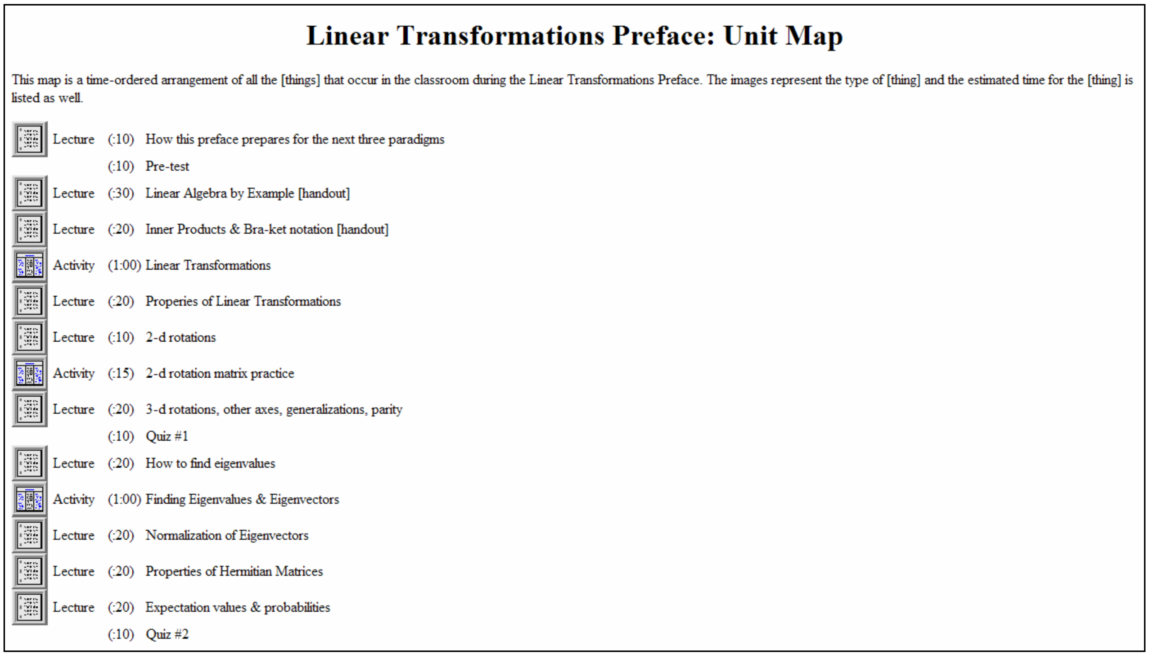
Also important in the white board questions is the motivation/impact discussion, so each of those questions must be included as well, for potential adopters as well as education researchers. The bulk of the page, however, is dedicated to the question, student response, and discussion, because the discussion is what the instructor wants in the first place. It is in discussions with the teacher or other students that students can change their fundamental ideas about physics.

Also on this first level will be artifacts like quizzes, handouts, Maple worksheets, etc. These can be useful for understanding of the concepts covered in the course, but the main reason they are included is for completeness and ease of implementation.

Level 2: The Unit Map

Our next question was this: How can we organize all of these isolated snapshots into a useable collection of resources? The idea of a time-ordered list is the first thing that comes to mind, but if there is a large amount of thought that goes into the organization of the content, then there must be some elegant way to represent that thought in our presentation of the snapshots.

In fact, the conceptual organization of the content is based upon fundamental blocks of instruction that deal with a singe concept, like eigenvectors or the Fourier Transform. Each unit consumes roughly five to ten hours of class time. Dividing the Paradigms courses into units yields a substrate that is small enough for the documentation group to discuss while at the same time presenting the organization of the relevant material.



Linear Transformations Preface: Unit Map

This map is a time-ordered arrangement of all the [things] that occur in the classroom during the Linear Transformations Preface. The images represent the type of [thing] and the estimated time for the [thing] is listed as well.

Lecture	(:10)	How this preface prepares for the next three paradigms
	(:10)	Pre-test
Lecture	(:30)	Linear Algebra by Example [handout]
Lecture	(:20)	Inner Products & Bra-ket notation [handout]
Activity	(1:00)	Linear Transformations
Lecture	(:20)	Properies of Linear Transformations
Lecture	(:10)	2-d rotations
Activity	(:15)	2-d rotation matrix practice
Lecture	(:20)	3-d rotations, other axes, generalizations, parity
	(:10)	Quiz #1
Lecture	(:20)	How to find eigenvalues
Activity	(1:00)	Finding Eigenvalues & Eigenvectors
Lecture	(:20)	Normalization of Eigenvectors
Lecture	(:20)	Properties of Hermitian Matrices
Lecture	(:20)	Expectation values & probabilities
	(:10)	Quiz #2

Figure 4. An example Unit Map.

This is the fundamental premise behind the construction of the Unit Map (Figure 4). The two sections of this page describe the problem or concept the unit is designed to address and organize links to the materials and activities used to do so. Each type of snapshot is differentiated by its icon, so the browser can easily identify the type of information they are most interested in.

Level 3: Course-Level Documents

As you may imagine, there is then a page to describe the nature of the course itself and some of the main topics addresses. That page will include a list of the units in the course, as well as a descriptive paragraph that contains all of the main features of that course, in a very similar style to the Unit Map.

Level 4: Supporting Documents

An extremely useful result of using web-based documentation is that it is possible to identify and comment on aspects of the program that appear in different places. For example, several of the activities used in the paradigms are what we call “compare & contrast” activities. The usefulness of these activities was identified by Katherine Meyer, and documented in her Masters project at OSU.

With the html architecture, it is simple to place a link on all of the compare & contrast activities to connect them to a central page about compare and contrast activities. That page could explain the major features of the compare & contrast activities, or discuss tips on how to use those activities most effectively, etc.

We have already planned to write supporting documents for compare & contrast, whiteboard questions, constructing effective small groups, and using Maple worksheets.

Level 5: Overarching Documents

The final level includes the documents that address the Paradigms as a whole. The pieces that we already know will be included are the published Paradigms papers in AJP and Physics Today, as well as this thesis. These documents would serve to introduce an education researcher or potential adopter to the paradigms as a whole, or to broaden the understanding of browsers who have only read or used the lower-level resources.

Comments on the Structure

It is perhaps a pure accident that the lowest levels of the Paradigm Portfolio coincide with the scope of implementation that adopters may attempt. It is easy to implement a single activity or lecture. It is also possible to incorporate a single unit into a non-paradigms course to address a specific problem. Of course, it is the hope of the Paradigms Documentation Group that entire courses and groups of courses will be adopted at multiple universities.

On another note, it has been the goal of the Group to make all of the context-heavy pages a size that will fit onto a computer screen. The idea is that a browser desires information about the program or activity in small pieces that are easily integrated into their existing knowledge. By minimizing scrolling, we are attempting to make the Unit Map and the Activity page more accessible to readers.

Section 3: Conclusions

The work done by the Paradigms Documentation Group will be able to serve scores of universities, and hopefully be a significant piece of the twenty first-century struggle to build a national and international body of teaching knowledge and resources.

Value for the Paradigms

Though the focus of the Paradigms documentation project has been towards individuals and organizations outside the Department of Physics at Oregon State University, there will be several benefits for the existing Paradigms program here.

First, the reflection by teachers on how they are teaching and why they do what they do is a practice that makes the teaching better. As the paradigms teachers compose the outlines for their small group activities and Maple worksheets, they will be engaging with the material in a way that they most likely have not been asked to since developing the activities.

Another benefit is the ability of the Paradigms professors to talk about their teaching. There is now a medium for communication about the way they teach. Each can research the way others teach their Paradigms classes, to get a feel for the context that the students will be familiar with.

Perhaps the most useful benefit, however, is the value to new teachers. Already the paradigms have lost two of their founding instructors to retirement. If the reasoning for the choice and organization of content can be communicated to the incoming instructor, the potential for building the overall strength of the program grows substantially.

Further Work

We are only beginning to ask the questions that the Paradigms Portfolio enables us to ask. When the Portfolio is complete, it will itself only be a snapshot of the Paradigms curriculum at a point in time. The Paradigms have been constantly changing since the original idea of reforming the upper-division curriculum.

Because of its modular structure the Portfolio has the ability to grow with the Paradigms, but I trust that historical artifacts will be retained, should later researchers want to investigate the question of how curricula evolve.

The remaining design work that needs to be done in the Paradigms Portfolio is not in the realm of the physics education researcher, but the web designer. Similarly, evaluating the success of many of the innovations in the Paradigms Portfolio naturally falls to information technology researchers.

This is an exciting time when fields are integrated by necessity and convenience, and we are blessed at Oregon State University with a wealth of information technology expertise in both the College of Engineering and the College of Business. By joining with available partners here at the university, we can ensure the success and usefulness of the Paradigms Portfolio

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References

Bennett, C. (2000). *Advanced mathematics for secondary teachers: Course portfolio*. Retrieved on December 7, 2005, from http://gallery.carnegiefoundation.org/cbennett/index.html.

Boyer, E. L. (1990). Scholarship reconsidered: Priorities of the professoriate. San Francisco: Jossey-Bass Inc.

Carnegie Academy for the Scholarship of Teaching and Learning (*CASTL)*. (n.d.). http://carnegiefoundation.org/programs/index.asp?key=21.

Cerbin, W. (1996). Inventing a new genre: The course portfolio at the university of Wisconsin-La Crosse. In Pat Hutchings (ed.), *Making teaching community property: A menu for peer collaboration and peer reviews*. (pp. 52-56). Washington, DC: American Association for Higher Education.

Chein, O. (1998). A course portfolio in mathematics. In Pat Hutchings (ed.), *The course portfolio: How faculty can examine their teaching to advance practice and improve student learning*. Washington, DC: American Association for Higher Education.

Dray, T., & Manogue, C. A. (2003). Using Differentials to Bridge the Vector Calculus Gap. *College Mathematics Journal*, 34, 283-290.

Hake, R. R. (1988). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics students. *American Journal of Physics*, 66, 64-74.

Halloun, I., & Hestenes, D. (1985). The initial knowledge state of college physics students. *American Journal of Physics*, 53, 1043-1055.

Heller, P., Keith, R., & Anderson, S. (1992). Teaching problem solving through cooperative grouping. Part 1: Group versus individual problem solving. American Journal of Physics, 60, 627-636.

Heller, P., & Hollabaugh, M. (1992). Teaching problem solving through cooperative grouping. Part 2: Designing problems ans structuring groups. American Journal of Physics, 60, 637-644.

Huber, M. T., & Hutchings, P. (2005). *The advancement of learning: Building the teaching commons*. San Francisco: Jossey-Bass Inc.

Hutchings, P. (ed.). (1998). *The course portfolio: How faculty can examine their teaching to advance practice and improve student learning*. Washington, DC: American Association for Higher Education.

Janvier, C. (ed.). (1987). *Representations in Mathematics*. Hillsdale, NJ: Erlbaum.

Knowledge Media Laboratory (KML). (n.d.). http://carnegiefoundation.org/programs/index.asp?key=38.

Larkin, J. H., McDermott, J., Simon, D. P., & Simon, H. A. (1980). Expert and novice performance in solving physics problems. *Science*, 208, 1335-1342.

Larkin, J. H., & Reif, F. (1979). Understanding and teaching problem solving in physics. *European Journal of Science Education*, 1, 191-203.

Manogue, C. A. (2003). *A novel curriculum*, Retrieved on November 27, 2005 from Oregon State University, Department of Physics website: http://www.physics.oregonstate.edu/paradigms/AdopterFiles/adoptersoverview.html

Manogue, C. A., Siemens, P. J., Tate, J., & Browne, K. (2001). Paradigms in Physics: A new upper-division curriculum. *American Journal of Physics*, 69, 978-990.

National Commission on Excellence in Education. (1983). *A Nation at Risk: The Imperative for Educational Reform*. Washington, DC: U.S. Department of Education. Retrieved on June 2, 2006, from http://www.ed.gov/pubs/NatAtRisk/risk.html.

Redish, E. F., Saul, J. M., & Steinberg, R. N., (1996) On the effectiveness of active-engagement microcomputer-based laboratories. *American Journal of Physics*, 65, 45-54.

Urbach, F. (1992). Developing a teaching portfolio. *College Teaching*, 40, 71-74.

van Heuvelen, A. (1991). Learning to think like a physicist: A review of research-based instructional strategies. *American Journal of Physics*, 59, 891-897.

Weiser, C. J., & Houglam, L. (1998). Scholarship unbound for the 21st century. Journal of Extension, 38(4).