A DYNAMIC DIGITAL ENVIRONMENT FOR THE EXPLORATORY LEARNING OF PHYSICS PEDAGOGY

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ABSTRACT
A new physics teacher faces a daunting task. All too frequently he or she is asked to teach physics without sufficient background knowledge in either the content or pedagogy of physics. Yet, obtaining that background information is not easy for an in-service, under-prepared teacher. The Physics Teaching Web Advisory (Pathway) is addressing this issue by creating a system that builds on a unique collaboration among several longstanding research projects in digital video libraries, advanced distance learning technologies, collaboration technologies, and nationally known experts in physics pedagogy and high quality content for physics teaching. This library provides information which can help teachers of all levels of proficiency prepare for their classes including a large corpus of virtual video laboratories and demonstrations that emphasize hands-on and minds-on activities as well as conceptual understanding of physics. Pathway is integrated with a novel system by which users can easily obtain valuable assistance through interactions with virtual experts in the field.

To make these materials accessible, Pathway includes state-of-the-art video retrieval tools: Informedia Digital Video Library, which extracts information from video and audio content, and Synthetic Interviews (SI) of expert physics teachers, with pedagogical advances developed at Kansas State University and with materials contributed by master teachers. With Synthetic Interviews developed for Pathway, the new-to-physics teachers, pre-service teachers, and experienced teachers will be able to become more effective teachers of physics by interacting, both virtually and directly, with knowledgeable experts on their classroom techniques and how those techniques are related to contemporary issues in physics teaching.

KEYWORDS
Digital Library Virtual Agent Physics Pedagogy
1. INTRODUCTION

Imagine a high school teacher who has been pressed into service to teach physics for the first time. If the school is fortunate, this teacher is likely to be a biology, chemistry or math teacher in a school that cannot find or cannot afford a teacher who concentrated on physics at a university. Less fortunate schools are “drafting” anyone who took a physics course as its physics teacher. These teachers face a daunting and all too frequently occurring task. Today, web resources abound to provide this teacher with assistance. Even with these aids, our teachers will undoubtedly have questions about the best approaches to help students acquire new concepts.

We are creating a digital resource to help a teacher who is new to physics teaching make the very large step from having completed a physics course in college to teaching the topic to bright high school students. Consider the following scenario: getting on the web, an educator newly assigned to teach physics asks a question to our on-line forum. This forum is monitored by virtual agents including an agent representing one of the foremost introductory physics textbook authors, Paul Hewitt. The virtual agent knows how to answer the question, and presents the answer using recorded video of Paul, along with suggestions for graphics, videos and laboratory experiments that the teacher can use. The teacher can ask follow-up questions, and can create his/her own on-line library to store all of the elements used in the lesson, student assignments, and notes to himself/herself for the full course.

A number of projects are creating traditional digital libraries for physics teaching. For example, the Just-In-Time Teaching activities (Indiana University 2002) use a pedagogical structure that is very similar to the one described in section 2.3. ComPADRE: Communities for Physics and Astronomy Digital Resources in Education (ComPADRE 2004), an interconnected set of digital collections of educational material under construction by four physics and astronomy professional organizations (the American Association of Physics Teachers, the American Physical Society, the American Institute of Physics/Society of Physics Students, and the American Astronomical Society) is a consortium of content providers devoted to creating and sustaining collections of learning resources for physics teachers and students. Each of these projects is creating collections of text, websites, animations and graphic simulations primarily through acquisition of existing traditional corpora.

We have constructed a system to provide an experience described in the scenario above with existing state-of-the-art technology and the creation of unique agents to assist users in the development of pedagogical expertise. Combining Carnegie Mellon University’s digital video library technology – Informedia (CMU 2002) and its Synthetic Interview (Stevens & Marinelli 1998) software – with pedagogical advances developed at Kansas State University and with materials contributed by master teachers, we have created the Physics Teaching Web Advisory (Pathway), a dynamic digital library for helping teachers who are new to physics teaching. Pathway goes beyond simply creating a collection of teaching and learning materials. It provides continuously improving assistance and expertise for teachers. Pathway is built on a unique collaboration between longstanding research projects in digital video libraries, advanced distance learning technologies, collaboration technologies, and nationally known experts in physics pedagogy and high quality content.

2. PHYSICS TEACHING WEB ADVISORY: PATHWAY

“High school physics teachers in short supply,” reads a front-page headline on the March 2000 issue of the American Physical Society’s News (APS News 2000). According to the article, only one-third of physics teachers are considered specialists in their fields. As a result, a very large fraction of the instructors who teach high school physics are teachers of other sciences, mathematics, or other subjects who have been pressed into service in the physics classroom. Frequently, these teachers are well intentioned and do the best they can, considering their limited background in both the content and the pedagogy of physics, but they still need additional support.

To address this and other issues related to under-prepared physics teachers, and to provide resources that can enliven even the most expert physics teachers’ classrooms, the materials in Pathway provide the under-prepared teacher with professional development and the well-prepared teacher with new perspectives on teaching physics. As will be seen below, Synthetic Interviews enable all users to “converse” with
knowledgeable experts on their classroom techniques and how those techniques are related to contemporary issues in physics teaching.

2.1 Informedia

Pathway is built on the Informedia Digital Video Library (Wactlar et al. 1999), which focuses specifically on information extraction from broadcast television video and audio content. It operates similarly to a Web search engine, but does so by searching on video and audio information. Informedia has automated the creation of a rich, indexed, searchable multimedia information resource through speech, image, and natural language processing. The interface has been designed to allow efficient browsing and access to information in spite of errors in the automatically produced descriptors of content, i.e., the metadata. Additionally, the Human-Computer Interaction Institute (CMU 2001) examines the social aspects of tools developed to assist human activity and evaluates those tools through carefully designed experiments. Figure 1 shows the interface of the standard Informedia client, where the query is at the upper-right window.

![Figure 1. Results of an Informedia search](image)


Pathway aims to foster inquiry-based learning through the use of these materials in “hands-on” virtual laboratories and demonstrations. Nonetheless, teachers will continue to spend time lecturing. In fact, some lectures can be highly motivating and useful for a variety of students (Schwartz & Bransford 1998). However, it is unlikely that under-prepared teachers will, in isolation, develop and present such lectures.

In addition to the above-mentioned video corpus, Pathway will also contain videotaped classes by Paul Hewitt, a master teacher who has just finished the 9th edition of the acclaimed text, *Conceptual Physics* (Hewitt 2001). Hewitt is a pioneer in the teaching of physics concepts rather than focusing on the mathematics of physics. Over several decades, Hewitt’s best lectures have been preserved and are being made available to teachers seeking presentation techniques, demonstration ideas, or basic teaching skills. Prof.
Hewitt recently completed a weeklong teacher enhancement workshop on teaching physics conceptually, and all of the workshop was recorded on video and will be available on Pathway.

Using Pathway, a teacher will be able to ask to see how Hewitt presented a concept and/or discussed his presentation with other teachers. If we were to simply give the teacher the ability to view an hour class, where only 5 or 10 minutes were relevant, few teachers would spend the time viewing the video. However, with Informedia’s capabilities teachers will be shown just the section of the presentation relevant to their query. As useful as these materials may be, nothing surpasses one-on-one interactions with a mentor. Paul Hewitt cannot be available 24 hours a day to answer questions from hundreds of teachers, and thus Synthetic Interviews provide the next best thing.

2.2 Synthetic Interviews

During the infancy of the Internet, pundits predicted that e-mail and chat rooms would usher in this new age by providing a forum where anyone could ask any question of world-class experts. The obvious error in this reasoning is that in any specialty, the number of experts is very small in comparison with the general population. Experts do not scale, and they do not want to spend all their time answering questions.

Figure 2: A Synthetic Interview session

Traditional formats such as linear interviews can contain a surprising amount of knowledge, but simply watching such a presentation is seldom effective. The Synthetic Interview is a technology and technique that creates an anthropomorphic interface into multimedia data of a particular kind: video of a person responding to questions (interacting with another person). The responses of the interviewee are presented in such a way as to simulate the experience of interacting with the expert. Synthetic Interviews allow learners to engage in active inquiry by providing the means for conversing in-depth with an individual, permitting users to ask questions in a conversational manner (just as they would if they were interacting with the expert face-to-face), and receive pertinent answers to the questions asked. It is even possible for the SI to present the equivalent of clarifying questions in order to present conditional responses. Synthetic Interviews permit knowledge capture in a new form. They are highly interactive and vastly more useful than videotape. They provide a utility similar to an expert system, but through a development effort approaching the simple videotaping of a conversation.
We have created and evaluated Synthetic Interviews in numerous fields including a panel of physicians (see Figure 2), historical figures (e.g. Benjamin Franklin), nationally renowned scientists (e.g. Albert Einstein), and sports stars (e.g. Joey Mullen). Existing Synthetic Interviews are accessible via either typed or spoken interfaces. Beyond just a talking head to answer the users’ questions, an SI response can present links to other sites, supporting video, images, or simulations. In short, the SI can present any information needed to support the discussion at hand.

In previous applications of Synthetic Interviews, the technology was so effective that some users thought they were chatting with a live person. We have performed several qualitative studies regarding the usability and impact of Synthetic Interviews (Stevens & Cross 1997). Users consistently preferred Synthetic Interviews to other web-based delivery forms. In the study, neurologists interacted with a Synthetic Interview of a world-class neurosurgeon. While their first preference was a live, real-time consultation with a specialist, they recognized that such consultations are not always possible when and where needed. Study respondents uniformly preferred the Synthetic Interview to purely text responses and would accept it as a replacement to a live consultation if such were not possible.

2.2.1 Pathway Synthetic Interview Experts

Current Pathway Synthetic Interviews include: Paul G. Hewitt (see Figure 3), who received Robert A. Millikan Medal from the American Association of Physics Teachers (AAPT) for his outstanding contributions to physics education, well-known both for his ability to teach conceptual physics and to describe the teaching process to others, in addition to his success as a textbook author, and Charles and Roberta Lang, two experienced and distinguished high school physics teachers and lecturers on physics pedagogy.

Figure 3: A Pathway Screen with a Synthetic Interview on the right and Informedia search results on the left

Charles and Roberta Lang are highly successful, recently retired high school physics teachers. Charles taught physics for almost 30 years in Omaha, Nebraska while Roberta was both a physics and chemistry teacher for about the same period in Orlando, Florida. Their teaching experiences thus range over a broad spectrum of physics content and approaches as well as different types of student audiences. Both of them are well known to the community of high school teachers. They frequently present workshops on aspects of teaching at regional and national meetings. They have been involved in a number of curriculum development projects including Physics: Cinema Classics (Fuller et al. 1995), Physics InfoMall (Fuller & Zollman 1995), and The Science of the Bicycle (Zollman et al. 1998). Charles Lang is a recipient of the Presidential Award for Excellence in Science and Mathematics Teaching. Together they provide a wide range of experience and advice to the under-prepared teacher.
2.2.2 Synthetic Interview Technology and Development Process

The Synthetic Interview maps videotaped responses to domain specific questions. The Synthetic Interview search engine technology matches the user’s question with the most appropriate response. This intelligent multimedia technology combines technologies all created at Carnegie Mellon University (Stevens & Wactlar 1996): the Sphinx speech recognition system (for spoken language queries), a highly modified algorithm from the Lycos search engine, and Informedia digital video information retrieval system.

One of the most daunting tasks in developing a natural language system is engineering a domain-specific grammar. Synthetic Interviews afford the opportunity to greatly reduce this effort with the searching algorithm. Initially, we seed the corpus with questions collected in existing dialogues between teachers and their mentors, archived email questions to master teachers, and captured instant message sessions during online dialogues. The recorded answers to those questions are the foundation upon which we build the Synthetic Interviews. To seed the Pathway Synthetic Interviews with answers to questions, we asked ten students in a graduate physics and education course at Kansas State what questions they would ask textbook authors or experienced teachers. Five of the students were former high school teachers, and the rest had undergraduate degrees in physics. The population in gender was balanced. A second group of questions was created by members of Kansas States’ Physics Education Research group. These questions were generated based on student difficulties gleaned from research papers on student learning of physics.

Processing of open-ended user questions is a challenging task. However, it is a tractable task because full processing and “comprehension” of the input is not required. Instead, mapping to functional meaning categories with appropriate responses is sufficient. Synthetic Interview technology employs both structural and statistical processing algorithms to perform its categorization. As users interact with a Synthetic Interview, questions and responses are stored in state variables that keep track of the history of the Interview. These variables capture information on the current topic of conversation, the length of focus on this topic, and the current speaker. Subsequent questions and responses are passed through a checker which checks for repeated queries and determines the need for and types of response. Meanwhile, we are investigating the use of Natural Language Processing (NLP), dialogue structuring techniques, and tools developed in related CMU projects (Aleven et al. 2001).

Figure 4. The process of Synthetic Interview

Effective Synthetic Interviews require iterative evaluation of question categories and extension of the response category corpus, based on continuous monitoring of the user questions (see Figure 4). In practice, teachers and students ask many questions in a conversational fashion. If the system determines it has a relevant answer to the question, the user will receive an immediate response. If there is no match, the question will be sent via e-mail to the appropriate respondent. The domain expert records a response, which is sent as video email to the inquiring teacher and entered into the corpus for the next time it is asked (dashed arrow in Figure 4).

Early observations suggest that the initial Pathway Synthetic Interviews, created with seed questions only, answered upwards of eighty percent of novice users’ questions. Various workshops have been held recently for potential users to experience the state-of-the-art Pathway system. In November 2003, 15 users at the N-OAK AAPT workshop tested the system and provided valuable questions and human-coded correctness of
the responses. In 2004, 7 different workshops have been held, and the Pathway system has been tested by more than 100 users. More than 50% of the questions asked were correctly answered, considering the fact that currently Pathway only covers kinematics and dynamics (the first few weeks of a typical physics class), and one-third of the questions asked were related to Newton's 3rd law, rotation, and thermodynamics. From our observation, all users were pleased with the digital video libraries, and users who were new to physics teaching were also satisfied with the Synthetic Interviews. In addition to asking questions, some users also suggested a pull-down menu on the interface with major topics, which we then implemented.

So far, we have collected more than 26,000 questions and created 112 answer categories for Pathway. As more and more questions are asked and answered overtime, a Synthetic Interview deepens its knowledge and increases its reliability. Thus, the system builds and improves its performance as teachers use it. The Pathway project is in a unique position with long term commitments from expert teachers to continue to develop their Synthetic Interviews.

2.3 Pathway Pedagogy

Captivating images help grab students' attention. By using interesting video of teachers who describe and use, on camera, pedagogically sound techniques, we leverage students' natural curiosity about the world around them to teach some exciting physics. By including learning materials developed at Kansas State University, we are encouraging an inquiry-based approach to physics learning. For example, all video developed by Kansas State University and used in the Pathway project uses "the learning cycle" as the pedagogical basis. The learning cycle is based on the work of Karplus (Karplus 1977) and has been very successful in teaching physics to future teachers (Zollman 1990, 1994). An entire learning cycle consists of three phases: exploration, concept introduction, and application. During the exploration phase, the students learn through their own more or less spontaneous reactions to a new situation. Meanwhile, they are exploring new materials or ideas with minimal guidance or expectation of specific achievements. Their pattern of reasoning may be inadequate to cope with the new data, so they begin to modify and develop their reasoning skills further.

During the concept introduction phase, a new concept is defined, a new principle introduced or an application is explained to expand the student's knowledge, skills, and/or reasoning. This step follows an exploration and relates to the exploration activities. An appropriate approach to concept introduction is to build on the exploration and encourage individual students to "invent" part or all of a new idea for themselves, before it is presented to them.

During the last phase of the learning cycle, application, a student finds new uses for the concepts or skills he or she has invented or learned in the concept introduction phase. The application phase provides additional time and experiences for the development of reasoning. It also gives the teacher the opportunity to introduce the new concept repeatedly to help students whose conceptual re-organization proceeds more slowly than average or who did not adequately relate the original explanation to their experiences.

Each video segment in Pathway carries with it information about how it can be used in a learning cycle format. In addition, text annotations identify how the segment is related to the National Science Education Standards. By attaching metadata and annotations to the lessons, we will significantly help teachers understand the lesson design, the lesson's pedagogical intent, and its correlation with the Standards.

3. CONCLUSION

To assure widespread usage of Pathway we are undertaking efforts to introduce in-service teachers and science educators, who are responsible for preparing future teachers, to its features and its advantages over other Web searches of database products. Our primary efforts in this component of the project is through workshops held at meetings of the National Science Teachers Association, the Association for the Education of Teachers in Science, and the American Association of Physics Teachers. These workshops provide teachers with a two to four hour introduction to the system and get them started in using it for their own teaching.

We are just finishing a two year development grant to create Pathway. We have presented the work to physics educators at the above mentioned workshops. Initial user response was uniformly positive. The video
corpus of demonstrations, virtual laboratories, and pedagogical lectures accessible through Informedia form a foundation supporting the improvement of physics teaching. Coupled with Synthetic Interviews, permitting a user to ask specific questions of domain experts, Pathway provides a more relevant, interesting, on-demand, and personal exploratory experience.

ACKNOWLEDGEMENT

This material is based on work supported by the National Science Foundation (NSF) under Grant No. DUE-0226219 and DUE-0226157.

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