# HIGHER ORDER THINKING AND CONCEPTUAL UNDERSTANDING OF PHYSICS USING STRUCTURED SCENARIO ONLINE GAMES

## **Project Summary**:

This *Instructional Materials for Students* IMD proposal will focus on physics, and includes *Benchmarks* from the nature of science and technology. The project targets third grade through eighth grade students and teachers. The predominant pedagogical strategies employed are learning by inquiry, facilitating constructivist classrooms, and using the Internet to access virtual gaming environments.

The intellectual merit of the proposal is the creation of coherent instructional materials using structured scenario games, to assist students from diverse backgrounds achieve several science literacy *Benchmarks*. This is significant because numerous studies, including a recent comprehensive University of Chicago longitudinal study (2000) of middle and high school students, have shown that individuals planning science or engineering careers make their decisions early and are quite persistent. The collaborators in this project bring their extensive experience to the study, having taught and published widely on topics relating to instructional design, technology adoption in schools, physics, cognition, career development, simulations, and computational neuroscience. The project will collect real-time data on student achievement and attitudes toward science, and help develop career management competencies.

The broader impacts of the project will be: more students having career options open due to their continued pursuit of science; students developing their social, cognitive and information processing skills; facilitating duplication of this coherent study model for increasing student achievement in other disciplines. The games and other instructional support systems, developed through national and international collaboration, will be available online for students, teachers, and parents in a dynamic portal website hosted at the University of Colorado at Denver.

## Project Description

OBJECTIVES

**First Year**:

### Curriculum Development

1. The senior personnel along with the consultants will investigate and develop model scenarios for use as instructional material. The scenarios will have several anchors (performance markers) to track the achievement of the *Benchmarks*. Student's suggestions of real-life scenarios and teacher's sharing difficulties from classroom experiences using the *Benchmarks for science literacy* (Project 2061, 1993) will be taken into consideration. The scenarios will be based on the schools' existing science curriculum (and State standards) so that they facilitate easy integration.
2. *Physicon Ltd*. http://www.openteach.com/soboleva.html (in Moscow, Russia) will develop both synchronous and asynchronous two-player computer games, using storyboards based on the scenarios presented above.
3. The Computer Science and Engineering Department at the University of Colorado at Denver will design and host a dynamic portal website for the project. Students can access the gaming, pre- and post-test areas *only* under adult supervision. A teacher, parent, or guardian can log the players in. This is to ensure authentic data collection for the research.
4. The curriculum development team will prepare an online and CD-ROM version of a hypermedia text to accompany the website, to include the physics concepts used in the scenarios and also recommend assessment procedures for the program.

### Formative Testing

1. Students will take an online pretest designed by the *Educational Testing Center* (*ETC*) http://www.etc.unsw.edu.au (in Sydney, Australia), in the participating schools to assess their physics, science, and technology understanding during enrichment (or after school clubs). These tests can only be taken in the school.
2. Students from participating schools (and homes, with parental supervision) will pilot test the online games.
3. Teaches will go through training on assessment procedures, recommended pedagogical strategies, and provided an opportunity to critique materials developed during two professional development one-day workshops.

### Revisions and Evaluations

1. Analyze and evaluate student understanding from results on pretest.
2. Revise instructional material and games developed at the end of the first year.
3. Collect participating students' *Colorado Student Assessment Program* (CSAP) scores in reading, mathematics, and science.

**Second Year**:

1. Field test curriculum developed in participating schools in Colorado. 2. Promote availability and encourage use of this curriculum during professional development meetings of teachers at pre-high schools in other states and also the *National Science Teachers Association* meetings. 3. Develop more scenarios and revise games based on feedback from students, teachers, parents, colleagues, and field tests. 4. Students will take their first online posttest developed by *ETC* at the end of the second year.

**Third and Fourth Years**:

1. Continue with field-testing in participating schools in Colorado and beyond. 2. Develop more scenarios and continue with curriculum revision. 3. Students will take two more online pretests designed by the *ETC*, in the participating schools at the end of third and fourth years. 4. Official survey on the curriculum developed. 5. Disseminate preliminary findings to researchers around the country.

## EVIDENCE

Internal and external evaluators of the project will analyze the data collected.

1. The primary evidence for student achievement of the *Benchmarks* will be through their performance in the pretest (at the commencement of the project), and three subsequent tests (at the end of the first, second, and third years of the project) offered by the *Educational Testing Center*. The three tests will also permit a longitudinal study of student performance in grades three through grade eight.
2. Students, teachers, and parents will also be surveyed formally at various stages of the project using the U.S. Department of Education *Program Effectiveness Panel* (PEP) to judge project's effectiveness.

## ANTICIPATED PRODUCTS

1. A battery of structured scenario online games, which facilitate student achievement and present a coherent view of science outlined in the *Benchmarks*.
2. A dynamic portal website to host the project (to continue beyond the duration of the project).
3. Online version of hypermedia text for students and teachers to supplement the games.
4. CD-ROM version of the hypermedia text for use by teachers.

## NEED FOR PROJECT AND RELEVANT RESEARCH

The observations of Schickedanz et al. (1990) about science education in elementary schools continue to describe the current state of physics programs in several schools. The authors and numerous other researchers (quoted by Asoko, 2000) observe that physical science is neglected because teachers themselves are not well prepared and are often under enormous pressure to teach language and mathematical skills. Several other researchers, including Martin et al. (2001), have elaborated on the remarkable similarities between the fundamental thinking skills used in science and reading. All argue that teachers fail to recognize that science programs also facilitate language and mathematics learning.

Numerous studies seek to remedy the problem of teachers' lack of subject knowledge, yet this approach deals with only one part of the problem. The present student-centered study using structured scenario online games, seeks to focus on how students learn physical science, the development of their social, cognitive and information-processing skills, students' career development competencies, and effect of other intervention activities on their thinking and learning. This is particularly important because Adey and Shayer (1994) have highlighted a 12-year gap of students in grade six; with the most able operating like 18-year olds and least able like 6-year olds. It is a challenging task for teachers to cope with learners of diverse ability levels without using technology. Gardner (1999) observes that only computer technology could facilitate personalized instruction and active, hands-on learning for all students in such settings. Clearly this can happen only when teachers are provided with adequate support and training in using new technology.

Gagné (1977) observes that learning can become over-verbalized – some students might use scientific terms correctly without understanding their real meaning, and consequently cannot demonstrate an understanding of even simple concepts outside the classroom. To remedy this very situation, Dewey (1933) observed that at every stage in the development of young children, each lesson must lead to conceptualizing of impressions and ideas, so that students have known points of reference with which they can find their bearings in new situations. The structured scenario games in this study, set in real-world contexts, will facilitate more constructivist and active inquiry-based pedagogical approaches during science lessons, and thereby advance students' ability to retain, understand, and actively use knowledge.

Students often complain that learning in school is boring, not fun, has nothing to do with them, and does not fit the way they learn. It is ironical, as Reiber (1995) observes that gaming, a basic component of human interaction, has received scant interest among instructional design researchers. Shank (1995) argues that there is an increased need for students to learn through goal-based scenarios and educational software to supplement existing curriculum. Students respond to teaching when they have some control over their learning environment and instruction is linked to their personal interests, goals, and needs. Computer games could encourage good principles of learning (Gee, 2003) and motivate players by providing them with appropriate levels of challenge, curiosity, control, and fantasy (Malone and Lepper, 1987). When these games are available online, it not only facilitates authentic real-time data collection, but also helps students enjoy learning in schools, as studies of Internet use in the classrooms have shown .

Studies by Linn (2002) and others found that when students were taught skills in one subject area, they were not able to apply this in other subject areas. This study is based on current research in cognition and instruction, and seeks to develop authentic student-learning experiences through structured scenarios to promote classroom learning using *Benchmarks* from the nature of science, physical world, technology, and human engagement. These scenarios might help students develop a more coherent view of science and facilitate the development of higher order thinking skills such as critical-thinking, problem solving, written- and oral-communication skills, teamwork, and also application, analysis, synthesis, and evaluation skills in Bloom's taxonomy (Meng and Doran, 1993), to some degree independent of disciplinary knowledge and problem context. Furthermore the proposed project focusing on science phenomenology, will effectively complement the TRAILS study (NSF #0205625), which seeks to improve higher-order mathematical thinking among K-12 students.

## ESSENTIAL FEATURES AND WORK PLAN

The primary features of this project are:

1. Designing and development of structured scenario games to facilitate higher order thinking and conceptual understanding of physics. During the first year, the project team expects to develop only one game for each grade that can be pilot tested and revised for field testing. Subsequently the game development process will be accelerated by concurrently developing more games through the rest of the project term.
2. Making the games and other instructional support material easily available to students on a dynamic website portal.
3. Providing teachers with necessary materials, support, assessment strategies, and encouragement for integrating the resources available in the portal with their existing curriculum.

This research seeks to carry out a four-year longitudinal study by following two teachers and two classes for <u>every</u> grade (grade three to grade eight) in <u>three</u> school districts in Colorado. A typically teacher-student ratios in schools is 1:24. Assuming that there are 24 students in a class, the proposed study will investigate 1728 students (=576 students/district x 3 school districts) using a pretest-posttest control group design. The numbers are tentative because the study will take into account both the actual class sizes and the attrition of students in schools. Two classes in each grade (from schools within the same district) will be the treatment group. Teachers will use structured scenario online games for facilitating an inquiry-based pedagogical approach for teaching physical science. Teachers might use their own classrooms or a media lab to access at least 12 computers. Two other classes (same school and district) in the same grade will be the control group. Teachers will continue using traditional forms of instruction here. The structure for an experimental design within each school district is summarized in the following matrix.

| Random Assignment of students | Groups/ grade | Pretests | Treatment | Posttests | Number of students/ grade | Number of grades (Gr.3-Gr.6) | Total no. of students/ district |
|---|---|---|---|---|---|---|---|
| R | A & B | O | X | O | 24 | 6 x 2 | 288 |
| R | C & D | O | - | O | 24 | 6 x 2 | 288 |
| | | | | | Total no. of students per district in study | | 576 |

Fig. Illustrative experimental design within a school district

Three participating schools districts in Colorado: Adams County School District 14, Aurora Public Schools, and Cherry Creek Schools, will write letters of support for the final proposal. Hispanics constitute almost 2/3 of the enrollment in Adams County School District 14. Blacks and Hispanics constitute 24% and 26% in Aurora Public Schools. Minorities constitute less than a third in Cherry Creek Schools. The overall academic performance of several schools is three districts are low, low, and high respectively, according to the Colorado School Accountability Reports.

The project will be built around a dynamic portal website that will include provisions for:

**Student/Teacher/Parent support**:

1. ONLINE higher order thinking and conceptual understanding of physics structured scenario games with embedded dynamic models and worked examples. A prototype game on forces, with bridge builder (http://www.pbs.org/teachersource/mathline/concepts/architecture/activity3.shtm) and embedded W.I.S.E. (http://wise.berkeley.edu) activity, will be included in the final proposal.
2. DIGITAL LIBRARY that will contain: a) *Instructional Support Materials*, with links to science demonstrations, simulations, modeling, videos, textbooks, magazines, local community events, science fairs, TV science programs, current science, news, FAQs, etc. b) *Communication link*, to include multilingual dictionary to help English Language Learners, c) *List serve/Online Discussion Forum*, for posting questions, communicating ideas, etc. d) *Glossary* of key scientific terms and concepts, e) *Career development* activities and games using the Blueprint for Life/Work Designs framework (http://blueprint4life.ca/whatis.cfm), f) *Higher Order Thinking*: Including reflective, Critical, and Breakthrough thinking, g) *Benchmarks* that facilitate developmentally appropriate curriculum.
3. PROGRESS & ASSESSMENT. Will link to a) *Educational Testing Center* pre- and post-tests. The tests will be offered online only within the school, during enrichment time. b) *Multiple choice question* (MCQ) quizzes to assess students' physics, science, technology, and career development competencies. c) *Journal/Portfolio* for keeping personal log of goals, self-assessment, sample graphic/symbolic data representations tools. *Teachers* will have a **summary report** of class performance at the end of each lesson, for accountability purposes.
4. FEEDBACK & SURVEY. *Instant reports* on student performance in MCQ quizzes, and ongoing feedback for students from the server about their choices and performance in the gaming activities to facilitate learning. Students can pause, save, and print at any time during the gaming activities.

**Senior/Key personnel support**: a) ONLINE conference for periodic discussions with advisory committee members b) PROGRESS REPORT c) ACCESS to all student/teacher/parent resources detailed above.

**Administrators support**: Useful information for school administrators (principals, assistant principals, curriculum directors, etc.) on students' overall performance.

# CONTENT AND PEDAGOGICAL STRATEGIES

The great curriculum period in the 1960s and 1970s saw a surfeit of elementary science programs, which subsequently sparked several debates on the emphases on processes and concepts for elementary and secondary school science. The current goals of science education, reflected in the *National Science Education Standards* and the *Benchmarks*, highlight the importance of inquiry:

> Inquiry is a step beyond "science as a process," in which students learn skills, such as observation, inference, and experimentation. The new vision includes the "processes of science" and requires that students combine processes and scientific knowledge as they use scientific reasoning and critical thinking to develop their understanding of science.

Inquiry-based teaching is a highly structured instructional strategy, which requires a teacher knowledgeable about both, scientific content and pedagogy (Cozzens, 1997). Clearly this task can be overwhelming for both teachers and students, as some studies have shown (Etheredge and Rudnitsky, 2003). Novak, Mintzes, and Wandersee (1999) argue that the *Benchmarks* essentially detail a "laundry list" of topics to be taught, are very conservative in their scope, and ignore the importance of metacognition during instruction. Kokkotas et al. (1995) highlight that teachers simply repeat the language used in textbooks and students carry out "cookbook" labs from textbooks to facilitate hands-on learning. In *Science for all children* (1997), the *National Science Resource Center* observe that operating efficient science materials support centers that provide science kits for schools is challenging. Fensham (2000) argues that if the intention of science for all is to be furthered, teachers must help students see the benefits of studying science with reference to their long-term career goals.

Our constructive views on learning, acknowledging the efficacy of the BSCS (http://www.bscs.org/) 5-E learning cycle model: engagement, exploration, explanation, extension, and evaluation (Llewellyn, 2002), requires students to actively engage themselves with their learning environment to find meaning in their actions.

*Engagement, exploration*: When students are challenged with real-life structured scenarios and allowed to collaborate socially with other individuals to solve problems, their conceptual understanding is enhanced. The guided inquiry approach advocated by Thier and Daviss (2001), and the research on the Internet as an effective learning tool by Roschelle et al. (2000, quoted by Donnerstein, 2002), support this approach. Furthermore, studies have shown how games strengthen students' engagement, information processing, problem solving, social development, and academic skills (Funk, 2002).

The word "game" is used in this study because the gaming activities, with teachers and the computer mediating, will help the players understand that their choices and actions affect the two players. The principles used for designing the games will use simple ideas from cooperative game theory and focus on deductive thinking, outcomes, fairness, and equity (Aumann, 1999; Rasmusen, 2001). The moving and termination rules of the game will include details about players, actions, payoffs, and information. The idea of using computer games to facilitate learning is not new. Newman et al. (1989) advocated that within well-designed environments, students could use computer technology to learn traditional school subjects, problem solving, and other metacognitive skills. Generally, children across cultures have a preference for playing together. The social constructivist perspectives (Oldfather et al., 1999) underlying the game design requires players to learn and make sense of the scenario presented by each other, and communicate both orally and in written form to achieve the games mission.

What will be unique about the project is its coherent presentation of science outlined in the *Benchmarks* and an organized data management system that will facilitate a systematical study of student understanding, learning, and achievement. The proposed project will be creating server based structured scenario games by drawing on successes of initiatives such as *Principles of Technology* developed by the

Center for Occupational Research and Development (http://www.cord.org) adopted by School District of Washington, and best practices in existing simulations such as *Educational Software Components of Tomorrow* (http://www.escot.org), *Project Interactivate* (http://www.shodor.org), and *STELLA* developed by High Performance Systems Inc. (http://www.hps-inc.com/) , to name a few.

*Explanation*: After completing 2-E in the learning cycle through strategies outlined above, teachers could offer a formal explanation of the concepts to reinforce conceptual understanding.

*Extension*: To encourage students to continue the cycle, teachers could assign students project work using W.I.S.E. (The Web-based Inquiry Science Environment: http://wise.berkeley.edu) to examine real-world evidence and analyze current scientific controversies.

Furthermore, since numerous researchers (Bandura, 1997; Doty and Stanley, 1985), have observed that the sooner students are able to see themselves in a career development (lifelong learning) process, the sooner their present education will have more meaning, teachers could also encourage students to participate in some activities suggested in the career development section of the website.

*Evaluation*: The rubrics for evaluating the games and quizzes will predominantly use a criterion-referenced system to assess students' mastery of the *Benchmarks*. The tests offered by the *Educational Testing Center* will assess largely higher order thinking skills such as interpreting visual data, inferring, predicting, concluding, investigating, reasoning, and problem solving. Teachers will also have an opportunity to evaluate students' online journals and W.I.S.E. projects.

## EVALUATION PLANS

During the early stages particularly, extensive formative evaluations, using student and teacher feedback on the games and the website portal, students' attitudes and performance on games during the pilot and field tests, journal entries, and the quality of work done using W.I.S.E., will be carried out to help revise and develop a coherent framework for the project. These ongoing formative evaluations by the senior personnel, teachers, and graduate students will help improve student learning and achievement.

*RMC Research Corporation* (http://www.rmcdenver.com/) will be the external evaluator for this project. The current project will not only investigate students' understanding of conceptual physics and the nature of science, through pre- and post-tests designed by the *Educational Testing Center*, but also gather data from students' CSAP scores in reading, mathematics, and science, to investigate the projects broader impact. The tests will be examined for their bias in language and content to ensure fairness to all students. Student performance on tests and teacher assessments of project will be included in the summative evaluation of the project.

## DISSEMINATION PLANS

From the second year, the senior personnel and the advisory team will actively promote curriculum availability and encourage its use during professional development meetings of teachers at pre-high schools in Colorado and other States. Our support partners, including *Interwest Equity Assistance Center (*http://www.colostate.edu/programs/EAC/), *African American Leadership Institute* (http://www.aali-rockymtn.org/), and other organizations recommended by the key personnel, will also play a crucial role in the dissemination process. The key personnel will also conduct workshops at *National Science Teachers Association* meetings, *American Association of Physics Teachers* meetings, and *American School Counselor Association* Annual Conferences, to familiarize more teachers with the project.

**SUMMARY BIOGRAPHICAL SKETCHES**

| **Senior Personnel** | | | |
|---|---|---|---|
| No. | Name, Title, & Institution | URL, E-mail, and phone number | Expertise |
| 1 | **Brent Wilson** (P.I.) | http://carbon.cudenver.edu/~bwilson/ | Instructional Design, |
| | Professor, Information & | brent.wilson@cudenver.edu | Technology Adoption |
| | Learning Technologies | (303) 556-4363 | in Schools, and |
| | School of Education | | Constructivist Learning |
| | University of Colorado at Denver | | Environments |
| 2 | **Nathan Balasubramanian** | http://www.innathansworld.com | Middle and High School |
| | Project Director and co-P.I. | nathan@InNathansWorld.com | Physics and Science, |
| | School of Education | (720) 936-5999 | Teacher preparation |
| | University of Colorado at Denver | | |
| 3 | **Krzysztof Cios** (co-P.I.) | http://isl.cudenver.edu/Cios.htm | Computational Neuro- |
| | Professor and Chair, Computer | Krys.Cios@cudenver.edu | science and Data Mining |
| | Science & Engineering Department | (303) 556-4314 | Methods |
| | University of Colorado at Denver | | |
| | **Key Personnel (Consultants)** | | |
| 1 | **Fred Goodman** | fgoodman@umich.edu | Design of Simulations |
| | Professor of Education | (734) 763-6717 | and Games for Schools |
| | University of Michigan, Ann Arbor | | |
| 2 | **Curtis J. Hieggelke** | curth@jjc.edu | Physics Education & |
| | Professor, Physics & Robotics | (815) 280-2371 | TIPERs |
| | Joliet Junior College, Illinois | | |
| 3 | **Brian Jones** | bjones@lamar.colostate.edu | Science Instruction, |
| | Director, Little Shop of Physics | (970) 491-5131 | Interactive Traveling |
| | Colorado State University | | Science Experience |
| 4 | **Richard Krantz** | krantzr@mscd.edu | Physics Education & |
| | Associate Professor, The | (303) 556-8560 | Effective Pedagogical |
| | Metropolitan State College of Denver | | Techniques |
| 5 | **Alexander Repenning** | ralex@cs.colorado.edu | Agentsheets and |
| | Research Asst. Professor, Dept. of | (303) 492-1349 | Interactive Simulations |
| | Computer Science, University of | | |
| | Colorado at Boulder | | |
| | **Key Personnel (Advisory Committee)** | | |
| 1 | **Rich Feller** | feller@cahs.colostate.edu | Career Development |
| | Professor, Counseling and | (970) 491-6879 | |
| | Career Development, School of Edu. | | |
| | Colorado State University | | |
| 2 | **Marcia Linn** | mclinn@socrates.berkeley.edu | Cognition and Web |
| | Professor of Cognition and Education | (510) 643-6379 | Integrated Science |
| | University of California, Berkeley | | Environment (W.I.S.E.) |
| 3 | **Valerie Otero** | valerie.otero@colorado.edu | Elementary Science |
| | Assistant Professor, School of Edu. | (303) 492-7403 | Methods, Physics for |
| | U. of Colorado at Boulder | | Elementary Teachers |
| 4 | **Robert Poel** | bob.poel@wmich.edu | Physics Education |
| | Professor, Physics | (269) 387-3336 | OPPS, OpPhys, CPU, |
| | Western Michigan University | | CIPS, PIPS |
| 5 | **Paul W. Zitzewitz** | pwz@umd.umich.edu | Physics Education |
| | Professor of Physics and Chair of | (313) 593-5277 | and Pre-High School |
| | Department of Natural Sciences | | Education |
| | University of Michigan - Dearborn | | |