Designing for Enhanced Conceptual Understanding in an Online Physics Course

By Joanna C. Dunlap, Thomas E. Furtak, and Susan A. Tucker

Overview of the Physics 100 Online Project

The calculus-based, introductory physics course is the port of entry for any student interested in pursuing a college degree in the sciences, mathematics, or engineering. There is increasing demand for online delivery options that make the course more widely available, especially those that use best practices in student engagement. However, effective teaching strategies for active engagement and social dialogue are difficult to represent in an online course. In joint collaboration between the physics department at the Colorado School of Mines and the instructional technology program at the University of Colorado, Denver, and supported by a federally-funded USDE FIPSE grant, our project adapted beneficial classroom practices to *Physics 100 Online*, an online version of our calculus-based introductory course for students in science and engineering degree programs.

We modeled *Physics 100 Online* after the studio teaching method (Furtak & Ohno, 2001; Wilson, 1994) (see Figure 1). The studio version reflects what is known about effective physics education, emphasizing the importance of social context through:

- Small group learning by working on applied, context-rich exercises;
- Peer tutoring, which exploits socially enabled learning through social dialogue, idea testing, negotiated meaning, and the co-creation of solutions.

The face-to-face studio method improves student retention in the major and provides students with a generally favorable impression of physics that persists after the course has ended. However, the course's reliance on hands-on application of physics knowledge to experiments and small group interaction and problem solving made it challenging to develop an effective online version that authentically reflected the strengths of the studio method. Therefore, after three years of development, the evaluation of the teaching effectiveness of this approach is an integral part of our activities as we strive to answer:

Figure 1. Physics students completing team projects in the studio classroom.

- In what ways did our instructional approach to the online version of the calculus-based introductory physics course serve to engage students?
- Is the online version equal to the existing highly effective campus-based course in terms of students' content and skill acquisition, students' attitudes about physics and learning physics, and students' satisfaction with the learning experience?

In this article, we describe our design of an online version of the calculus-based introductory physics course, demonstrate critical course components that exploit social context strategies in both self-paced and group-paced learning activities, and share the results of one study conducted to examine an important aspect of research question 2—how the growth of online students' conceptual understanding of physics compares to the growth of on-campus students' conceptual understanding of physics.

From Classroom to Online: Course Design and Instructional Approaches

Physics educators have come to understand that traditional lecture-based teaching is not the most effective way to approach physics instruction (McDermott, 1993, 2001). The realization that higher cognitive processes originate from social interactions (Vygotsky, 1978) has catalyzed a revolution in the manner that physics educators design and teach their courses. More physics educators are now incorporating into their courses instructional techniques influenced by socio-cultural constructivist learning theory such as modeling (Halloun & Hestenes, 1987), peer tutoring (Mazur, 1996), role-playing, and collaborative learning (Heller, Keith, & Anderson, 1992), because they now recognize the many advantages of learning in a social context (Dunlap & Grabinger, 2003):

- Groups give rise synergistically to insights and solutions that would not come about individually.
- Students experience and develop an appreciation for multiple perspectives when working with others.
- In collaborative work, group members draw out, confront, and discuss misconceptions and ineffective strategies.
- Social learning experiences allow learners to observe and subsequently emulate other students' models of successful learning.

However, these approaches are not making their way consistently into online versions of physics courses. Therefore, using Flash, Javascript, and MySQL, we developed an online version of an introductory, calculus-based physics course that emphasizes the social context of learning. We followed the design recommendations of the Rich Environment for Active Learning (REAL) model (Dunlap & Grabinger, 1996; Grabinger & Dunlap, 1995), anchoring learning in larger, more authentic and complex contexts; using generative learning activities in which students take an active role in forming new understandings through the creation of products and solutions to authentic challenges; and engaging students in collective problem solving, the examination of multiple viewpoints, and confronting misconceptions and misunderstandings through collaboration and social discourse. To this end, we used two instructional approaches: collaborative team projects and simulated social interactions.

Collaborative team projects

Using asynchronous and synchronous communication tools (e.g., discussion forums, chat rooms, white boards, document sharing), students worked in teams to solve multi-step, challenging projects. Grounded in the metaphor of a team of technical consultants in the motion picture industry, students were tasked with applying the laws of physics to create accurate and realistic special effects for motion pictures, developing detailed solutions to complex physics problems. Examples include:

The team helps stage a movie scene involving a runaway train carrying radioactive waste. The team works from design parameters of the chase vehicle to give the movie director guidance about where to set up the cameras based on an analysis of how the chase will occur.

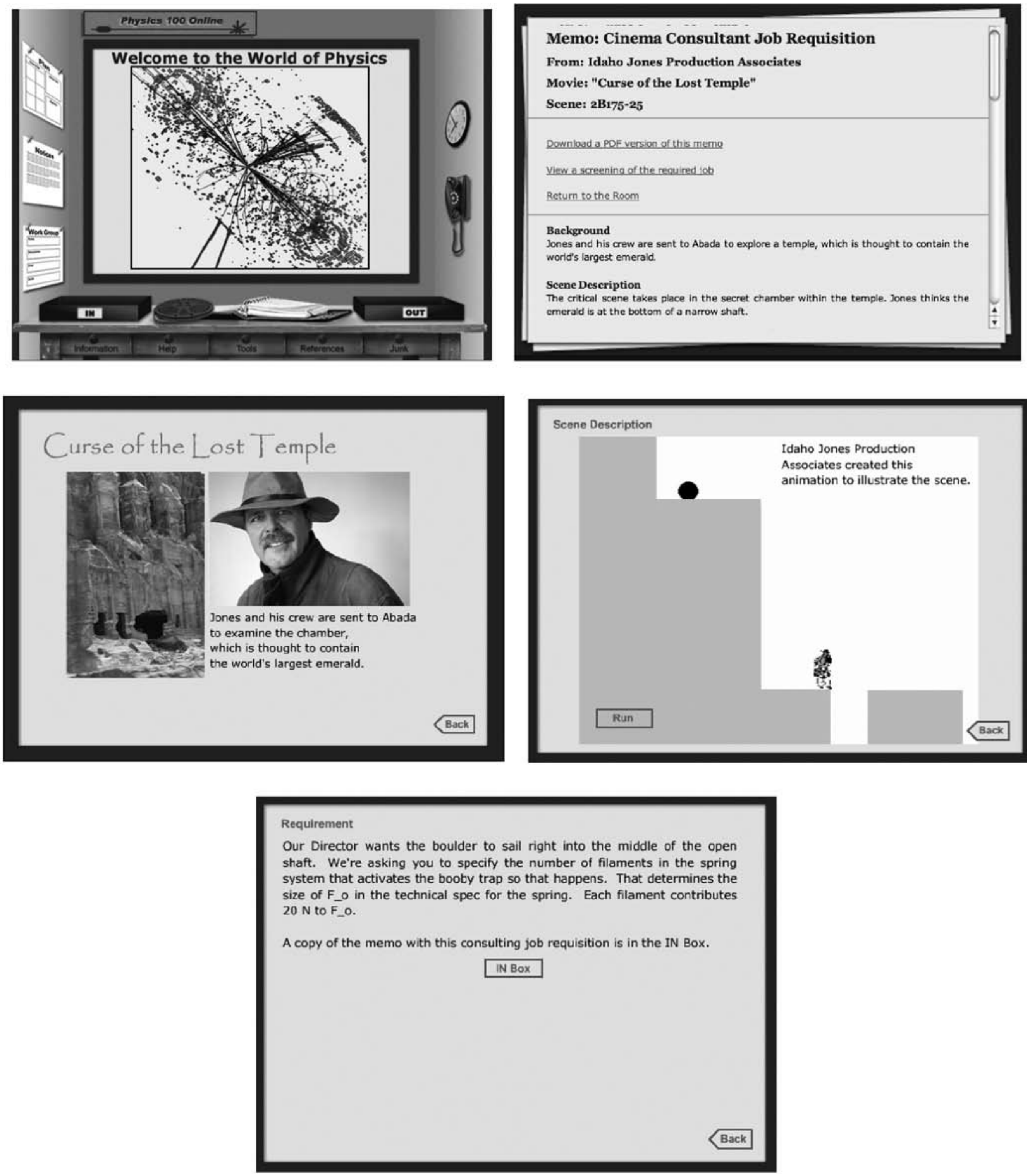
The team helps plan a murder mystery. The crime occurs when the bad guy pushes his business partner out of a speeding roller coaster. The team needs to plan where the body will land and provide a report about whether the impact will damage an expensive mannequin used in the scene.

In a science fiction movie, the characters must use a nuclear weapon to split an asteroid that is on a collision path with Earth. The team must analyze the physics of the situation to propose the minimum size of the weapon such that the fragments spread before the asteroid reaches Earth.

Figure 2 shows a sequence of screens that introduced the "Curse of the Lost Temple" project in which student teams had to determine, using calculus-based physics, the realistic action of a large, rolling boulder for an Indiana Jones-like special effect, and report their recommendations to the movie's director.

Simulated social interactions

In order to simulate social interactions while students worked through the self-paced components of the course – these are the materials contained in an online textbook referred to as the *Notebook*, which help students prepare for the collaborative team projects by providing foundational physics instruction, practice, and assessment – we employed a database of student responses to provide authentic feedback to each student. The instructor chose responses from the pool of available items for random display. Examples of the types of simulated social



Memo: Cinema Consultant Job Requisition

From: Idaho Jones Production Associates

Movie: "Curse of the Lost Temple"

Scene: 2B175-25

Download a PDF version of this memo

View a screening of the required job

Return to the Room

Background
Jones and his crew are sent to Abada to explore a temple, which is thought to contain the world's largest emerald.

Scene Description
The critical scene takes place in the secret chamber within the temple. Jones thinks the emerald is at the bottom of a narrow shaft.

Curse of the Lost Temple

Jones and his crew are sent to Abada to examine the chamber, which is thought to contain the world's largest emerald.

Scene Description

Idaho Jones Production Associates created this animation to illustrate the scene.

Requirement

Our Director wants the boulder to sail right into the middle of the open shaft. We're asking you to specify the number of filaments in the spring system that activates the booby trap so that happens. That determines the size of F_o in the technical spec for the spring. Each filament contributes 20 N to F_o.

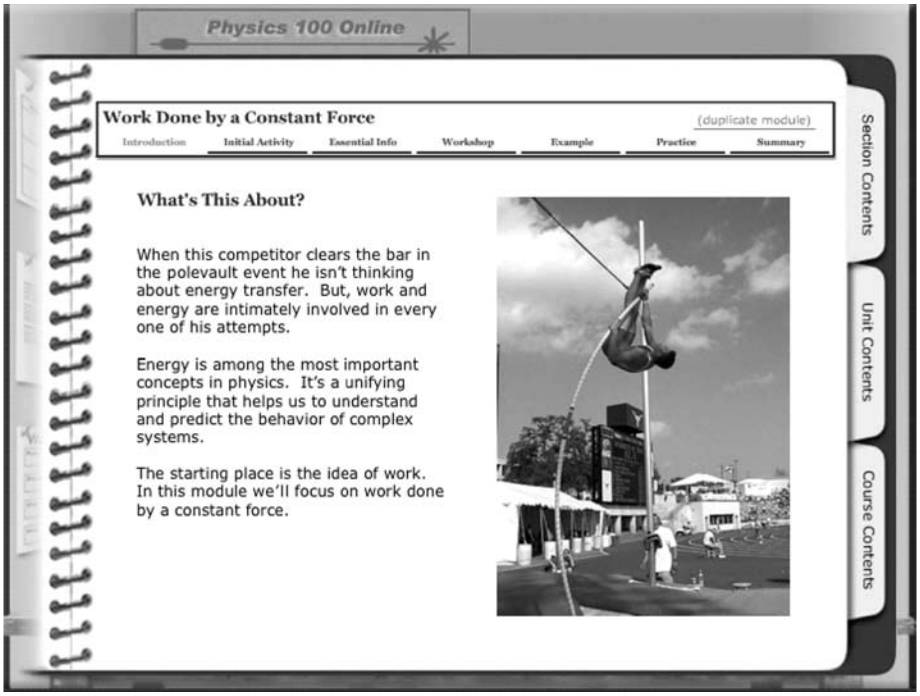
A copy of the memo with this consulting job requisition is in the IN Box.

Figure 2. Sequence of screens presenting an authentic team project in Physics 100 Online.

interactions in the course included ConcepTest, Diagram Gallery, Paradox Discussion, Response Ranking, and Process Discussion.

ConcepTest. Students consider a multiple-choice question. The students are asked to justify their answer in the text box in the second frame. They receive a gallery of justifications in the third frame. They vote a second time (not shown), and then have access to the instructor's explanation. Complete statements are available by hovering the mouse.

Diagram Gallery. Students use the drawing tool to design a diagram, mark a previously provided image, demonstrate a mathematical step, or produce any other input that can be created as a line drawing. Upon submission, they com-



What's This About?

When this competitor clears the bar in the polevault event he isn't thinking about energy transfer. But, work and energy are intimately involved in every one of his attempts.

Energy is among the most important concepts in physics. It's a unifying principle that helps us to understand and predict the behavior of complex systems.

The starting place is the idea of work. In this module we'll focus on work done by a constant force.

Figure 3. Opening Notebook page for the Work and Energy module.

pare their diagram with a collection of diagrams from the database, after which they rank order the diagrams from most accurate to least accurate. Then, students are given the correct ranking and a correct diagram to compare with their own diagrams. Finally, students are provided an explanation of the correct diagram and are asked to apply their new learning to another question.

Paradox Discussion. Students confront a commonly misinterpreted situation. After contributing a text explanation, the students see a small gallery of responses from the database produced by students who previously considered the same situation. Then, students have a second opportunity to submit an explanation. Finally, students have access to the instructor's response.

Response Ranking. Students view a selection of responses from the database to a question and rank them according to which ones are most consistent with correct physics principles.

Process Discussion. Students examine the method by which they reached the answer to a problem. After contributing a response, they are shown a small gallery of similar analyses (from the database) contributed by other students. Finally, students have access to the instructor's response, and are asked to self-assess the accuracy of their order.

Readers are invited to link to *http://www.augustcouncil.com/~jdunlap/physics100online/* to see examples of the social interaction simulations discussed above and to learn more about *Physics 100 Online.*

Examining Students' Changes in Conceptual Understanding

The evaluation of teaching effectiveness is an integral part of the *Physics 100 Online* course design and the focus of our research activities. For this study we considered the following research question: *Is the online version equal to the existing highly effective campus-based course in terms of students' content and skill acquisition?*

To examine this question, we focused on one module of instruction that is particularly challenging for physics students: work and energy. This module begins with students, in their roles as technical consultants to the motion picture industry, being introduced to the "Curse of the Lost Temple" project (see Figure 2). Once they have reviewed the project requirements as a team, students access the *Notebook* within their virtual office and complete 16 modules on energy, including simulated social interaction activities (for the full module, see *http://higgs.mines.edu/ph100online*). Typically, there are one or two simulated social interactions per module, so students had the opportunity to complete up to 24 of these interactions in preparation for working on the team project.

During the spring 2008 term, we asked for student volunteers from the on-campus section of the course to complete the online module on energy in lieu of attending the lectures and completing in-class activities on the same topic. Over a 10-day period, 30 students completed the online module on energy, while the remaining 146 students participated in the on-campus instructional activities.

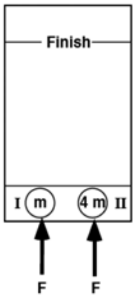
We developed a quiz—the Energy Concept Survey—to explore how growth in understanding of energy by students completing the online physics instruction compared with the growth experienced by students in the face-to-face experience. The nine-question ECS covers both conceptual and quantitative reasoning. Some questions were taken from the Force and Motion Concept Inventory (Thornton & Sokoloff, 1968). We designed the remaining questions. The ECS is similar to exam questions used to assess students in the on-campus physics course. Figure 4 includes a few examples from tat survey. The complete survey is available at *http://www.augustcouncil.com/~jdunlap/physics100online/*

We used a non-experimental research design to examine conceptual growth by compar-

Energy Concept Survey

(The complete survey is available at http://www.augustcouncil.com/~jdunlap/physics100online/)

1. The diagram depicts an overhead view of two pucks on a frictionless table.



Puck II is four times as massive as puck I. Starting from rest, the pucks are pushed across the table by two equal forces. Which puck will have the greater kinetic energy upon reaching the finish line?

A. Puck I
B. Puck II
C. They both have the same kinetic energy at the finish line.
D. There is not enough information given to say which puck has the greater kinetic energy at the finish line.

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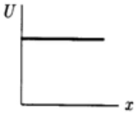
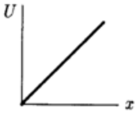
6. Which of the five graphs correctly shows the potential energy of an ideal spring as a function of its elongation, *x*?



A



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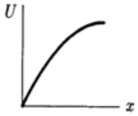
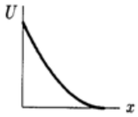
C



D



E

7. When a certain rubber band is stretched a distance *x*, it exerts a restoring force $F = b x^2$ where *b* is a constant. The work done in stretching this rubber band from x = 0 to x = L is:

A. bLx^3
B. $2bL^2$
C. $2bL$
D. bL
E. $(1/3)bL^3$

8. An object moves in a circle at constant speed. The work done by the centripetal force is zero because

A. the displacement for each revolution is zero.
B. the average force for each revolution is zero.
C. there is no friction.
D. the magnitude of the acceleration is zero.
E. the centripetal force is perpendicular to the velocity.

Figure 4. Energy Concept Survey examples.

ing both the online group's and the on-campus group's performance or level of change (posttest results) to their respective baseline levels (pretest results), and then comparing the online group's pre- and posttest results with the on-campus group's results.

Results

Students completed the Energy Concept Survey prior to the start of the module on energy and again upon the immediate completion of the module on energy. First, since students in the online-module group were volunteers, we established that there was no significant difference on the pretest between the online-module group and the on-campus group. The pretest mean for students who completed the online module on energy was 3.60 (SD = 1.80, N = 25). The pretest mean for students in the on-campus group was 3.25 (SD = 1.87, N = 146). Based on the pretest results, there was no significant difference between the two student groups [t(169) = 0.88; p = 0.38].

Next, we looked at changes from pre- (reported above) to posttest for each student group. The posttest mean for students who completed the online module was 5.23 (SD = 2.13, N = 30). A two-sample t-test determined pretest-posttest differences in the online-module group's scores. The mean scores increased significantly from the pretest to the posttest [t(53) = 3.035;

$p = 0.004$], indicating a significant positive change in the online students' conceptual understanding of energy.

The posttest mean for students in the on-campus section was 4.42 ($SD = 2.15$, $N = 117$). A two-sample t-test determined pretest-posttest differences in the on-campus group's scores. The mean scores increased significantly from the pretest to the posttest [$t(261) = 4.73$; $p < 10^{-5}$], indicating a significant positive change in the on-campus students' conceptual understanding of energy. These results imply that both instructional approaches (online and on-campus) lead to students' enhanced conceptual understanding of energy.

Finally, we compared the posttest results from both groups. A two-sample t-test indicated that the online group performed better on the ECS than the on-campus students [$t(145) = 1.86$; $p = 0.065$]. We also examined the normalized gain factor, calculated as the difference between the post- and pretest scores, divided by the difference between a perfect score and the pretest score. The normalized gain factor for the online-module group was 30%, compared to 20% for the on-campus group.

Educational Value of the Findings

One issue in the development of online programs is whether online courses can achieve the same level of quality as the on-campus versions, that online education "does no harm." This is especially true for institutions that use a highly effective instructional format for on-campus courses, which was the case at our institution. This study, along with others, has helped us ensure that the online version of Physics 100 does no harm. In fact, we are enthusiastic about the results as they allow us to offer a viable online option for students who may in fact perform better under online learning conditions than in an on-campus classroom. In addition, it helps us offer an effective option to students beyond our local geographic reach.

Given the significant effort needed to create engaging, interactive online instructional materials, we pursued a small-scale line of inquiry about the effectiveness of our approach in order to quickly inform our own design and development activities and those of our colleagues in the science and online education communities. Based on the favorable preliminary results, we are continuing to develop the online Physics 100 materials at the Colorado School of Mines and look forward to continuing our investigation of various aspects of the project and the overall effectiveness of our approach.

Design Challenges and Recommendations

Most of the challenges associated with our design and development of the *Physics 100 Online* course stemmed from our desire to capture the highly effective collaborative strategies employed by the studio teaching approach. First, when coming up with team projects, we had to consider:

Are the projects challenging enough to warrant student collaboration and relevant enough to engage them without being so complex that they become unnecessarily frustrated?

How will we balance the need for authentic projects with the desire to confine the project requirements and specifications based on the content and skills students had covered in the course?

Are there synchronous and asynchronous communication tools, preferably Open Source tools for easier dissemination, available to support the level of sharing of and collaboration on technical schemata and mathematical equations needed to work on the projects, or were we going to have to create these tools from scratch?

Accomplishing this involved working with a small group of expert practitioners to develop potential project ideas and then an iterative design process involving extensive formative evaluation with groups of representative students. Luckily, we were eventually able to solve the tools issue by using an established learning management system, LON-CAPA (Kashy et al, 1998). Answering these questions to our level of satisfaction took more finesse, resources, and time than we anticipated. We learned that it is important to build time into the project schedule to research tool solutions, select appropriate and sustainable tools, and work with experts and students on design and assessment activities.

When determining how we would present the course content in support of team projects in a way that allowed for multiple practice opportunities while still reflecting the need for collaboration and social discourse, we were stymied by the desire to honor the *anytime-anyplace* objective of many online and distance programs and courses. We wanted to blend group-paced (e.g., team projects) and individual-paced elements, so we had to figure out how to allow students to work through the content in an asynchronous, self-paced way. Our solution utilized *simulated social interactions*. Although quite effective, it required significant time and skill to program them. The interactions relied on high fidelity animations programmed in Flash and elaborate database interactions programmed in MySQL. The learning curve was quite high, and our cost-limiting plan to use student programmers resulted in a much slower design-development-implementation sequence than we had anticipated. Given our strict budget for technical support, we made due, but this was a significant lesson for us. [Note: There will be a final report of the FIPSE-sponsored portion of this course development project, in which some development data (such as time, effort, and cost) will be available.]

One of our project goals was to create a product that could be used in diverse ways (e.g., as a fully online course, as supplemental to an on-campus or online university or high school course, as part of a field-based training workshop) and in a variety of settings (e.g., university, high school, on-the-job). We wanted each component of the online course to be able to stand alone; for example, we wanted the team projects to be used without the notebook, and the notebook to be used without the team projects. It was challenging to meet this goal because we wanted the course components to work seamlessly together—to function as a coherent unit—and at the same time be components that other educational institutions could pick and choose from based on their academic goals and objectives. Further, we were motivated to create a set of online instructional materials in which traditional and non-traditional content distributors in physics publishing would be interested after preliminary feedback from publishers who liked the concept. When designing for this sort of flexibility, we recommend elaborate storyboarding be completed early on in the project to make sure that each course component has all elements accounted for and can function as a lone unit.

Finally, a significant focus of our design was on strategies for student social interaction. Given the effectiveness of social interaction in promoting student learning in the Colorado School of Mines' on-campus Physics 100 course, we worked tirelessly to create multiple opportunities for students to engage in social interaction. Supported by the preliminary results of our inquiry into the effectiveness of our approach, we believe that technically difficult online courses may benefit from explicit efforts to encourage student collaborations and instructional activities that are based on social interactions, even if those interactions are simulated.

Conclusion

Introductory calculus-based physics is an important foundation course required for all degree programs in engineering and science throughout the United States. Many talented students are discouraged from pursuing careers in these disciplines because of the intimidating nature of this foundational course, the misconceptions of physics that students have upon course entry, and students' limited ability to use calculus to examine real physics problems. Flexible access to an engaging, high-quality version of calculus-based physics via the online education format will lower this barrier, leading to a new level of interest in science, mathematics, and engineering fields. Our continued evaluation of the effectiveness of online instruction will lead to the dissemination of design guidelines and technical recommendations to support the appropriate implementation of social context strategies in both self-paced and group-paced online learning activities, information that supports the design efforts of all online educators.

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Susan Tucker *has been conducting improvement-oriented program evaluations for over 20 years. These evaluations range from universities, medical schools, school districts, state departments of education, federal programs, foundations, and the private sector. Grounded in her experiences as a teacher and administrator at K12 and university settings, she concentrates on evaluating large-scale, complex systems projects such as USDE's Teacher Quality Enhancement programs and instructional technology projects for organizations such as USDE, AACTE, AASCU, NCATE, United States-Japan Foundation and the British Government's Teaching and Learning Technology Programme.*

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