Coupling Conversational Interactivity with other Presentation Modes in the Exploratory Learning of Physics

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Abstract. A variety of interfaces have been used to enable students to interact with learning technologies. However, these technologies seldom attempt to provide an interface that is similar to a conversation between two people. Building on work at the Carnegie Mellon Human-Computer Interaction Institute and Entertainment Technology Center, we have applied such a conversational interface to the enhancement of physics teaching. This paper reports on early work extending this unique learning environment; plans to formally studying student exploratory learning within the environment; and establishing, through this research, design principles which are specifically focused on this new mode of computer-student interaction.

Keywords. Active learning environment, Synthetic Interview, digital video library, physics education research

Introduction

A small number of universities have made the move from large lectures with smaller recitations and laboratories to small inquiry-based classes. Notable in this movement are Studio Physics [1, 2] and Investigative Science Learning Environment [3]. However, even in these student-centered classrooms, the relatively low teacher-to-student ratio (typically ~1:40) remains a bottleneck in providing students the individualized support that yields the most effective learning.

Imagine, in contrast, a college student, Chris, learning physics in an early 21st century classroom in which teacher access is no longer a scarce resource. Chris will spend relatively little class time listening to the teacher lecture and will spend more time actively constructing knowledge of physics. But further imagine that as Chris works:

- A personalized tutor is constantly available for Chris.

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- Chris is able to ask questions and the tutor is always available to engage Chris in interactive exploration of these questions.
- Through the presentation and discussion of motivational, pedagogically sound multimedia learning objects, the tutor encourages Chris to develop the metacognitive "learning to learn" skills that are essential to future academic success.
- The tutor individualizes the learning and problem-solving experiences and discussions to help Chris develop a deep, conceptual understanding.
- Chris and classmates can work together and query the tutor even from different locations.

When Chris leaves campus, the tutor comes along both to help with homework and engage Chris in wide-ranging question-and-answer dialog! Later that evening, Chris joins a group of three other students online. Each student in the group sees and interacts with the same learning environment. As individuals ask the tutor questions, all in the group see and hear the response and are able to interact collectively or individually with identical multimedia learning objects.

A university teacher with 30 to 40 students cannot provide this level of individual attention, but with advances in computational technologies and in our understanding of pedagogy, the development of this level of support through interactive, collaborative computer-based learning environments is within our reach. However, we need an increased level of understanding about the best way to utilize the various forms of media that can be invoked in such a technology-based tutor. This research is investigating which components of such an interactive system contribute best to student learning.

We are building a body of research on effective learning and design strategies for a novel interactive communication technology, Synthetic Interviews, combined with other interactive media. Our goal is to demonstrate that an advanced version of our Pathway system, which is now limited to helping individual teachers and students, can approach the effectiveness of human tutors in supporting collaborative deep student learning.

The Synthetic Interview (SI) provides a unique way for students to interact with learning technologies. The combination of the SI with other interactive learning modes and collaborative networking has the potential to greatly enhance learning. Because this type of interactivity has not been readily available for science teaching, it has not been carefully studied. This research is providing data and results about methods of integrating a human-style computer interface with other types of interactive, computer-based learning enabling students to interact individually or in groups for more efficient, effective, persistent learning.

We begin by describing the enabling technologies that comprise the original Pathway system designed for use by teachers [4]. First, we describe Pathway's Informedia Digital Video Library system and the current corpus. The section below details the Synthetic Interview technology and Pathway's existing SIs that capture pedagogical knowledge for use by in-service and pre-service teachers. Finally we describe a formative study of SIs and high school and college students.

1. Pathway Informedia Digital Video Library

Pathway is built on the Informedia Digital Video Library [5], 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. Unlike YouTube which searches only on keywords provided by the contributor, 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 [6] examines the social aspects of tools developed to assist human activity and evaluates those tools through carefully designed experiments. Informedia provides Pathway with a foundation of a unique, well-developed infrastructure and research base. It enables us to provide an audio-video search engine, which is unprecedented in present science or science education digital libraries. The investigators have experience in evaluation work, with Informedia interfaces scoring best or statistically clustered with the best for all the years 2001-2006 in which we participated in the benchmark NIST TREC video retrieval interactive search task; details are recorded in online proceedings at [7].

2. Synthetic Interviews

Today, a popular Internet application is the chat room or its contemporary extension, Twitter and Instant and Text Messaging. During the infancy of the Internet, pundits predicted democratization of expertise and knowledge. Email and chat rooms would usher in this new age by providing a forum where anyone could ask any question of world-class experts. An error in this reasoning is that in any specialty, the number of experts is very small when compared to the general population. Experts do not scale, and cannot spend all their time answering questions.

A variation to convey information is a linear interview which can contain a surprising amount of knowledge. But simply watching such a presentation in which someone else is asking the questions is seldom an effective learning tool. The Synthetic Interview addresses the passive nature of the interview by creating an anthropomorphic interface into multimedia data video of a person responding to questions (interacting with another person). However, the responses of the interviewee are presented in such a way as to simulate the experience of the user interacting with the expert. Thus, SIs allow learners to engage in active inquiry by providing the means for conversing in-depth, permitting users to ask questions in a conversational manner (as they would if they were speaking to the person face-to-face), and receive relevant, pertinent answers to the questions asked. The SI can even present the equivalent of clarifying questions in order to simulate conditional responses. SIs permit knowledge capture in a new form.

We have created and evaluated Synthetic Interviews in numerous fields, including a panel of physicians, historical figures, and sports stars. We have begun the evaluation of the use of SIs in enhancing physics teaching. In previous applications of SIs, 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 SIs. Users consistently preferred SIs to other web-based delivery forms. In one study, neurologists interacted with an SI 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. In this study, respondents uniformly preferred the SI to purely text responses and would accept it as a replacement when live consultation was not possible.

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. SI technology employs both structural and statistical processing algorithms to perform its categorization. The SI performs this mapping from query to answer via an information retrieval algorithm based on "tf.idf" (term-frequency, inverse document frequency[8]. Initial question-matching occurs statistically based on relative word frequency in the database of known questions and the user query, rather than through knowledge-based natural-language processing (NLP). Systems that use knowledge-based NLP often encounter an implementation bottleneck due to the knowledge engineering effort required to create them [9]. Unlike the reliance of such NLP systems on *explicit* domain knowledge authoring, SIs possess *implicit* domain knowledge via what questions are answered and how.

Using this technology, we have developed the Physics Teachers Web Advisory (Pathway) for out-of-field high school physics teachers. Current Pathway SIs include: Paul G. Hewitt, a well-known author of both high school and college physics texts; Charles and Roberta Lang, two experienced and distinguished high school physics teachers; and Leroy Salary, an Associate Professor at Norfolk State University. Together they provide a wide range of experience and advice to the physics teacher. Roberta Lang is shown in Figure 1.

The Pathway database has 6,687 questions, with more than 454,000 utterances (variations), and 20,158 unique question/answer pairs. 3,569 of the questions are directly associated with National Science Education Standards. At this time the evaluation of Pathway has continued to be a combination of Contextual Inquiry and Heuristic Evaluation at workshops and at professional meetings, feedback from individual users, and the beginnings of an analysis of the questions which teachers ask of the system. Users of the system continue to have very positive comments, especially noting the effectiveness of searches. Teachers who are relatively new to physics teaching have found the natural language "interviews" useful. Ongoing analysis of the questions posed by users shows that almost three-quarter of all questions relate to issues of physics pedagogy. This result indicates the inexperienced teacher is much more interested in and concerned about the methods of teaching rather than the physics subject matter [10].

Informed by evaluations, the user interface was significantly redesigned and completely reprogrammed during the past year [11]. In addition to the ability to answer questions, the interface adds the capability of showing graphics which the expert teacher is discussing, improved lists of related questions and quick start questions. These latter two are particularly important to out-of-field teachers because they sometime do not know what question to ask. By providing questions which are related to their or some questions on each major topic in physics, we give these teachers a place to start the conversation with the expert teachers. A recent addition is a connection to comPADRE, the National Science Digital Library portal for physics and astronomy education. After listening to the SI response the teacher can "ask comPADRE" the same question and obtain links to teaching tips and related physics education research.

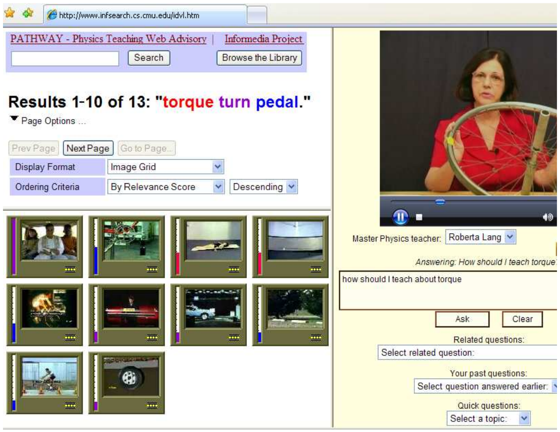

Figure 1: A Pathway Screen with a Synthetic Interview on the right and Informedia search results on the left.

In a case study approach to evaluation, we asked a physics teacher with three years of experience to use Pathway to enhance some of the lessons which she had been teaching. She asked questions of our expert teachers on sound and electrostatics. Then as appropriate she added or changed items in her lesson plan. She was able to find a large number of useful suggestions and made some changes to each day of the lessons.

3. Tutorials in the Pathway Active Learning Environment.

As an extension to Pathway and with NSF funding under the Advanced Learning Technologies program we are building and studying the *Pathway Active Learning Environment*. In this project the Synthetic Interview is being tightly integrated with other media such as video, text, animations, illustrations, and simulations. The result gives the students the impression of a person who is talking directly to them, explaining complex concepts and helping them use highly interactive illustrative media. The research component of this effort is testing the hypothesis that the combination of the SI with other interactive media will create a system that will improve student understanding of topics in physics.

Three tutorial lessons have been developed to serve as the basis for the research on various aspects of the tutorials. Each lesson focuses on one of Newton's Laws and is based on some of the questions on the Force Concept Inventory [12]. The lessons include active learning which students complete by using video and audio delivered through the *Pathway Active Learning Environment* tutoring system.

To prepare appropriate Synthetic Interview responses that will accompany the tutorials, we have been testing each of the lessons using instructors or written instructions to substitute for the Synthetic Interview video. The tests have been conducted in algebra-based and conceptual physics classes as well as one-on-one interview settings. Based on the preliminary findings (reported below), modification to the lessons and the development of the Synthetic Interview responses are being completed.

Preliminary testing has focused on determining what students will ask and what types of tasks challenge them. To that end we began by conducting 7 interviews with students in either algebra-based or conceptual physics classes. Students were asked to work through our lesson materials and ask the facilitator for assistance as needed. The students provided written answers to both quantitative and qualitative questions. From these interview data we hoped to get two pieces of information. We sought to gauge whether our lesson materials were appropriately challenging to students without overtaxing them, and to determine what kinds of questions students would ask so that we might generate a list of questions to which we should provide answers via the SI. Interactions with the students indicated that we needed to include answers to questions about background concepts such as kinematics even though the lessons do not focus on kinematics. Although most students were familiar with the kinematics concepts needed for study of Newton's laws, they were not always capable of applying those concepts correctly. This difficulty could seriously hinder their ability to successfully work through the lesson materials. The students did, however, recognize that they needed assistance with those concepts, and so providing that support allowed them to be more successful in their observations, measurements, and calculations.

To expand the information from students before all of the capabilities of the *Pathway Active Learning Environment* were ready, we implemented our lessons on the Internet using an online survey system embedded in the lesson content. This arrangement created a system in which students could complete the lessons at their homes or in a computer lab and we could collect their detailed responses to our questions -- both quantitative, and qualitative. Eighty-nine students in a college algebra-based physics class completed all three lessons. Thirty students in a high school physics class are currently working through the lessons. Preliminary analysis of the college students' responses confirms that many students struggle with the correct application of kinematics. Another interesting observation is that some of these students seem to have memorized a correct interpretation such as that an object's speed is constant as predicted by Newton's first law and provide this interpretation even when their calculations, which may be incorrect, indicate quite the opposite. This result suggests that providing students with feedback about the correctness, and self-consistency of their answers may be important. Clearly this feedback must be done in a careful way, a pop-up box that says "I'm sorry that is not correct" is certainly not enough, and may simply promote guessing. A prompt that promotes thinking will need to be developed by further study of how students work with the lessons. Additionally we have asked students who worked through our lesson materials on the web to help us rate the utility of Socratic hints, which could be useful for encouraging the students themselves to act as a check on the correctness and self-consistency of responses. A detailed analysis of these data sets will reveal more methods of optimizing scaffolding and the challenge level of the lessons.

With this preliminary information we have begun to implement the full SI system. The system will enable us to control variables to determine which of the multimedia components of the Web-based system are most valuable and which provide appropriate scaffolding in different situations.

4. Research Design Methods

Building on the Pathway Active Learning Environment, we are creating a collaborative learning environment by expanding the capabilities of the Pathway system, study its effects on student understanding of physics, and define the process for designing learning experiences in Pathway. In order to accomplish this, we are developing the infrastructure to support the following interaction hierarchy of SI with other media interaction types in a distributed, collaborative environment and study how groups communicate and learn with them:

- Synthetic Interview and other media operate as separate, non-communicating processes.
- Synthetic Interview response is played after which SI brings up other media in a separate pane.
- Synthetic Interview response is played after which SI controls predetermined interactive learning media which are automatically played (plays video, starts simulation).
- Synthetic Interview response plays synchronously with predetermined other media (SI is responding to and discussing what the student is viewing).
- Synthetic Interview response plays synchronously with predetermined media objects (SI is responding and discussing what the student is viewing) – SI is informed of student’s actions and conditionally the SI may initiate further dialog and/or subsequent SI responses may be modified based on student input.

Synthetic Interview responses that communicate with and control learning objects such as images, videos, simulations and applications will provide opportunities for students not only to develop their understanding and reinforcement of physics concepts, but also to develop their skills in scientific investigation and inquiry. SI responses communicating, controlling, and monitoring media learning objects will enable students to become involved in the active process of learning science.

5. Learning Research Framework

Until the late 1990s and early 2000s, most physics education research focused on investigating whether students had understood a particular concept by asking them to apply it in a variety of contexts. If students were unsuccessful at applying the concept correctly, researchers concluded that the students lacked conceptual understanding. Some diagnostic instruments, such as the Force Concept Inventory [12], attempted to go a step further to identify the students’ misconceptions by using carefully selected distracters based on prior research on students’ misconceptions. However, researchers [13, 14] soon realized that students’ misconceptions were often manifestations of flawed deeper understanding of how the world worked. In a sense, the misconception was analogous to the symptom, while the more deeply flawed worldview was analogous to the disease. It was the latter that needed to be identified and treated.

Within this research context, several investigators noted that knowledge is fragmented and have alluded to the notion that students do not have well developed or coherent mental models that they use, instead activating pieces of knowledge [15, 16, 17, 18, 19]. In turn the activation of these pieces depends upon the problem context. diSessa points out these pieces themselves may not be correct or incorrect, but they may be correctly or incorrectly activated in a particular context [20, 21].

In relation to the knowledge-in-pieces view proposed by several researchers, recent findings by Hrepic and Zollman [22, 23] demonstrate that students often make up answers on the spot. Students may combine ideas and dynamically choose, apply, and reject ideas as they think through the answer to a question. Often they combine seemingly disparate ideas to form a hybrid mental model [23] that "works" in a given set of contexts.

Based on these findings, several researchers [24] have begun to focus on the process by which students construct these models, regardless of whether these models are scientifically accepted. The focus then is on the dynamics of the knowledge construction process by the students, rather than on the scientific correctness of the end product. This perspective is a more student-centered approach to thinking about students' mental models than previous perspectives .

Attending to the pieces of knowledge that are activated by students when they are asked a question is a useful perspective to adopt, because it allows us to develop instructional strategies that help students activate and build on the productive nuggets of knowledge that they already possess, while inhibiting the activation of unproductive pieces of knowledge. Evidence exists that some students who are successful in their classes may be doing that already. These students often obtain a 'good' grade in their course based on 'traditional' assessments such as class examinations. Also, many of these students go on to take more advanced classes in physics or engineering and have successful professional careers in these fields. However, the numbers of students are relatively small compared to the number who could succeed in STEM courses. Thus, we need to investigate further to understand how students think, under what conditions they activate their productive pieces of knowledge, and what characteristics of both the students and the learning environment help with the activation process, particularly when technology is involved in the learning.

The educational research component of this effort is focusing on how students and student groups make connections and transfer knowledge as a function of our interaction hierarchy between the SI and other learning components. The framework for this research is based on prior work at KSU in which we built a framework for investigating transfer of knowledge during an interview [24]. This framework was, in turn, built on the work of Redish [18] in which he broadly applied results and theories from the behavioral sciences to physics education research. In both of these efforts, a focus is placed on fundamental units of knowledge, which we will call *resources*. In this constructivist model, students build new knowledge by associating resources with each other. These associations are implicitly controlled by external inputs or cues received by the student.

In the adapted framework, which we use in this work, the SI and the other learning components are the two resources. The type of interactions between the SI and objects is the external input that controls the way in which students' construct associations between these resources.

The ways in which a student uses the SI and Informedia are external manifestations of the implicit associations made by the student between these two resources. By providing students with different interaction types, we are providing them with different external inputs which in turn control (i.e., either turn-on or turn-off) the associations between these resources. If in a particular instance, students combine these resources synergistically to construct their understanding, we conclude that they have created productive associations between these resources.

Our research will investigate how differences in interaction types affect the students' abilities to make associations or exercise control over them. We are investigating the following hypotheses:

- Certain learning hierarchies resulting from the combination of the Synthetic Interview with other interactive media will be more effective than others for the learning of introductory physics by students.
- Carefully developed and executed scaffolding can improve the technology-based individualized and group learning for all of the hierarchies when applied to learning physics for students.
- The lessons learned from this research can be applied to the improvement of technology-based learning and help designers select an appropriate hierarchy for many different tutoring environments.
- Individual differences among students are important in determining which interaction type is best to help them construct knowledge from their existing resources and our external inputs.
- Each of the above hypotheses may be different for students of different ethnicity, gender, or academic background.

Using various types of observation protocols to analyze the ways in which students interact with the system and each other, we will learn how the various integrations provided to the students control the associations to build new knowledge. We are adapting the analysis methods such as those used to conduct research on one-on-one tutoring [25] and on transfer of learning [24].

Our research will use primary methods of analysis:

- <u>Phenomenographic Analysis</u> Categories for coding the interactions will emerge from the analysis of the students' interactions with the system and will be based on students' ideas rather than researchers' preconceptions. This strategy is consistent with contemporary notions of transfer and knowledge association in which the researcher does not prejudge what idea a student must associate to build new knowledge; rather he/she looks for what, if anything, the student has associated and controlled.
- <u>Thematic Analysis</u> Phenomenographic categories, together with observers' field notes and reflections will determine the main themes and variations on that are most effective in aiding the creation of associations and controls.

Through this analysis, we will be able to learn what types of computer interactions within Pathway most effectively aid student understanding. Further, we will have learned how interaction types differ with student characteristics such as gender and ethnicity, enabling us to use these data to address the hypotheses stated above.

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