Creating Constructivist Physics for Introductory University Classes

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Abstract

We describe the setting and effectiveness of a constructivist, project-enhanced environment in an Introductory Physics course. Force Concept Inventory measurements show that students made significant gains in their understandings of mechanics concepts. Student interviews revealed that group project work assisted in students' assimilation of course material.

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Rationale

Research shows that students who are taught physics by traditional methods fail to learn essential physics concepts (Bowen, 1998; McCaskey & Elby, 2004; McDermott, Shaffer, & Somer, 1994; Mullins, 1998; Sadler, 1998). Most of this research has been done in university level, calculus-based physics courses. Our approach combines the demonstrated success achieved by research-tested, calculus-based physics with modifications made to adapt to algebra-based physics curriculum appropriate for use within high school classrooms (Wells, Hestenes, & Swackhammer, 1995) and within university physics classes for non-physical science majors. This modified curriculum replaces the traditional textbook-lecture-lab format with a hands-on, project-based laboratory learning environment. The curriculum was designed and developed by making use of the research on how people learn science (Bransford, Brown, & Cocking, 1999; Travis & Lord, 2004; Donovan & Bransford, 2004). We created a constructivist-based approach within our university Introductory Physics sections to test if this method made physics concepts visible and meaningful to students.

The purpose for these research-based modifications within our Introductory Physics classes was three-fold. Firstly, we wanted to observe similar success within our algebra-based physics courses (for non-physical science majors) to those calculus-based physics courses cited in the literature. Secondly, we wished to field test and refine this curriculum with university students prior to its enactment within a high school physics environment. And thirdly, the sections of Introductory Physics that were taught with this modified curriculum contained a large percentage of pre-service teachers. Therefore, we wanted these pre-service teachers to have a first hand opportunity to experience and hopefully find value in this non-traditional form of teaching so they might implement it within their future classrooms.

Constructivist Physics

To better understand our constructivist framework, we utilize Hoovers' (1996) definition of constructivist learning. "*Learning is active rather than passive…if what learners encounter is inconsistent with their current understanding, their understanding can change to accommodate new experience…they apply current understandings, note relevant elements in new learning experiences, judge the consistency of …emerging knowledge, and based on that judgment, they can modify knowledge*" (p. 1). Confrey and Kazak (2006) unpack "the grand theory" of constructivism in mathematics and science. According to Confrey and Kazak, constructivism concentrates on how "actions, observations, patterns, and informal experiences can be transformed into stronger and more predictive explanatory ideas through encounters with challenging tasks…constructivism recognizes the value of other forms of securing mathematical certainty, such as the coordination of representations, the identification of patterns, the recognition of similar ideas in apparently dissimilar settings (connections), the development and refinement of conjectures, and the applications of the ideas to other fields" (Confrey and Kazak as cited in Confrey and Maloney, 2006, p. 7). This idea of constructivism is very much in line with inquiry learning where students actively engage in an instructional sequence of purposeful events such as problem sensing, problem formation, search, and resolution (Siegel, Borasi, and Fonzi, 1998, Dewey, 1933).

Classroom environments that incorporate constructivism and inquiry into their daily organization can allow students the chance to 'think scientifically' (Polman, 2000) and to carry out investigations in a focused, collaborative, and meaningful manner. According to the National Science Education Standards or NSES (NRC, 1996), K-12 students "should have the opportunity to use scientific inquiry and develop the ability to think and act in ways associated with inquiry, including asking questions, planning and conducting investigations, using appropriate…techniques to gather data, thinking critically…about relationships between evidence and explanations, constructing and analyzing alternative explanations, and communicating scientific arguments" (p. 105). Although NSES describes the types of events that K-12 students should experience, we believe that similar opportunities should be afforded to university students.

Harwood (2004) developed a model for inquiry with the following essential components: (1) asking general questions; (2) defining a problem; (3) forming a question; (4) investigating the known; (5) articulating an expectation; (6) carrying out a plan; (7) examining results; (8) reflecting on findings; (9) communicating with others; and (10) making observations. Similar models have been documented in the literature (Llewlleyn, 2002; Borasi & Siegal, 1994). This model is not unique to only science, but is applicable to all disciplines.

Studies have shown that physics students taught with traditional methods fail to do as well as those students taught with constructivist, inquiry approaches, or what Hake (2000) defines as interactive engagement methods.

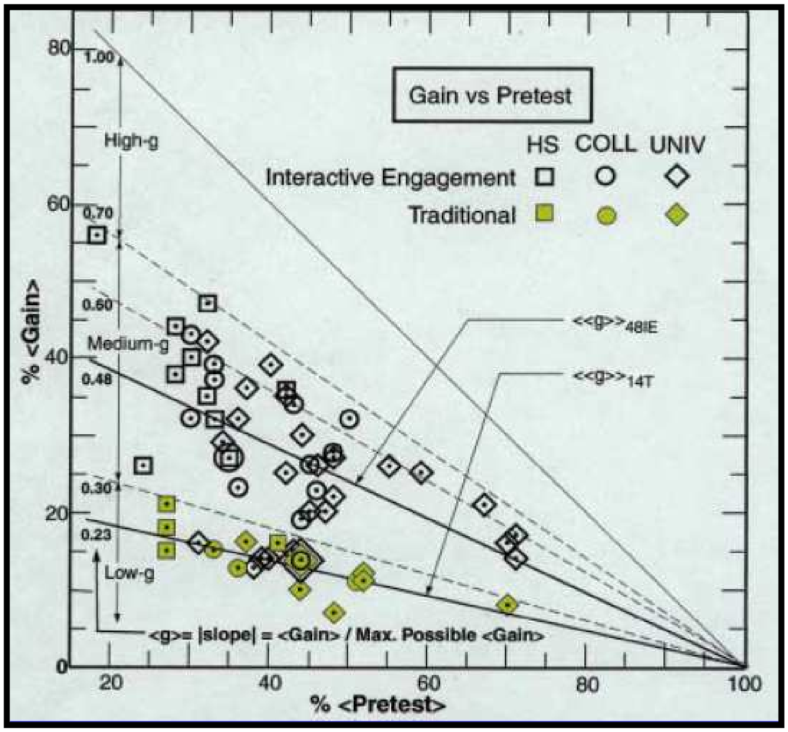
> *Interactive Engagement (IE) Methods* are those designed at least in part to promote conceptual understanding through interactive engagement of students in heads-on

> (always) and hands-on (usually) activities that yield immediate feedback through discussion with peers and/or instructors.
>
> *Traditional (T) Methods* are those methods relying primarily on passive-student lectures, recipe labs, and algorithmic-problem exams. Traditional courses as those reported by instructors make little or no use of IE methods.

Crouch and Mazur (2001) found that both Calculus-based and Algebra-based Harvard University Introductory Physics courses taught through interactive peer instruction showed significant gains in students' conceptual understanding on the Force Concept Inventory (FCI) test (Hestenes, Wells, and Swackhammer, 1992a; 1992b). The average normalized gains of a traditionally taught Physics course is 0.23, and the average normalized gains of an Interactive Engagement taught course is 0.48 according to the Hake (1998 study) of six-thousand student surveys of test data for introductory physics courses.

Figure 1 displays a graph comparing gains in the FCI and Mechanics Diagnostic Test (Halloun and Hestenes, 1985) versus pre-test scores for both T (filled symbols) and IE (open symbols) methods (Hake, 1998). The graph includes scores obtained from high school, college, and university physics students. Clearly, IE students have greater normalized gains than their T counterparts at all levels of introductory physics.

Figure 1
Gain versus Pre-test Scores (Hake, 1998, p. 65)



For the past year, we have engaged in improving the constructivist inquiry model within our Introductory Physics classes. Although all three authors in previous years implemented pieces of inquiry within their courses, a focused effort on inquiry in

Introductory Physics emerged due to combined frustrations stemming from low achievement by students with non-physical science majors. We believe that in order for students to understand and be able to apply physical concepts, they need to engage in constructivist physics learning by becoming ***full participants*** during their investigations (Lave and Wenger, 1991).

Novak, Patterson, Gavrin, and Christian (1999) described a Just-in-Time Teaching method of teaching introductory physics blended with active learning. This type of IE method featured professors adapting their lectures to student learning difficulties on solving problems exhibited in electronic responses. This method also included collaborative recitations and students using an on-line homework system. Novak et al.'s IE method contained a significant lecture component and is designed to address large numbers of students in a lecture hall. Mazur (1997) discussed how an IE method of teaching can include a lecture demonstration that leads "into a question whose answer forces students to think about what they have just observed. Working the other way…ask students about a particular question and use a demonstration to answer it" (p. 27).

Both of these above examples are considered to be IE methods using the Hake definition; however, they are very different when compared to our IE method since our students are doing much more than problem reflecting and problem solving.

"Perhaps the most serious difficulty among introductory students is the failure of many to integrate related concepts. The lack of a coherent framework may pass undetected because mathematical manipulation often suffices for the solution of standard problems. To be able to apply a concept in a variety of contexts, students must be able to not only define the concept but also to recognize its relevance to a given physical situation. They are unlikely to develop this facility, however, unless they themselves have gone through the steps necessary to construct the concept" (McDermott, 1998, p. 2).

Through the constructivist, project-based approach, our students experienced the steps of question formulation and conjecture, experimental design, examination of results, and explanation of the physical phenomenon. In addition, final project work required our students to apply multiple physics concepts in a variety of contexts. We follow with a description of our research study and will map our results onto the Hake (1998) plot shown in figure 1.

Participants

For this paper, we will focus on two physics classes taught by the first and third authors having enrollments of 24 and 14, respectively. These 38 students (16 males and 22 females) had the following majors: 31.6% life science, 21.1% education, 15.7% pre-medicine or pre-pharmacy, 15.7% architecture, and 15.8% other, such as history, theater arts, Spanish, and undeclared. The student body consisted of 84.2% White, 7.9% African-American, and 7.9% other, and 36.8 % of the students were from the Honors College. There were a total of five freshmen, eleven sophomores, eighteen juniors, and four seniors.

Procedures

Our Introductory Physics sections were offered as four-credit hour classes but unlike the traditional sections that had three hours of lecture and two hours of laboratory, our sections were completely laboratory-based with individualized group “lectures.” Within these two physics sections, students (working in cooperative learning groups of four and five) learned by performing guided hands-on, minds-on, computer-based laboratory experiments. Using the constructivist method of instruction, students did not follow the regular textbook/lecture/lab format, but instead:

a) Made predictions that required them to examine their preconceptions about the phenomenon being studied.
b) Reflected on their observations and refined their conceptions.
c) Developed conjectures and generalizations based on their observations, and then designed their own experiments that would confirm their conjectures (Confrey and Kazak).
d) Performed experiments intended to verify predictions and applied their new understandings of the phenomenon to the solution of other related problems (Confrey and Kazak).
e) Worked on a final motion project of their choosing. For the final project, students videotaped various motions and analyzed the motion using VideoPoint (Lenox, 2002) software.

All laboratory activities within the Physics courses required students to keep journals and encouraged them to document their thinking processes in a narrative format. All groups were not necessarily working on the same inquiry experiment at the same time. Differentiated instruction was achieved by having students work in cooperative groups while the instructor circulated, facilitated group work, and provided “just-in-time” group lectures. Students could perform their inquiry experiments in multiple ways and had learning opportunities through assessing their own conjectures, by teaching their peers, and with individualized instructor attention when needed.

Research Focus and Methods

Our research study focused on an examination of whether physics concepts were made visible and meaningful to students using our constructivist technique of instruction. In addition, we detail our IE, constructivist approach through illustration of curricular units and group project work. Although other studies report that reform-oriented, constructivist methods of teaching physics are beneficial, few describe in depth exactly how the curriculum and instruction were enacted or showcase students’ voices regarding what they learned. In this paper, we compare our constructivist Physics FCI test results with the Hake (1998 study) of six-thousand student surveys of test data for introductory physics courses and provide detailed information regarding how we created our constructivist physics environment enhanced with final student projects.

This study is of a mixed method research design (Creswell, 2003). Data collections included students’ final projects and presentations, pre and post Force Concept Inventories (FCI), and end of course interviews. Through triangulation of the data

(Caracelli & Greene, 1997; Denzin & Lincoln, 1998), we analyzed students' understandings and knowledge constructions of physics concepts and applications.

The FCI, a multiple-choice diagnostic test, was developed by Arizona State University physicists Ibrahim Halloun and David Hestenes "to measure students' conceptual understanding of force and motion, topics that constitute 70-100 percent of the content of the first semester of virtually every undergraduate physics course" (Wyckoff, 2001, p. 311). The six Newtonian concepts tested in the inventory are (a) kinematics, (b) First Law, (c) Second Law, (d) Third Law, (e) Superposition Principle, and (f) kinds of forces (Hestenes, Wells, & Swackhamer, 1992b).

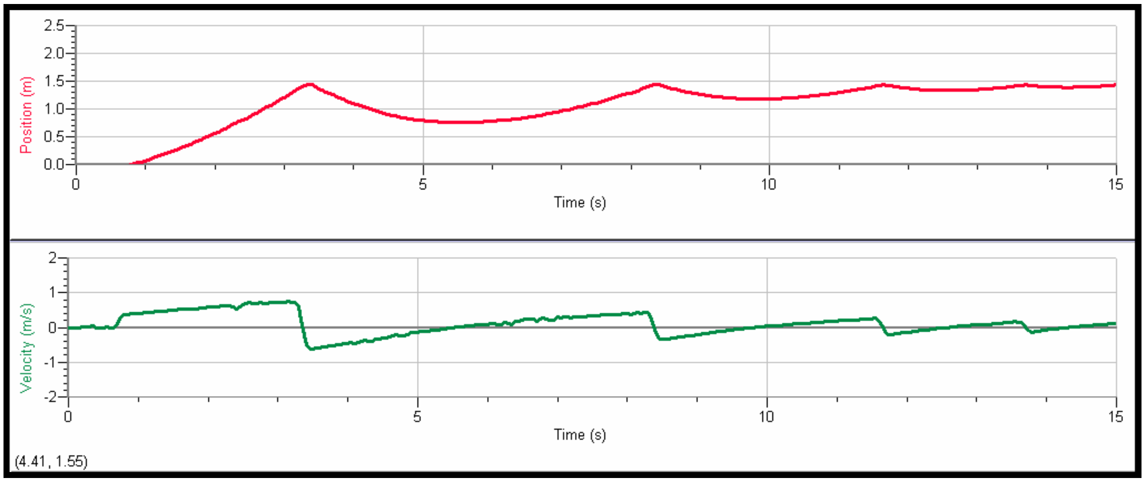
Along with the FCI data, eight student volunteers were interviewed by the first author. The interview protocol was open ended where students were simply asked to reflect on their experiences in this physics course and compare them with their other science learning opportunities. The open ended protocol also requested that students comment on their final projects. We follow with examples of the physics units and students' classroom work and final projects.

Examples of Physics Units

Throughout all curricular units, students used their previous knowledge and current observations to construct models for each area of investigation, giving them a context through which new understanding emerged. They developed scientific and mathematical procedures driven by observations which created authentic scientific and mathematical real world connections. They predicted and considered a range of various physical situations (see syllabus with scope and sequence in the appendix). After carrying out their experiments to test their predictions and examining their resultant graphical representations, students were able to discover functional relationships and equations that described the event.

Figure 2

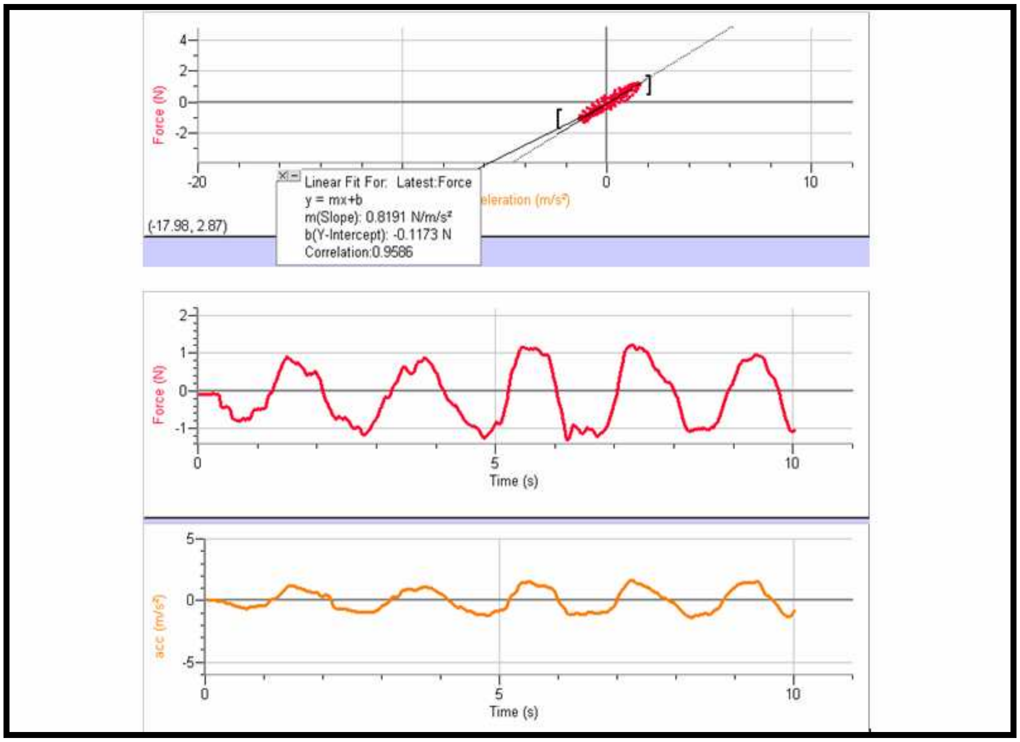
Position versus Time and Velocity versus Time plots of a cart's motion moving up and down an inclined track.



One of the first units enacted using this constructivist curriculum involved motion. Students learned multiple ways to explain one dimensional motion using words, graphs, and mathematical modeling. Students developed an intuitive understanding of position, velocity, and acceleration recognizing how graphs could be used to describe changes in position, velocity, and acceleration of an object. For example, Figure 2 displays plots that students created of position versus time and velocity versus time of a cart moving down an inclined track, hitting a bumper at the end of the track, moving back up the inclined track, and repeating the process several times losing energy after each bumper collision. Students became aware that the position versus time plot appeared to show a quadratic relationship between bumper collisions and began to interpret and to connect kinematic functional relationships with the physical cart's motion.

A following unit involved forces applied in one dimension. Students devised a method of applying a constant force to an object, created a scale for measuring force, and discovered a relationship between force and acceleration based on observations of an object's motion. For example, Figure 3 shows student-generated plots (using force and motion sensors) of force versus acceleration, force versus time, and acceleration versus time of a cart's motion loaded with a 500 gram mass along a flat track. Students observed the similarities between the force versus time and acceleration versus time plots. Students also were able to discover the linear relationship between force and acceleration when they plotted the force versus acceleration, and that the physical meaning of the slope was the mass of the loaded cart.

Figure 3
Force versus Acceleration, Force versus Time, and Acceleration versus Time plots of a cart's motion loaded with a 500 gram mass along a flat track.



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Linear Fit For:  Latest:Force
y = mx+b
m(Slope): 0.8191 N/m/s²
b(Y-Intercept): -0.1173 N
Correlation:0.9586
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As with the above examples, all other units in the curriculum involved similar student-centered explorations which used an interactive, constructivist format.

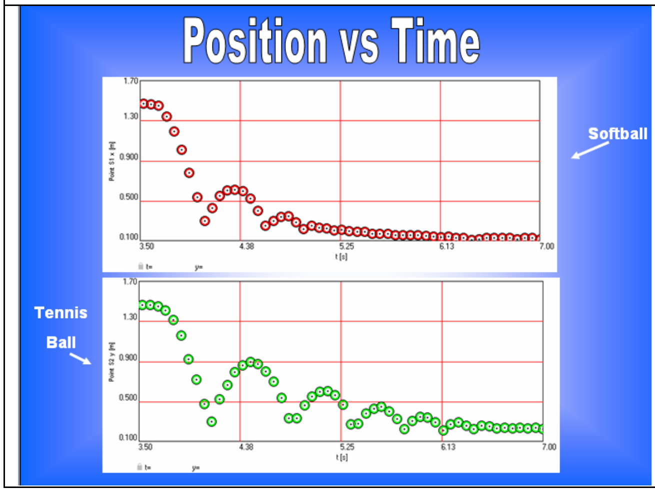
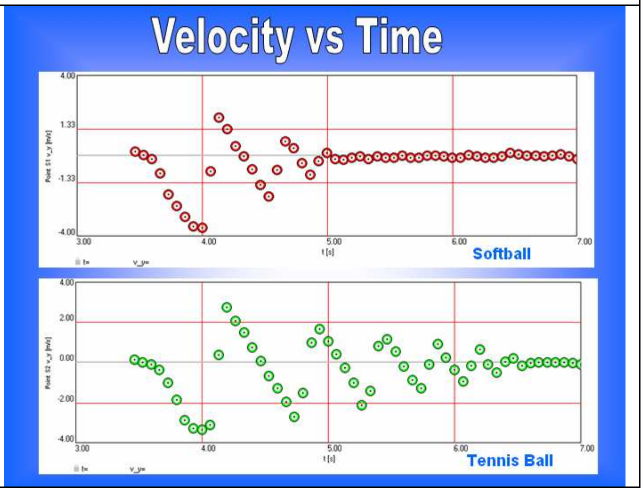
Inquiry Motion Projects

Students' final projects were used as a form of authentic assessment as well as a means of connecting much of what they had learned throughout the term (Wilhelm and Walters, 2006). For their final project, students formed research questions and videotaped a variety of motions that would assist them in answering their generated queries. In order to analyze these motions, students utilized VideoPoint software which allows the user to extract motion information from digital movies. Using this software package permits one to obtain position information from objects on a frame-by-frame basis. VideoPoint has tools to analyze the resulting data expressed as columns of numbers (position, velocity, acceleration, time) or as graphs. Student projects included analysis of bouncing balls, projectile motion of objects with and without parachutes, of a person moving down a playground slide, the motion of the computer created 'Mario' from the Nintendo software game, the balls' motion in Newton's Cradle (five balls hanging side by side in pendulum arrangement), and a golf swing. Two examples of the students' motion projects follow:

Bouncing Balls Project

A group of four students chose to videotape, examine, and compare the physical and mathematical motion of a softball and tennis ball that were dropped simultaneously and bounced several times on the floor. Figure 4 displays this group's graphed representations of each ball's position versus time and velocity versus time. Students explored each ball's location relative to the floor throughout its velocity versus time graph and noticed how quickly the softball dampened out when contrasted to the tennis ball. They also investigated and explained the physical and mathematical meaning of slope (acceleration) in the velocity versus time plot as well as the positive or negative values of velocity which indicated the ball's direction.

Figure 4
A. Graphed Representations of Position versus Time for the Bouncing Balls, B. Graphed Representations of Velocity versus Time for the Bouncing Balls.

A.	**B.**
	

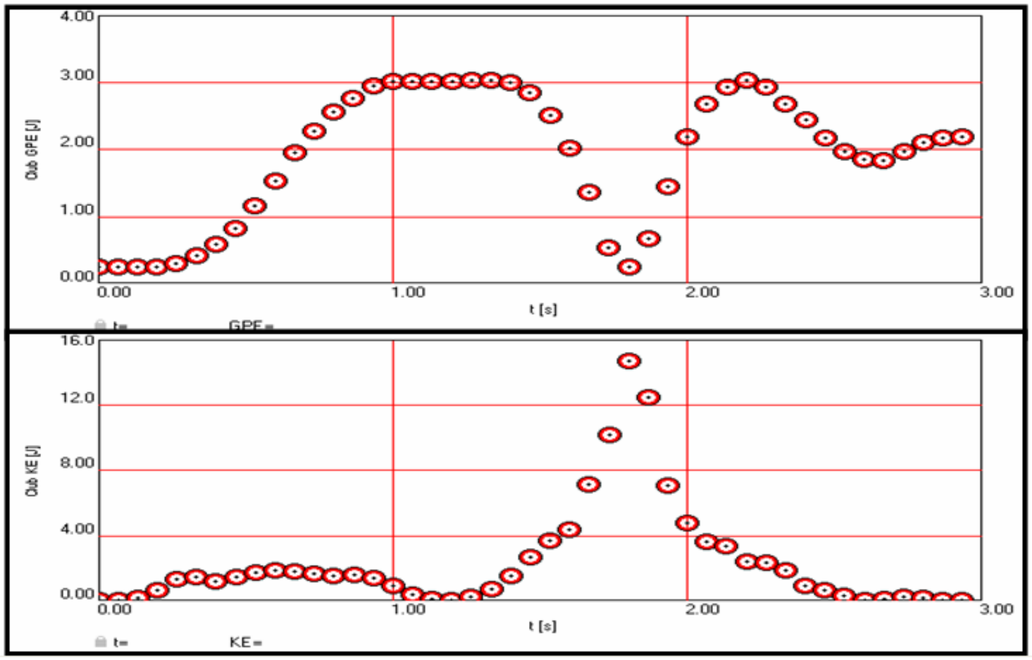
Golf Swing Project

Another group of five students was interested in the physics of sports. In particular, one group member recalled seeing a type of software available to golfers designed to improve their golf swing. The group decided to use VideoPoint software to analyze the motion of a group member's swing (see Figure 5).

Figure 5
Movie Clips of Student's Golf Swing

The golfing group focused their research on energy conservation. They examined the potential and kinetic energy of the golf club's head throughout the entire golf swing motion. They explained "*that as the club moves upward the potential energy increases and the kinetic energy decreases…As the club moves down, the kinetic energy increases as the potential energy decreases.*" They also presented graphical representations of potential energy versus time and kinetic energy versus time of the golf club head shown in Figure 6.

Figure 6
Top graph – Potential Energy vs. Time of Golf Club Head.
Bottom graph – Kinetic Energy vs. Time of Golf Club Head.



These two examples illustrate how students constructed and applied their newfound understandings to real life situations. Other student projects investigated accelerations in the microworld of a Mario computer game; periodicity, momentum conservation, and energy transfer in Newton's Cradle; the coefficient of friction between a person and a slide, and the effect of air drag on projectiles. Students conducted inquiry throughout this project work as they defined a problem to investigate, carried out a plan, made observations, collected data, examined findings, and communicated with others their final results. This entire act of constructivist inquiry was student-centered and the tools they used were student-contextualized. To complete their project work, students had to draw on all their experiences in order to fully interpret their observations. This is the essence of what real scientists do and this is the essence of our newly designed physics course.

Results

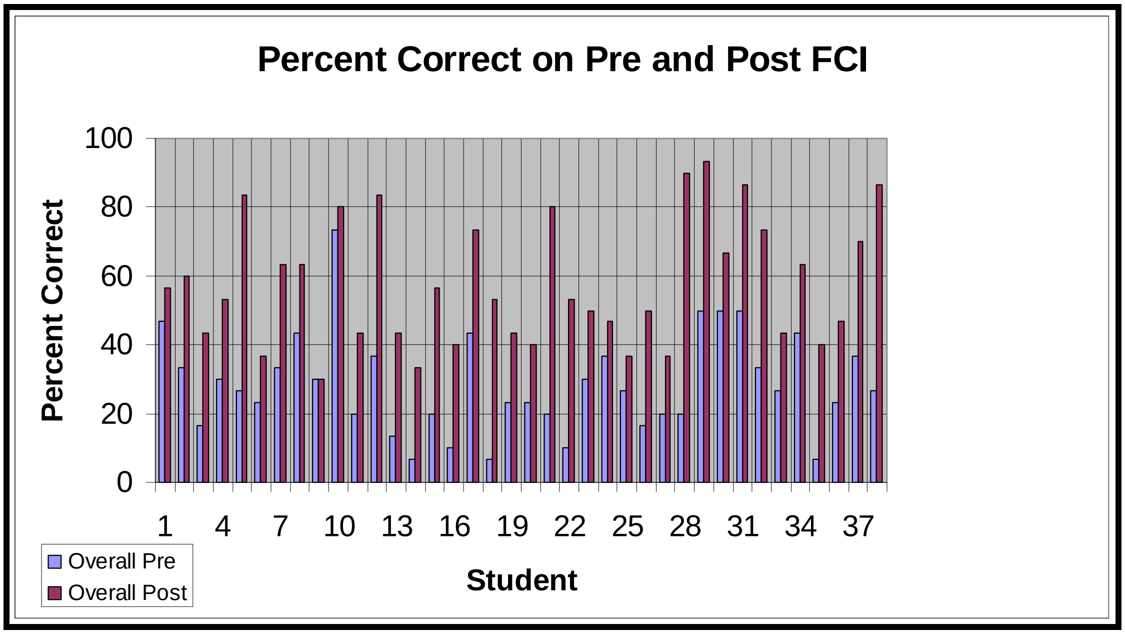
In order to assess the effectiveness of implementing this constructivist model within our physics courses, we administered pre and post FCI assessments to the 38 students. In addition to this measurement, we also interviewed eight students concerning their thoughts and views about the course in general and their group project work. Students volunteered for all interviews.

Our two Physics classes were given the pre-FCI prior to instruction and the post-FCI was given during the students' scheduled final examination. The mean pre-test score was 28.6 % correct with a standard deviation of 14.5 % and the mean post-test score was 57.7 % correct with a standard deviation of 18.2 %. A repeated measures analysis of variance (ANOVA) revealed a highly significant increase in understanding of FCI concepts upon completion of the Physics course, $F(1,37) = 126.655$, $p < .001$. The partial η^2 was .774, which indicates that approximately 77.4 % of the gain in FCI understanding can be directly attributed to the constructivist Physics course.

Figure 7 shows the percent correct on pre and post-FCI tests per student. Students made significant gains on 20 of the 30 multiple choice test items. The overall test average gain factor [(gain by student)/(possible gain)] was 0.41, which when plotted with their mean pre-test score of 28.6 % and mapped onto the Hake (1998) plot shown in figure 1, places our classroom data well within the Interactive Engagement group range. Of the ten test items that did not show significant gains, 70% included questions concerning circular motion and centripetal force.

Along with the FCI data, eight student volunteers were interviewed by the first author. The open ended interview protocol asked students to reflect on their experiences in this physics course and compare them with their other science learning opportunities. The protocol also requested that students comment on their final projects. Representative interviewees' statements follow.

Figure 7
Percent Correct on Pre and Post FCI per each student



Student Reflections on Physics Course

"This one made us actually think about what we're doing. Some (*science courses*) are telling us that this is how it is and then take formula and put in the numbers, but this one you actually saw why the formula makes sense" (Middle Level Mathematics/Science Pre-service Teacher).

"It was a lot different because in high school, they just lectured and pretty much just put the formulas up on the board and told us when to plug them in and stuff. It was just a lot different, (*in this class we*) like actually doing the experiments and come up with the formulas on our own. It was a lot more hands on….We had to figure it out more for ourselves more in this class instead of just being given it" (Middle Level Mathematics/Science Pre-service Teacher).

Representative Student Project Comments

One student expressed her interest in the course and in its project component, she explained, "I was more interested. This way I thought about it more. It was really cool to put everything we learned all semester into our project. It like put problems that we had been doing…into real life situations. It pulled everything that we did all semester into one real life problem" (Zoology Student and Playground Project Member).

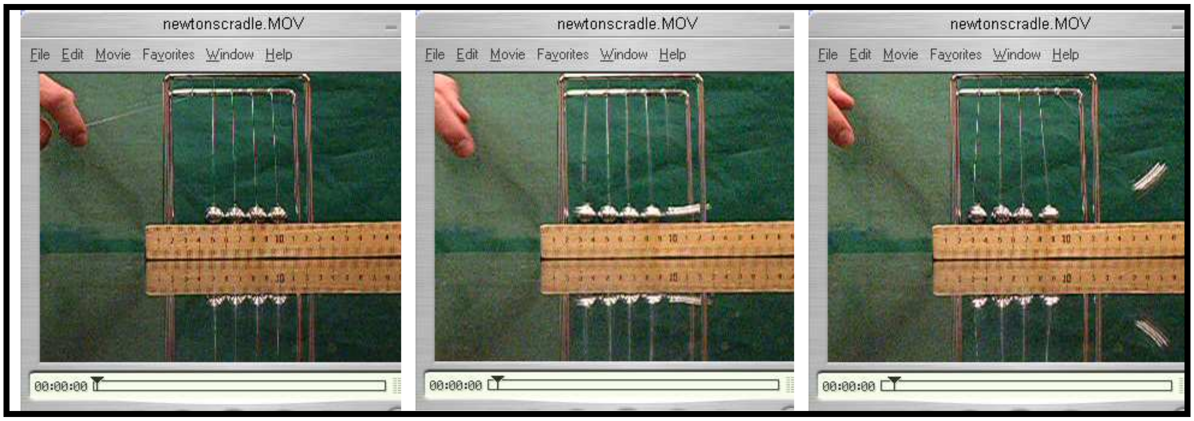
Below is an excerpt from the transcription of a student's final project comments that involved the analysis of Newton's Cradle (see Figure 8) with a focus on momentum conservation and energy transfer.

"Ok, Newton's Cradles. I was really fascinated with that one. I was always fascinated by the fact that energy is never just lost, but it's just being transferred from one ball to the other even though the other three (in the middle) are not moving. It's still transferring, which made me think of the other day. I asked my wife, 'what can we do to cars to keep them from crushing?' If in Newton's Cradles, one ball hits another and transfers the energy and knocks the other one off, if we could put some sort of like, ah, something to soak up that energy on the bumpers of the car, how would that affect it? If one car hit another one, is there any natural resource that we have that soaks up energy and just keeps it stored? I was trying to figure out what would make it safer."

This student's research project caused him to wonder about possible life applications linked to his new knowing and understanding of physical concepts like energy conservation, momentum conservation, and energy transfer. He speculated how one might make a futuristic car that would use the laws of physics to create safer automobiles.

Figure 8

Movie Clips of Newton's Cradle



Seven of the eight students interviewed clearly expressed their favored preference to the constructivist teaching approach. However, one student responded, "Personally, I like hands on, but I do better at having a lecture first because I learn by writing it down. I like having notes. I know how boring that sounds, but that's how I learn better by writing, so, it is easier for me that way." This particular student was a middle level mathematics/science pre-service teacher who made an average normalized gain score of .17 (less than half of the class average normalized gain score). The interviewer asked this student how she planned to teach her own future mathematics and science classes. She stated that she would incorporate a mixture of inquiry and straight lecture.

The interview results exposed the students' voices regarding this course and their project work. Students stated that this physics class made them "actually think" and "actually do experiments and come up with formulas on their own," and "put problems into real life situations." Both interview and project data illustrated how students applied their physics coursework to "real life situations," and even caused some "fascination" as they pondered such things as energy transfer.

Conclusion

This paper showed through students' project work, interview responses, and FCI results how using a constructivist inquiry method of teaching physics created relevance and meaningful learning for many students. The students participated in a classroom environment that provided a series of challenging tasks, the chance at posing conjectures, occasions for refining and/or altering prior understandings, and opportunities to apply their newfound understandings into novel situations (such as their project work)—all of which made the physical and mathematical concepts visible, connected, and useful. The Bouncing Balls group connected physics and mathematics as they conducted their project work and investigated the mathematical and physical meaning of slope (acceleration) in a velocity versus time graph as well as the positive or negative values of velocity which indicated the ball's direction. The Newton's Cradle group found the ideas of energy conservation and energy transfer useful, and one member imagined how he might design a safer vehicle. Other students voiced how physics taught in the constructivist manner meant they "had to figure it out more for ourselves," "come up with the formulas on our own," and "you actually **saw** why the formula makes sense."

Force Concept Inventory results revealed our students achieving a higher normalized gain score than those students taught in a traditional manner (when comparing our normalized gain score of 0.41 with Hake's, 1998, average normalized gain score of 0.23 for traditional groups). In addition, we found that our average gain factor of 0.41 versus our mean pre-test score of 28.6% (when mapped onto the figure 1 plot) fell well within the Interactive Engagement group range. Other FCI results showed our students had greatest difficulty on topics of circular motion, which we will need to further address in future courses.

This research is much more than a small verification study of Hake's large analysis of the six-thousand student surveys of test data that compared results of Interactive Engagement versus Traditional classrooms. What makes our study unique and educationally beneficial is that we provided descriptive information about our introductory university physics class that was designed with constructivist and project-based ideals. This information can assist educators in their own design of their constructivist science classrooms. Along the lines of Confrey and Kazak's "grand theory" of constructivism in mathematics and science, we reported our students' actions, experiences, inquiry tasks, and final project work. Students' final projects contained Harwood's essential inquiry components of formulating a question, carrying out a plan, examining results, reflecting on findings, and communicating with others. As prescribed by McDermott (1998), our students made connections among concepts and the real world as they worked through the steps of inquiry and participated in our constructivist, project-enhanced environment.

Our future goal is to implement a similar classroom experience within high school physics environments with this modified, constructivist, project-enhanced approach.

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Appendix

Introductory Physics I

Course Description

Algebra and trigonometry based treatment of the laws of motion, energy, momentum, circular motion, gravitation, waves, and sound. Credit 4 hours.

The Nature of the Course: The course will be completely laboratory-based. (It will NOT be divided into Lecture and Laboratory.) Content will be learned through experimentation and projects. The focus is on understanding the experiments and on learning to develop models of physical phenomena based on experimental evidence. Answers to laboratory questions will be documented within a journal along with a recording of all thinking processes. There will also be readings, exercises, homework, and a final project.

Outcomes

The student will have:

1. Knowledge of basic processes, concepts and principles of the laws of motion, energy, momentum, circular motion, gravitation, waves, and sound;
2. Understanding of the concepts and laboratory techniques found in general physics;
3. Knowledge of metric measures;
4. Proficiency in organization and use of laboratory equipment;
5. Proficiency in process skills, including identifying and controlling variables, interpreting data, formulating conjectures and hypotheses, and experimenting.

Course Objectives:

Upon completion of this course, the student will be able to:

1. State the fundamental physical laws of motion, energy, momentum, circular motion, gravitation, waves, and sound;
2. Use algebra in solving problems in the fields mentioned in the objective above;
3. Use the concept of a vector along with basic trigonometry to solve a wide range of problems;
4. Utilize basic problem solving processes, including observation, inference, measurement, prediction, use of numbers, classifying and use of space and time relationships;
5. Use computers to perform laboratory experiments and analyze and graph data;
6. correctly use measuring devices and other equipment introduced in the lab;
7. Work effectively in cooperative group situations.

Methods of Accessing the Expected Learning Outcomes

Quizzes, two midterms, journal and homework assignments, pre-tests, post-tests, surveys, a final project, and one final exam which will assess your level of understanding of basic concepts, facts, discussed topics and reading material. Graded journal entries and homework assignments will be used to assess understanding of individual topics covered in daily discussions and pre- and post-tests will be used to assess gains in understanding over the extent of the course.

Pre-tests, post-tests and surveys: A general pre-test and a survey will be given at the beginning of the semester and some sections will start with pre-tests. In addition, a general post-test and survey will be given at the end of the semester.

Homework: Homework will be assigned each week. <u>Each homework assignment will include written work recording all thinking processes with each problem.</u>

Journals: All lab topics will be written in course journals.

Project: One project on motion analysis will be studied and presented in detail by each cooperative group.

Quizzes: There will be quizzes on content and process covered in class, homework, readings and exercises up to that point.

Exams: There will be two midterm exams and a final exam on content and process covered in class, homework, readings and exercises up to that point

Week of class	Topics
1	**Vectors and One-Dimensional Motion Graphing**
2	**One-Dimensional Forces and Motion**
3	**Gravitational Force and Two-Dimensional Motion**
4	**Newton's Third Law, Force Diagrams and Forces**
5	**Applications of Newton's Laws**
6	**Statics and Torque**
7	**Circular Motion**
8	**Work**
9	**Energy**
10	**Momentum**
11	**More Momentum**
12	**Waves**
13	**Sound Waves and Simple Harmonic Motion**
14	**Rotational Kinematics and Dynamics**
15	**Final Physics Project Presentations**