CHANGING ONLINE PARADIGMS: BEYOND INFORMATION TRANSMISSION 'LECTURES' TO RESEARCH-BASED INTERACTIVE SCIENCE LABORATORIES

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ABSTRACT
Robust online courses in the sciences must be based on: (1) sound, research–based pedagogy, (2) rich laboratory environments with skills and operational knowledge transferable to the wet 'lab', (3) a paradigm that is economically scalable. LAAPhysics courseware is designed to meet these challenges in the distance-learning field. LAAPhysics uses Java, C, C++, XML and other server/client technologies to develop and build a complete, highly interactive online physics laboratory comprised of equipment and instrument objects and associated research-based curriculum modules. Information exchange between client and server in the LAAPhysics environment enable users to increase the depth of guidance which a student receives. Data includes dialog (guide agent/tutor and student), white board discussions with virtual peers, UI selections, assessment items and capstone investigations. Complete portfolios of student performance are generated, permitting individual and aggregate analyses not only of conceptual understanding but also of peer to peer interactions and student understanding of various representations of experimental data. We report on the development of this unique online instrument which will enable measurement of student learning not previously attainable.

KEYWORDS
Online, laboratory environment, asynchronous, modules, tutorials, peers, assessment, capstone, client, server

START OF PAPER

"This is just like being back in lab, Dr. M!" enthused one recent student tester of the LAAPhysics Constant Velocity Module. "If I had to choose between LAAPhysics and a lecture course? No contest—LAAPhysics!" replied another, echoing a shared sentiment of the testing group, and "The graphics are terrific!" were other common responses.

Perhaps the most important reaction, from the developers' point of view, is best summarized by one young woman who said: "I really appreciated not being told I was wrong but rather being led to another [laboratory] investigation that let me see things correctly." And finally from a young man, "I finished the whole module in two hours and I had no idea I was working that long!"

These examples embody early (alpha or pre-beta) testing results of the Learn Anytime Anywhere Physics online virtual laboratory learning environment and tutorials. Although student response so far is extremely positive, a more thorough road test comes during the next academic year when the LAAPhysics (pronounced lap-physics) project begins extensive external beta testing with nearly one hundred faculty across the country signed up to participate.

Supported in part by funding from the U.S. Department of Education's Fund for the Improvement of Post Secondary Education, the goal of LAAPhysics is to replicate for students the experience of taking a real-world highly interactive immersive laboratory course. Directed by physicist Jerry Meisner and educational anthropologist Harol Hoffman at UNC Greensboro, the LAAPhysics project is authoring a unique online instrument that can be used by faculty in many disciplines. The robust and rich laboratory environment includes virtual lab equipment and instruments, associated curriculum modules and analysis tools. Real-time assessment and feedback, as well as virtual students who collaborate with their real-life counterparts, are integrated into each module or tutorial. [laaphysics.uncg.org URL]

We designed the online system to permit the creation of a laboratory-based physics course that incorporates both open exploration and guided investigations and that can be used either as a stand-alone distance learning course or as an enhancement to currently existing conventional lecture courses. However, our courseware architecture is not limited to physics curriculum. We are progressing towards the creation of tools that allow faculty to easily create their own virtual laboratories and course content. Faculty will then be able to use the LAAPhysics platform as the 'lab' component of any distance learning science course, as tutorials for remedial work in conventional courses, for extra credit or missed lab work, for interactive and open-ended student investigations, and for student assessment using model-based deployment activities. And all this in a 24/7 asynchronous mode – something that our non-traditional students greatly appreciate!

The key advance of the LAAPhysics system is a philosophical rather than technical one. LAAPhysics is designed to support an approach wherein students are actively engaged in their learning [Arons] [McDermott]. This approach goes beyond current interactive simulations where students may manipulate variables, but where independent decision-making is constrained [Physlets, 2001]. In 'naked' or canned simulations, the amount of interaction and the level of student engagement fall far short of the real lab experience. However, the central idea of LAAPhysics is the implementation of a virtual lab environment that offers students all the attendant manipulative features, ability to make mistakes and measurement errors, and much more– conditions very similar to those realized in real labs.

The pre-beta or 'alpha' students quoted above were referring to their use of one of the LAAPhysics courseware tutorials which we are authoring to provide rich laboratory-based learning environments in the sciences for those unable to obtain such experiences in traditional college and secondary school settings. The science education research community currently faces a lack of data on the effectiveness of 'good' online science laboratories [Brown]. The reason for that lack of data is that no one has solved the problem of how to successfully port an exemplary science laboratory to a meaningful interactive online environment. Without good online laboratories, necessary tools to conduct basic research on student learning in these settings are missing. This confluence is a recipe for a closed loop. To date, there has been no sustained and successful effort to bring together experts in content, technology, design and discipline-based education research to address these two interrelated problems [Meisner]. LAAPhysics uses internet-based technologies and physics education research results to create pedagogically sound teaching and learning laboratory online courseware environments [Van Heuvelen]. This approach will increase opportunities for individuals who are outside the conventional educational 'loop' and transform the current limitations imposed by traditional classroom settings. Since LAAPhysics is being authored as a complete, self-contained course, it's presence will also make available to pre-service and in-service teachers a dynamic research-based 'online textbook' which can both increase their content knowledge and influence the way in which the discipline can and should be taught [McDermott].

LAAPhysics can be regarded both as an extensible system for creating dynamic, interactive science laboratories, tutorials for building scientific models of physical systems and as an instrument which can be used to investigate both general and discipline-specific learning issues and questions. The LAAPhysics system consists of a number of innovative subsystems, which are now in various degrees of completion. All are in at least alpha stage, with extensive beta testing of selected introductory physics 'tutorials' incorporating many of these subsystems to start during the fall semester of 2003. The cross platform system contains:

- open-ended simulated 3D laboratories for the physical sciences that permit exploratory student investigations in which students are interactively engaged with their environments of space, equipment, instruments and data analysis tools. These laboratories will use research-based guided inquiry pedagogies from the science disciplines (such as Workshop Physics [Laws], the Modeling Method [Hestenes], and Physics By Inquiry) [McDermott] along with the most appropriate current computer technologies. (We avoid using technologies which, however 'sweet', have not been shown to be pedagogically effective.) A virtual tutor will guide students, as would an expert modeler, in, say, Hestenes' Modeling Workshop.
- a research-based model pedagogy [Hestenes] which is the driving force behind the interactive scripting and guided, laboratory-based tutorials in physics, chemistry and other sciences for students of diverse populations in diverse settings. LAAPhysics permits students to experience the scientific investigation paradigm in the context of a guided learning experience [McDermott], with branching logic enabling faculty to accommodate students of various backgrounds and levels of understanding.
- procedures to assess student content understanding within the tutorial settings under varying conditions. Students are exposed to both higher-level concepts/tasks in which they deploy their developed models in novel situations, and lower level tasks such as learning how to use instruments and equipment, or how to identify dependent and independent variables in an experimental investigation. Assessment and evaluation (A&E) questions are currently being authored which go beyond the common algorithmic questions at the 'end of the chapter'. Online environments permit a richness of A&E not possible with hard copy texts, provided appropriate courseware tools are authored for faculty and student to use. We have authored a variety of these tools which permit faculty access to instantaneous qualitative A&E grading capabilities hitherto lacking: LAAPgraph, LAAPAnalysis, LAAPVector and LAAPMotionMap. These instruments have unique features which permit faculty to qualitatively (as well as quantitatively) grade a student's understanding of graphs, vectors, and kinematics. All will be beta tested in the coming semester by students of the nearly 100 faculty who are joining us in this R&D effort. As with all online developments, midcourse corrections can be easily and quickly executed. The extensibility of the LAAPhysics approach, along with authoring tools we are developing, will permit a community of developers to quickly emerge, both here and in other countries.

LAAPhysics uses current advances in cognitive science, pedagogy research [Redish] and user interface design considerations from both the scientific and the entertainment sectors. From this array, LAAPhysics is being developed as an integrated software package composed of the following modularized interconnected components:

- a Physical Reality Engine (PRE)©™ that re-creates real-world phenomena in a simulated 3D environment. The open-ended laboratory workspace contains virtual laboratory equipment and apparatus objects, the parameters of which can be varied by the user in an experimental setting. The open-ended nature of the lab space provides enhanced environments suitable for visualizing abstract concepts, and allows users (students and faculty) to employ the environment in unlimited creative ways;
- an Interactive Engagement System (IES)©™ that serves as the central management system of the application. The IES provides interactive content to the learner within a collaborative learning environment wherein students work together asynchronously with 'virtual peers' guided by a virtual tutor/guide agent. The IES monitors student progress and dynamically responds to student input with contextual modifications that individualize instruction. Through the script branching features, the IES thus guides the learner through appropriate sections and activities within each learning module, providing remedial experiences where needed;
- a System Tools Package that contains Learner Tools (LT) and Authoring Tools (AT). Each tool is a stand-alone component that can interface with various other components of the application. LT are student research tools that include graphing and data analysis tools. AT include an XML-based editor (LPML, or LAAPhysics Mark-up Language) and development tools that will enable faculty

to modify and extend either the engine environment or the content environment with minimal programming skill or knowledge;

- an Information Storage System that sorts and stores student and course data on a remote server and furnishes that information to the IES for display to the user (student and/or faculty).

The LAAPhysics system allows students the freedom to make errors; these errors and misconceptions can then be corrected through a further dialog between mentor (written script) and student. The modifiable software package is modularized and designed to provide an extensible interactive online learning environment for authoring introductory laboratory courses in physics (now), astronomy, chemistry and other sciences (in the future); nursing and other skill-based SMET-related disciplines; and for conducting research on student learning in web-based environments.

The LAAPhysics architecture is outlined in the figure below.

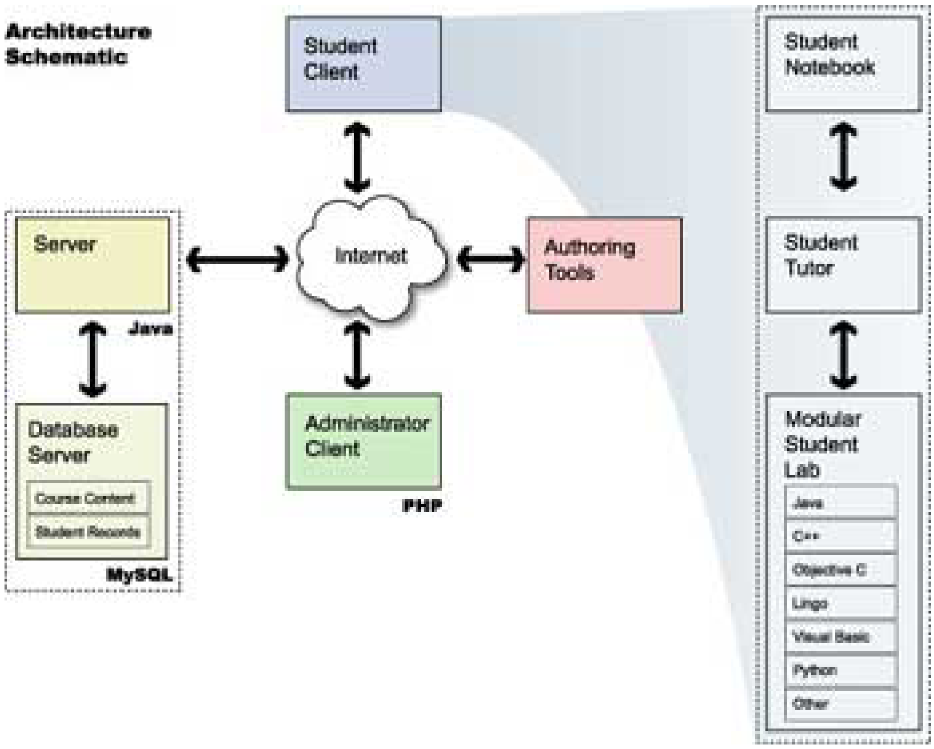

Figure 1

The LAAPhysics team is collaborating with other faculty in

- developing research methodology on the effectiveness of LAAPhysics learning approach compared to traditional methods of teaching. We will assess both content knowledge (using accepted instruments) and laboratory skills of students who learn in the online environment, comparing this to those students from various conventional learning situations. We will analyze beta testing results from several thousand students who will use our kinematics modules this fall.
- developing research methodology on the interface between student and machine in this interactive environment. Student interaction, such as use of graphs, tool selection, mouse actions, time on task, use of text to voice option and data analysis strategies, will be stored in databases that can serve as a research base for understanding important user interface and design issues.
- investigating techniques to enable those students with visual impairments to use and benefit from LAAPhysics.

Who Can Benefit From Use Of The Laaphysics System?

The beneficiaries of the LAAPhysics approach to online laboratory based courses are:

- Students: Underrepresented populations: inner city minorities, native Americans, and others missing from the MSET mix; whose labs are inadequate or missing: from poor regions of the country/world, economically strapped community colleges, under-funded high schools, and colleges with inadequate space; individuals with scheduling difficulties due to work, family or geographic location; those who are ill, injured or who have disabilities.
- Faculty: who are interested in conducting research on student learning in online environments; who are interested in conducting research on student conceptual learning by means of a detailed LAAPhysics portfolio which is automatically created for each student; who want the option of "customizing" course material, and those who want to adopt the role of mentor rather than dispenser of information.
- Institutions: where economic realities make it unfeasible to pay for the high cost of laboratory space; where there is a conflict between lab space and other space demands; where the number of well trained lab instructors is limited; where home schools or struggling charter schools are used.
- Distance Learning Community: where the current absence of scientific laboratory work places severe constraints on distance learning.

Online Course Barriers Addressed By Laaphysics

As we formulated and designed LAAPhysics, we tackled two online course barriers described by Bork and others [Bork]: cost and time effectiveness. Could a standard one thousand dollar computer provide a similar laboratory function as a several thousand lab work station which serves a limited number of physics students for a few hours each week? The Internet is available continuously. Could it be used effectively for laboratory work? Would it be cost-effective? And, most importantly, would it be learning effective?

The answer to online cost-effectiveness initially seemed to be yes, when taking into account economies of scale. However, early experience in the online astronomy course of one of the authors quickly uncovered a fatal flaw. Faculty time spent effectively communicating with students in a reasonably interactive Web course quickly exceeds the time, effort, and energy required for a traditional course. Cost-effectiveness therefore depends on reducing costly faculty time investment. This led us to the LAAPhysics solution. Our solution is initially expensive, since developing a stand-alone laboratory software product can incur hundreds of thousands of dollars of up-front costs. But these are one time costs. Once the software exists, replication of that software can be considered essentially free. Developing a virtual lab would make no sense if the significant cost was applied to only one course at one school, but if the expense were spread over a thousand courses, the cost per student might fall to pennies.

By contrast, creating a 'learning effective' online laboratory environment presented a difficult challenge, more daunting even than raising the needed funding. Email, chat rooms and streaming video can be used as communication tools, but are best described as data transfer tools—one participant has detailed data, and other participants receive it. This is an excellent paradigm where the goal is the efficient transfer of information, but introduces serious limitations where the objective is high-level conceptual scientific learning, wherein models must be experientially developed in various representations.

In the LAAPhysics solution, depending on how students respond at various branch points in the tutorial, they are guided to reach their own conclusions. Students actively participate in the decision as to what apparatus is needed, how to set it up, and how to refine an experiment to better achieve a goal. The built-in 'guide agent' feature is particularly important for schools or individuals without access to lab-based physics courses. Additionally, the difficulties inherent in training teachers in a scientific pedagogy can be reduced or eliminated with the incorporation of an integrated agent that can take over some or all of the task of guiding students through the learning process.

The guide agent's 'intelligence' is based on a large body of research on how students learn particular concepts in physics. This body of work significantly reduces the need for complex artificial intelligence systems since content developers can predict student responses at each of the various assessment branching points. Further enhancing the guided feature, is the inclusion of 'virtual' students who agree or disagree with the real student's response, raise questions, compare results, and/or present new ideas.

LAAPhysics is not being touted as being better than in situ, guided inquiry laboratory based courses. Rather, LAAPhysics addresses those instructional situations where in situ introductory courses are less than ideal: those that are based on lectures alone, or where students have limited access to laboratories outside of scheduled class time, and/or where students may lack the apparatus and instruments that have been central to scientific investigations of the 20^{th} century.

The LAAPhysics system/instrument/courseware offers an alternative to previous educational paradigms. The importance of any instrument depends both on its design features and on the imagination and skills of faculty who use it for different purposes, many of which are not imagined by the creators. More information is available at www.laaphysics.org

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