QMTools — Realizing the Promise of Multimedia in Teaching Introductory Quantum Physics

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1. Project Summary

Advances in desktop computing power and information technology are converging to make possible superior pedagogy and promote active classroom learning. But individual efforts toward technological innovation in higher education have not fulfilled their promise, in part due to the reluctance of educators to employ "canned" learning aids. We contend that systemic change will follow only when instructors can readily craft their own materials that effectively exploit today's technology. The proposed project endeavors to provide educators with the tools needed to seamlessly integrate multimedia and computational elements into their classroom materials, and to do so with minimal investment of time and effort. The required toolset for Quantum Physics — dubbed *QMTools* — will be developed and distributed *free of charge* to the academic community. Prior to final release, the product will undergo extensive testing by field testers nationwide, thereby ensuring that the toolset has maximum value for its intended purpose and is acceptable to a broad spectrum of college and university physics faculty. We also outline a non-proprietary strategy that uses *QMTools* together with other stock hypermedia elements to assemble "live" documents that can be tailored to individual needs and preferences. Widespread adoption of the *QMTools* concept would expose a vast majority of technically-oriented students to a rich multimedia educational experience, with improved prospects for retaining the best and brightest among them, and even attracting traditionally under-represented groups to the study of science and engineering.

2. Project Overview

Much has been written of late of the need for "active" learning in physics education, as opposed to the "passive" method practiced in the lecture model of classroom instruction [1,2]. Numerous studies indicate that students learn more effectively when they are openly engaged in the learning process, e.g., conducting experiments, exploring simulations, or participating in a cooperative learning exercise [3,4]. Yet educators are notoriously resistant to change, and the active model, when it is practiced at all, has been employed largely in entry level (i.e., freshman) courses, while upper-division courses continue to be taught in the traditional format. Gradually, this will change, and we will witness a transition from passive to active learning at all levels. At the core of this would-be revolution lie advances in multimedia and information technology that have brought an added dimension to classroom teaching. With this new technology comes empowerment of the user: inevitably, students *do* become active participants in the learning process, often working together in teams to share insights and experiences. Our basic premise is that the real potential now exists for the technical instruction process in higher education to undergo fundamental change to a superior form, exploiting recent advances in desktop computing power and information delivery systems.

The last few years have seen an explosive growth of computing power, widespread availability of desktop computers at nominal cost, and the appearance of sophisticated multimedia delivery systems. Yet the overall impact of these factors vis-a-vis the educational experience has been minimal: students still learn by reading or perhaps outlining chapters in textbooks, listening to lectures, taking notes, doing homework problems and projects, and taking exams. This is not to imply that computers are not used or useful in higher education. College science majors generally write reports with word processors, manipulate and plot data in spreadsheets, and often use more specialized applications programs or write small programs in high level languages. But in general, such computer usage can still be best characterized as peripheral or auxiliary. And while numerous specific curricular and pedagogical advances have taken place over the last decade, too often these are the work of individual educators acting alone to produce products that, for the most part, have not gained wide acceptance [5]. Continued progress toward technological innovation in education will require that these isolated efforts give way to sweeping changes. Paving the way for such changes in higher education, and specifically in the teaching of quantum physics, is the thrust of this proposal.

The transition from individual innovation to systemic change often proceeds at a slow and uneven pace, and is not without setbacks. In our view, past efforts to bring technology into the classroom have been severely hampered by the reluctance of one instructor to wholeheartedly embrace the pedagogy of another, however well thought out. Thus, it is rare for any professor to lecture from the notes of another. Each of us recognizes the need to prepare our own notes — to ensure uniform notation, to add the desired emphasis, to endorse a particular point of view or methodology, in short, *to impart a flavor uniquely our own*. And so it is with all the instructional materials we select; to be widely used they must be adaptable to individual prejudices and flexible over time. To expect Professor X to adopt a computer program or multimedia module developed by Professor Y is to ask us to teach from the notes of colleagues; it will not happen unless the fit is near-perfect and the learning curve not too steep. [And often we cannot know how good is the fit without first negotiating the learning curve!] Little wonder, then, why “canned” learning aids, however well designed, have not gained widespread acceptance. But the alternative is equally clear. We must allow individuals the freedom to craft their own instructional materials, while providing the tools that enable them to include multimedia and computational elements easily, without significant additional expenditure of time or effort. Only then will we realize the full promise of multimedia and computer technology for enhancing the learning process on a large scale. If, as we contend, the rigidity imposed by “canned” learning aids is the problem, then the solution (in the context of quantum physics) is *QMTools*.

With the foregoing as background, we can now state succinctly the goals of the proposed project. They are:

1. to provide educators with the tools needed to seamlessly integrate multimedia and computational elements into their classroom materials, and
2. to promote a strategy that will encourage widespread development, dissemination, and use of these materials for physics instruction.

QMTools refers to a suite of component objects, or controls, designed to facilitate the creation of multimedia-enhanced, computer-based classroom materials — lecture outlines, supplementary worksheets, student exercises, self-paced tutorials, even complete topical modules — for use in teaching introductory quantum physics. Each control would encapsulate a single pedagogical element that could be inserted into a document to provide an interactive, computer-based experience at any desired point in the presentation. These "live" documents — seamlessly integrating text, symbols, graphics, motion (animation), captured video, and even sound — can be far superior to the communication afforded by the traditional textbook and lecture medium, and should make the learning process more efficient, effective, and (yes!) even enjoyable. This proposal is a request for funding to develop the *QMTools* suite, and to demonstrate its feasibility by linking together the relevant hypermedia components to produce two sample multimedia forms; (1) a student activity suitable for classroom use, and (2) a self-contained module exploring the phenomenon of quantum tunneling. The complete set of *QMTools* is detailed in Sec. 3.

Linking pre-built components to create a "live" document requires some authoring tool. For live documents to become a staple of the educational experience, instructors must be able to create them easily and with minimal investment, both in terms of time and dollars. The HTML document format seems ideally suited to this role. Initiated as a set of informal rules for displaying plain text and hyperlinks, the HTML specification has emerged as an evolving industry standard. Its most recent incarnation, HTML 4.0, offers improved support for multimedia, scripting, and style sheets, and continues the evolution of this once-limited tool into one that furthers the goals of enhanced interactivity and easier construction and maintenance of Web documents. And while a separate HTML editor may be purchased (usually at modest cost), HTML documents can be generated by any of the leading word processors, or even with the most rudimentary text editor. For viewing HTML documents, all that is required is a browser, such as Internet Explorer or Netscape. Thus, in HTML we find a language for crafting live documents that is widely available at little or no cost, and that is already familiar to anyone who has created his/her own Web page. The use of HTML also means that educators will be able to leverage all the expertise and tools developed for building Web pages in creating their classroom materials, and delivering them over an intranet. Finally, the popularity and increasing importance of the Web will ensure that more and better authoring tools will continue to appear, and with a price tag affordable to all.

With the help of *QMTools*, it should become time and cost-effective to assemble activity-intensive learning units that integrate interactive computer exercises with digital multimedia. The possibilities seem almost endless. Units could be targeted to specific problem areas, viz., subject matter that students find especially challenging as they struggle to comprehend the unfamiliar and often bizarre principles of quantum physics. Still other units might be tailored to spur student interest and enthusiasm by illustrating the power of quantum methods in shaping our view of the real world. Units could be purposely designed to emphasize visual representation over analytical description, thereby fostering a greater degree of physical intuition and understanding while reducing the required level of mathematical preparedness. Limited mathematical rigor, coupled with an interactive multimedia format, can be expected to engage students to an unprecedented degree, hopefully reducing the risk of attrition and stimulating more interest among majors from areas outside of physics (e.g., biology, chemistry and engineering). Professional educators will agree that these students, many of whom take no physics beyond what is required — for fear of failure and/or a perceived lack of relevance — could profit immensely from an early exposure to quantum principles and methods.

Assessment will be a critical element of the project, on the one hand to ensure that the *QMTools* suite is user friendly yet sufficiently powerful and comprehensive, and on the other, to oversee that the courseware crafted with it will effectively increase student learning. Assessment will be both formative and summative in order to employ an iterative design procedure where inadequacies in the software can be discovered and corrected before completion of the final product. User surveys will be employed assessing the ease of use and effectiveness of *QMTools* for integrating multimedia and computational elements into a variety of learning activities. But the ultimate success of the *QMTools* concept will be measured by the extent to which the software and its products proliferate within the academic community. The suite will be used to craft classroom materials for several courses at the home institution, including Modern Physics and Quantum Physics.

QMTools will be offered to the academic community *free of charge*, and downloadable from a web site dedicated to that purpose. Further dissemination will be accomplished through annual meetings of the *American Association of Physics Teachers*, and through publication in journals such as *Computers in Physics*, and *The American Journal of Physics*.

3. *QMTools* — A Development Suite for Quantum Physics

The *QMTools* suite would consist of several controls, each encapsulating a single pedagogical element and representing one building block to be used in crafting a “live” document to aid in the study of quantum mechanics. The controls we envision are listed below:

1. Function Explorer
2. 3d Function Explorer
3. EigenSolver
4. EigenSolver3
5. Schrodinger WaveSolver

The Function Explorer series provides important functionality that transcends any one subject, and should find application in other toolsets; the remaining three “solvers” are specific to quantum physics. Other controls may be added as the project matures. Evidently, the modular approach we propose makes it easy to extend the basic toolset if the need for additional controls should arise.

Controls must be designed for optimum flexibility and ease of use. To this end, related features for each control are grouped into *feature classes*. The idea here is that entire classes may be hidden from the user as the context merits. For example, a first exposure to stationary states might employ the EigenSolver control with just the minimal feature set exposed; a study of particle scattering could use the same control, but with the basic features extended to include access to more sophisticated operations, etc. Extended feature sets should be useable in any combination.

4. References Cited

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