Running Head: Student achievement in reform

Project-Based Science Curriculum as a Vehicle for Reform in Science Education: Why Do I Need to Wear a Bike Helmet?

Rebecca Schneider
University of Toledo

Robert Geier
University of Michigan

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More information about this work including the curriculum materials "Why do I need to wear a bike helmet?" used in this study, can be obtained from our project's web site at this address: http://hi-ce.org/teacherworkroom/middleschool/physics/index.html

Correspondence concerning this article should be addressed to Rebecca Schneider, College of Education, University of Toledo, Toledo, Ohio 43606. E-mail: Rebecca.Schneider@utoledo.edu

Project-Based Science Curriculum as a Vehicle for Reform in Science Education: Why Do I Need to Wear a Bike Helmet?

Introduction

Improved student achievement is a central goal of efforts to improve science education. To promote student achievement, reformers have established standards for what students should know and be able to do, as well as what instructional methods should be utilized (AAAS, 1993; NRC, 1996). Key concepts and principles have been identified as targets for student learning. In addition, reformers recommend student-centered, inquiry-based practices that encourage deep understanding of science embedded in the everyday world. Moreover, it is intended that *all* students achieve the understanding described in these standards (American Association for the Advancement of Science, 1990). This is a challenging agenda in any school setting. However, finding a way to systemically promote high levels of student achievement in large urban districts is particularly important (Atwater, Wiggins, & Gardner, 1995; Blumenfeld, Fishman, Krajcik, Marx, & Soloway, 2000; Lee, 1997; Settlage & Meadows, 2002).

One method used by reformers to promote student learning on a large scale is the development of curriculum materials to guide classroom instruction (Cognition and Technology Group at Vanderbilt, 1992; Linn, 1998; Songer, 1993). The idea is that materials can be designed to address important science ideas and to provide students multiple opportunities to actively construct understanding. However, we can not take for granted that materials will necessarily promote student learning (Anderson, 1992, 1995; Wallace & Louden, 1998). As new materials are developed it is important to measure student achievement in regular classrooms (Anderson & Helms, 2001).

As part of an ongoing systemic initiative of a large urban public school district, the Center for Learning Technologies in Urban Schools (LeTUS) has developed curriculum materials to reflect desired reforms and provide teachers with needed support to learn and enact innovative curriculum. Developers created materials based on the premises of project-based science and were guided by design principles that include: contextualization, alignment with standards, sustained student inquiry, embedded learning technologies, collaboration and discourse, assessment techniques, and scaffolds and supports for teachers (Krajcik, Czerniak, & Berger, 2002; Singer, Marx, Krajcik, & Clay-Chambers, 2000). Lessons were developed to address important science ideas, offer multiple leaning opportunities, and provide appropriate instructional supports for students. Materials included detailed lesson descriptions to assist teachers in enactment and features to address the learning needs of teachers in content, pedagogy, and pedagogical content knowledge (PCK) (Schneider & Krajcik, 2002). Teachers are also encouraged to modify the curriculum to meet the needs of their students and circumstances. The goal of this research was to measure student achievement on standards-based science as a result of participating in a project-based science unit.

Methods

Background

This study was embedded in the work of the Center for Learning Technologies in Urban Schools (LeTUS), a National Science Foundation funded urban systemic initiative to reform science and mathematics instruction in a large urban public school system. As a systemic effort, changes were being attempted at all levels of the school system; teachers' instructional practices were only one facet of the change process under study (Blumenfeld et al., 2000). This study was conducted in urban middle schools located in low SES neighborhoods selected to participate in initial stages of the reform effort (Krajcik, Marx, Blumenfeld, Soloway, & Fishman, 2000). Students in these schools were predominantly African American (95% to 100%) with high percentages of students receiving free or reduced lunch (29% to 66%). Scores on local and statewide achievement testing in science were reported as below grade level. During four school years between 1998 and 2002, 16 teachers and over 1500 students completed the *Why do I need to wear a bike helmet?* unit (Table 1).

Curriculum material development was considered an essential component of the change effort, particularly to facilitate change within classrooms on a large scale (Blumenfeld et al., 2000; Singer et al., 2000). The project-based science curriculum materials used by teachers in this study were developed as part of the larger reform effort. As a researcher and curriculum developer, the first author took a lead role in designing these materials to support both students and teachers in the transition to inquiry based science instruction (see Schneider & Krajcik, 2002; Schneider, Krajcik, & Blumenfeld, 2002). However, the educative features of the materials were only one part of the professional development involved in this reform effort (Fishman & Best, 2000).

Curriculum Materials

The curriculum materials used in this study were developed to involve eighth-grade students in a ten-week extended inquiry. Students investigated the driving question, *Why do I need to wear a bike helmet?* (Schneider & Center for Highly Interactive Computing in Education, 1999). Lessons were designed to help students develop understanding of Newton's first law, velocity, acceleration, and force as well as graph interpretation and experiment design (see Table 2). These learning goals align with national and local standards for science (see Appendix A and B). The lessons integrate use of motion sensors with computer interface and emphasized collaboration among learners. Students create various artifacts to both develop and demonstrate their understanding. Science specific instructional strategies such as predict-observe-explain (POE) are used throughout the unit.

The curriculum materials include teacher materials and student worksheets. In the teacher's material, the unit is divided into five sections called learning sets, which were based on main ideas. Each learning set consists of several one to three day lessons. Teachers' materials include detailed description of lessons and explicit support for teacher thinking in the areas of content, pedagogy, and pedagogical content knowledge (Schneider & Krajcik, 2002).

Why do I need to wear a bike helmet? is an 8-week project-based science unit designed for eighth grade students. The driving question leads students through an inquiry into the physics of collisions (see Appendix C). This begins with an exploration of motion and how motion changes and continues force and how it can be changed during a collision. An unprotected egg riding a cart, representing a student riding a bicycle, is used to illustrate the possible result of a collision. This engaging demonstration becomes the anchoring experience that students use to think about physics concepts of motion and force including Newton’s laws of motion, velocity, stopping time, force, and the relationships between them. The egg and cart demonstration is revisited periodically through out the project and is the focus of the final artifact where students create a helmet for the egg and demonstrate their understanding of collisions.

Students participate in several investigations while exploring each stage of the driving question. Students begin by examining how evidence can be used to make explanations and gradually develop the ability to design their own investigations. They first focus on collecting evidence with the aid of computer generated graphs and motion sensors. Students develop understanding of motion and velocity as well as how to read and interpret motion graphs. Students continue to use computer generated graphs as they explore the relationship between variables assigned, evidence collected and what can be explained as they think about force, velocity, and time. Students will use motion sensors again in their own investigation of their egg helmets.

During the course of this unit students construct three main artifacts to develop and demonstrate their understanding of the science content and process described. Each is introduced early in the project and are added to and revised through out the project. First students are asked to describe and explain the events that occur during a collision. This is structured around four questions that focus students' attention on each phase of a collision and the physics that explains it. Second students construct concept maps. These maps incorporate each concept as it is developed and relationships are added and revised. Students work individually and in groups to create these maps. Third students design, conduct, and present their helmet investigation. In this final artifact students apply their knowledge of collisions and investigations to test the helmet they created to protect an egg during a collision.

Over the four years of this study the unit has undergone annual revision based on student and teacher data. In most cases the revisions entailed additional explanations or features in the materials. For example, student reading material was added in the third enactment year to give students additional opportunities to think about the concepts. However, this unit did undergo substantial changes in regard to the explanation for "why do I get hurt?" In years one and two, acceleration was used to explain why stopping fast caused more injury than stopping more slowly. In year three, based on feedback from experts in physics and the fact students had difficulty with understanding acceleration, the focus was changed to an energy explanation. Stopping more quickly involved greater energy transfer and thus more injury. In year four, again based on the advice of physics experts, the explanation returned to a stopping time explanation. This time, however, the explanation was modified to focus more on force–time relationships rather than the idea of acceleration explicitly. These curriculum changes were reflected in the pre-post test assessments used in this study.

Student Achievement Measures

Written assessment instruments were developed to assess student understanding of the curriculum content and science process skills (Krajcik et al., 2000). Example items for the *Bike Helmet* unit are listed in Table 3. The assessments were administered to each student participating in the curriculum projects. The assessments consisted of a combination of multiple choice and free response items that were further classified as either curriculum *content knowledge* or *science process* skill items. Content and process items were categorized by one of three cognitive levels required for arriving at a complete answer: *lower* (recalling information; understanding simple and complex information); *middle* (drawing or understanding simple relationships; applying knowledge to new or different situations; shifting between representations such as verbal to graphic; identifying hypotheses, procedures, results, or conclusions); and *higher* (describing or analyzing data from charts and graphs; framing hypotheses; drawing conclusions; defining or isolating variables given in a scenario; applying investigation skills; and using concepts to explain phenomena). The curriculum development teams (including science educators, content specialists, educational psychologists, and classroom teachers) constructed the tests. We analyzed all potential questions according to the scheme described above with teams of three to five raters achieving 95% accuracy in categorizing items.

Disagreements were settled by consensus. The use of rubrics for each open-ended question produced over 95% agreement by two to four raters each. Again, disagreements were settled by consensus.

Findings

A matched two-tailed t-test analysis was conducted to compare the pretest and posttest results. Table 4 presents pre- and posttest means and standard deviations, gain scores, and effect sizes for the results from each of the 4 years of enactment of the *Bike Helmet* unit. Total scores as well as scores on each of the target content areas are reported. The effect size column indicates the average gain on the posttest measured in the pretest standard deviation units. To aid interpretation, Cohen (1998) offers conventional definitions for the effect size as small (ES = 0.2), medium (ES = 0.5) and large (ES = 0.8). Figure 1 illustrates overall trend in effect sizes over the 4 years.

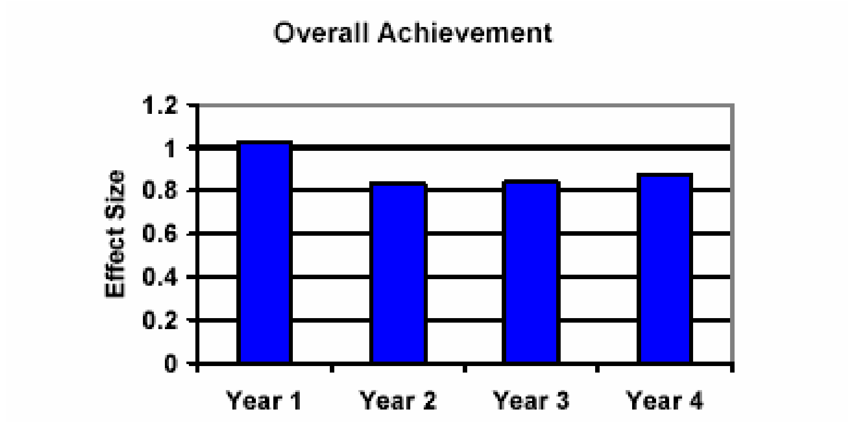

Figure 1: Overall achievement.

Figure 2 illustrates trends in effect sizes over the 4 years by student learning goals. This chart shows the wide range of effect sizes in year 1 followed by narrowing of the range with slight increase in effect size over time.

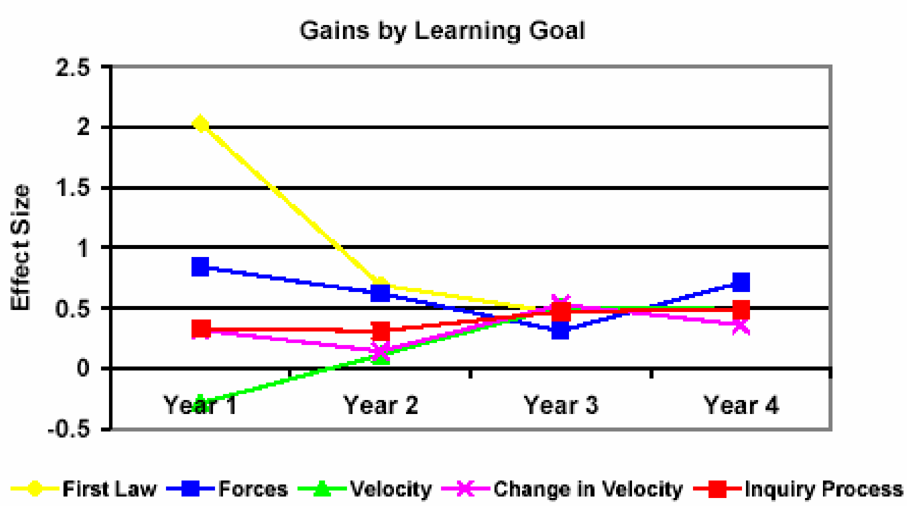

Figure 2: Gains by learning outcome.

In addition, effect sizes were determined for low, medium, and high cognitive level items for each of the 4 years (Table 5). As illustrated in figure 3 the range of effect sizes is the greatest in year 1.

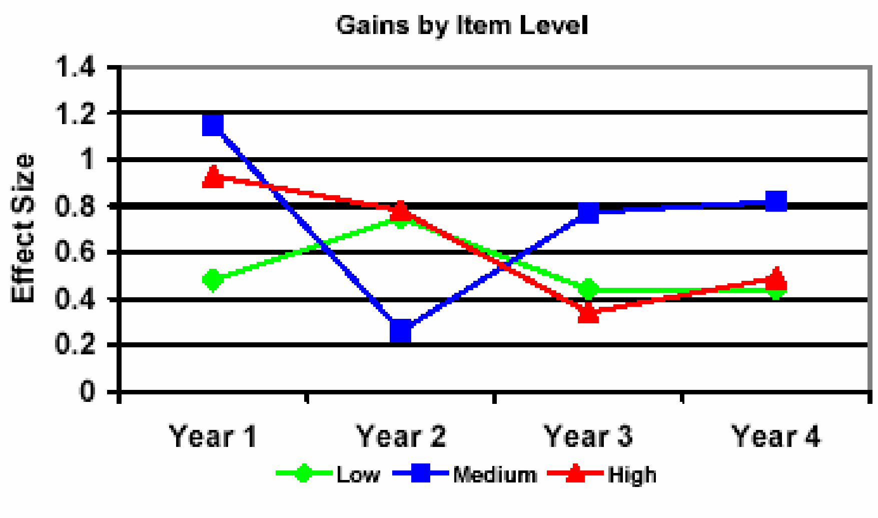

Figure 3: Gains by item level.

Student achievement gains also varied by teacher. Table 6 lists gains and effect sizes for each teacher overall and for low, medium, and high level items. Figure 4 illustrates the variation in effect sizes for different teachers. In addition, when looking at repeated enactment of the unit by an individual teacher, effect sizes do not show a general trend of improvement over time for all teachers.

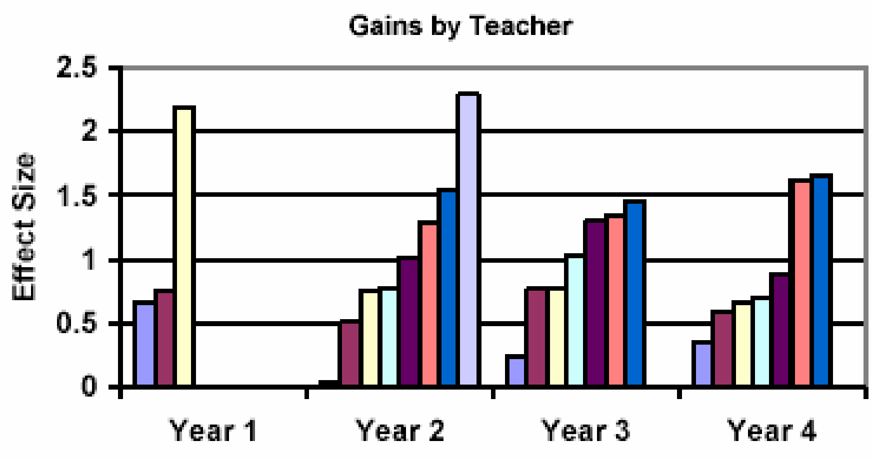

Figure 4: Gains by teacher.

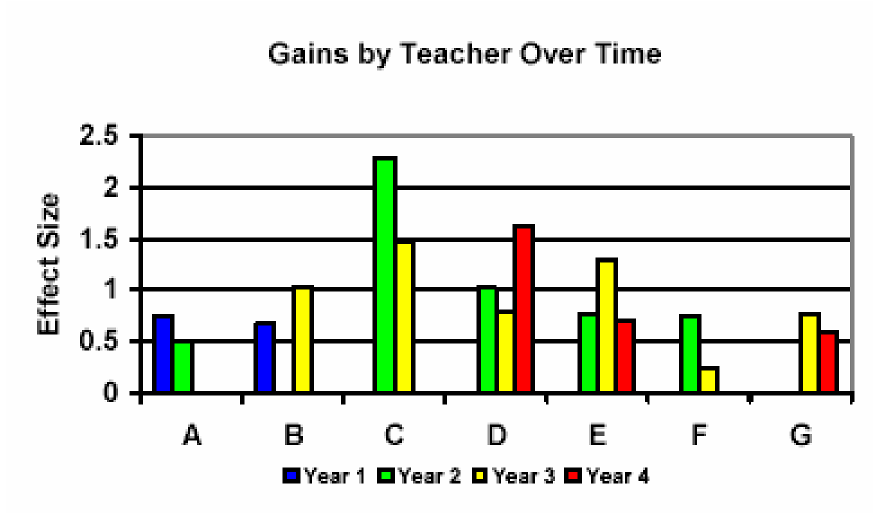

Figure 5: Gains by teacher over time.

Discussion

The student achievement scores for the *Bike Helmet* unit demonstrate encouraging results for many students. Student scores also illustrate the complexity of reforming science education. Overall effect sizes are in the large range as defined by Cohen (1988) for each of the 4 years. In addition, students generally did well on some concepts (first law, force, and graphing) and on medium and sometimes high cognitive level items. However, concepts of changing velocity (acceleration or impulse) proved to be more difficult. This finding is consistent with the difficulty most students have with this physics concept (American Association for the Advancement of Science, 1993; Driver, Squires, Rushworth, & Wood-Robinson, 1994). In addition, the process skill of using evidence was also difficult for students. Again, this is a difficult skill to acquire but also may reflect teachers' difficulty in presenting inquiry as a learning goal rather than as activities to motivate student participation (Krajcik, Blumenfeld, Marx, Bass, & Fredricks, 1998; Lunetta, 1998)

The results also show that curriculum materials alone are not sufficient to promote student achievement. When some students show encouraging gain scores we have some evidence that the materials have merit. However, differences by year and by teacher also indicate that reform efforts need to provide support for teachers in learning and enacting new curriculum (Schneider et al., 2002). Moreover, teachers and students need the support of school administration to provide necessary resources and policies (Blumenfeld et al., 2000). When teachers repeat a unit over 2 or three years an increase in effect sizes might be expected. However, the results in this study showed increasing, decreasing, increasing then decreasing, and decreasing then increasing. One reason for this variability may be the annual modifications in the unit based on feedback from teachers, students, and physics experts. Another reason may be the variability in other components of the reform effort such as professional development, in class support and availability of technology. All aspects of systemic reform are essential to promote real improvement.

The results do show gradual improvement overall. After the initial enactment year, effect sizes increased and the range between concepts narrowed. Specifically, improvement was seen in the areas that were most difficult for students, the concepts of velocity, change in velocity, and overall inquiry. These materials also help students achieve on higher cognitive items including items that require extended responses. Reform is not a straight path but a gradual process that requires years. Well designed curriculum materials can be an important component of systemic reform and support standards-based student achievement for *all* students.

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Table 1: Number of teachers and students by year.

School Year	Number of Teachers	Number of Students
1998 – 1999	3	78
1999 – 2000	8	529
2000 – 2001	11	413
2001 – 2002	7	523

Table 2: Science content addressed by the Bike Helmet project

First Law – Student describe that objects continue in their state of motion.

Opportunities to learn in *Bike Helmet*

- **Looking at motion:** Students begin to define motion and ask questions that will help them to answer the driving question of the unit.
- **Ballistics Cart Demonstrations:** A series of 5 demonstrations using a spring loaded cart and ball are used to develop the concept of Newton's 1st law step by step. For each of the demonstrations students make a prediction, observe, and offer explanations for the observed phenomena.

Force – Students describe force as an interaction between two objects and identify forces acting on an object.

Opportunities to learn in *Bike Helmet*

- **Exploring Force**: Using magnets, spring scales, toy cars, etc. students explore and feel the push and pull of forces cause motion and practice drawing diagrams to represent the forces on an object.
- **Force and velocity demonstrations.** Using tin pie plates, students observe the effect of different velocity on the force applied to the pie plate.
- **Force and time demonstrations.** Using an egg with cushioning materials, students observe the effects of changing the amount of time taken to stop the cart with the egg in a collision.

Velocity – Students describe motion by position, direction and speed.

Opportunities to learn in *Bike Helmet*

- **Egg and Cart:** Students observe a cart and egg in motion at increasing velocities.
- **Visualizing Motion:** Students perform a series of motions at different velocities to produce position time graphs. Students compare position-time graphs for each motion.
- **Challenges:** Students are provided a motion situation and challenged to match the situation to a graph that represents the motion. Students are also provided a graph and challenged to produce a motion that matches the graph.

Change in velocity – Students explain that net force is needed to change the state of motion of an object and the greater the change in motion the greater the force needed.

Opportunities to learn in *Bike Helmet*

- **When did velocity change?** Student groups share their motion detector results and determine commonalties and differences between motions for which the washer or bubble stays on center or moves off center. Change in velocity is operationally defined as any change in direction or speed due to a force.
- **Visualizing Carts at Constant and Increasing Velocity:** Students perform motions to produce distance-time graphs and velocity-time graphs of objects at constant velocities and increasing velocities in order to graphically visualize changing velocity.
- **Force and velocity demonstrations.** Using tin pie plates, students observe the effect of different velocity on the force applied to the pie plate.
- **Investigating force and velocity.** Students design and carry out an investigation to test their hypotheses about the relationship between velocity and force.
- **Force and time demonstrations.** Using an egg with cushioning materials, students observe the effects of changing the amount of time taken to stop the cart with the egg in a collision.
- **Helmet Investigation** Students perform the investigation as they designed it, collect and analyze data and form a conclusion.

Table 2 continued

Graphing – student create and interpret motion graphs.

<u>Opportunities to learn in *Bike Helmet*</u>

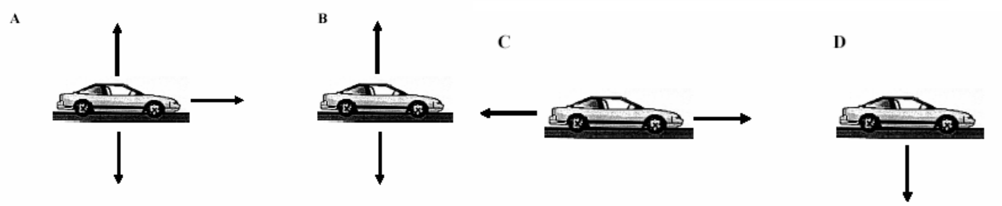
- **Visualizing Motion:** Students perform a series of motions at different velocities to produce position time graphs. Students compare position-time graphs for each motion.
- **Challenges:** Students are provided a motion situation and challenged to match the situation to a graph that represents the motion. Students are also provided a graph and challenged to produce a motion that matches the graph.
- **Helmet Investigation** Students perform the investigation as they designed it, collect and analyze data and form a conclusion.

Evidence – Students assign independent, dependant and control variables and use evidence to develop explanations.

<u>Opportunities to learn in *Bike Helmet*</u>

- **Helmet Investigation Planning** Students collect data as a class for an egg without a helmet.
- **Investigating force and velocity.** Students design and carry out an investigation to test their hypotheses about the relationship between velocity and force.
- **Investigating force and time.** Students investigate the effects of changing the stopping time and collect data about using different cushioning materials.
- **Helmet Investigation** Students perform the investigation as they designed it, collect and analyze data and form a conclusion.

Table 3: Assessment Items for Bike Helmet

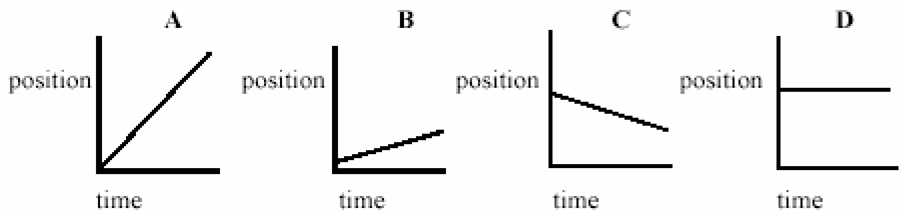
Concept	**Sample Test Item**
First Law	<u>Medium</u> 5. While riding your bike, you drop a quarter out of your hand. You continue on your way at the same speed. Where does the quarter hit the ground? a. in front of you b. beside you c. behind you d. far away from you
Forces	<u>Low</u> 3. A car is parked on the street in front of your house. The street is level. Which of the following diagrams shows all the forces acting on the car?  a. car A b. car B c. car C d. car D
Velocity	<u>Low</u> 7. What two measures are necessary for describing the speed of an object? a. the velocity of movement and time the object moves b. the distance the object moves and velocity of movement c. the distance the object moves and time the object moves d. the acceleration of the object and the distance the object moves
Change in Velocity	<u>High</u> 14. It is less dangerous to jump from a 5 foot high wall onto very loose sand than onto concrete pavement. You may be injured by the force involved in landing. Use ideas like speed and acceleration.

(table continues)

Table 3 continued

Graphing <u>Low</u>

14. Which of the following position-time graphs shows a person moving closer to the motion sensor?



a. graph A
b. graph B
c. graph C
d. graph D

Evidence <u>High</u>

Rosa wonders what affects the time it takes for a ball to roll down a ramp. She decides to test the hypothesis that the size of a ball affects the time it takes to roll down a ramp.

17. When Rosa designs her investigation she should do all of the following <u>except</u>
   a. list possible variables and determine how they will be measured.
   b. look at what she is testing in her hypothesis to choose the variable to change.
   c. look at what she is testing in her hypothesis to choose the variable to observe.
   d. write her step-by-step procedure before choosing her variables.

Table 4: Achievement outcomes by content area

	Pretest Mean (SD)	Posttest Mean (SD)	Gain (SD)	Effect Size
Year 1 (1998) N = 78				
Total Score (53)	13.29 (4.39)	17.82 (7.26)	4.53 (5.00)	1.03***
First Law (12)	2.60 (1.16)	4.95 (2.15)	2.35 (2.27)	2.03***
Force (19)	2.33 (1.41)	3.53 (2.50)	1.19 (1.88)	0.84***
Velocity (2)	0.83 (0.66)	0.64 (0.65)	-0.19 (0.81)	-0.29*
Acceleration (9)	1.92 (1.36)	2.36 (1.66)	0.44 (1.85)	0.32*
Inquiry Process (11)	5.66 (2.38)	6.44 (2.56)	0.78 (2.62)	0.33*
Year 2 (1999) N = 529				
Total Score (21)	5.97 (2.06)	7.67 (2.73)	1.70 (2.61)	0.83***
First Law (2)	0.72 (0.67)	1.18 (0.55)	0.46 (0.84)	0.69***
Force (4)	0.93 (0.82)	1.43 (1.17)	0.51 (1.26)	0.62***
Velocity (3)	0.86 (0.72)	0.95(0.82)	0.08 (1.06)	0.11
Acceleration (4)	1.46 (0.87)	1.58 (0.89)	0.12 (1.12)	0.14*
Graphing (3)	1.28 (0.85)	1.60 (0.87)	0.31 (0.97)	0.36***
Evidence (2)	0.56 (0.64)	0.58 (0.65)	0.03 (0.83)	0.05
Year 3 (2000) N = 413				
Total Score (21)	6.69 (2.56)	8.83 (3.28)	2.14 (3.20)	0.84***
First Law (3)	1.25 (0.85)	1.64 (0.84)	0.39 (1.09)	0.46***
Force (3)	1.16 (0.81)	1.41 (0.89)	0.25 (1.06)	0.31***
Velocity (4)	0.73 (0.74)	1.11 (0.93)	0.38 (1.12)	0.51***
Energy Transfer (6)	0.71 (0.75)	1.11 (1.00)	0.40 (1.13)	0.53***
Graphing (3)	1.26 (0.82)	1.77 (0.88)	0.51 (1.11)	0.62***
Evidence (5)	1.57 (1.19)	1.79 (1.36)	0.21 (1.49)	0.18**
Year 4 (2001) N = 523				
Total Score (24)	7.55 (2.55)	9.77 (3.30)	2.21 (3.23)	0.87***
Force (4)	1.19 (0.86)	1.80 (1.03)	0.61 (1.17)	0.71***
Velocity (5)	2.46 (1.02)	2.96 (1.13)	0.50 (1.38)	0.49***
Impulse (7)	1.62 (1.04)	1.99 (1.17)	0.37 (1.47)	0.36***
Inquiry Process (8)	2.28 (1.51)	3.02 (1.78)	0.73 (1.89)	0.49***

Effect Size: effect size was calculated by the difference between the means divided by the standard deviation of the pre-test.
*$p < .05$. **$p < .01$. ***$p < .001$.

Table 5: Achievement outcomes by question level

	Pretest Mean (SD)	Posttest Mean (SD)	Gain (SD)	Effect Size
Year 1 (1998) N = 78				
Low (16)	6.27 (2.73)	7.59 (3.29)	1.32 (3.09)	0.48***
Medium (19)	5.79 (1.83)	7.91 (2.81)	2.12 (2.46)	1.15***
High (18)	1.23 (1.17)	2.32 (2.17)	1.09 (1.83)	0.93***
Year 2 (1999) N = 529				
Low (8)	2.37 (1.27)	3.33 (1.40)	0.95 (1.62)	0.75***
Medium (9)	3.37 (1.37)	3.73 (1.56)	0.36 (1.71)	0.26***
High (4)	0.23 (0.50)	0.62 (0.81)	0.39 (0.85)	0.78***
Year 3 (2000) N = 413				
Low (8)	2.44 (1.33)	3.03 (1.46)	0.59 (1.77)	0.44***
Medium (10)	3.12 (1.54)	4.30 (1.71)	1.19 (1.98)	0.77***
High (6)	1.14 (1.05)	1.50 (1.36)	0.36 (1.40)	0.34***
Year 4 (2001) N = 523				
Low (9)	3.17 (1.32)	3.75 (1.68)	0.58 (1.92)	0.44***
Medium (9)	3.69 (1.37)	4.82 (1.63)	1.14 (1.81)	0.82***
High (6)	0.70 (1.02)	1.20 (1.28)	0.50 (1.32)	0.49***

Effect Size: effect size was calculated by the difference between the means divided by the standard deviation of the pre-test.

*p < .05. **p < .01. ***p < .001.

Table 6: Student achievement by teacher and low, medium, and high items.

Teacher (N)	Total	Low	Medium	High
	Gains (effect size)	Gains (effect size)	Gains (effect size)	Gains (effect size)
Year 1				
A (25)	2.48 (0.75)**	1.52 (0.68)*	0.96 (0.51)*	0
B (24)	3.00 (0.67)***	0.83 (0.34)	1.42 (0.73)***	0.75(0.59)*
C (29)	7.55 (2.19)***	1.55 (0.68)*	3.69 (2.54)***	2.31 (2.14)***
Year 2				
A (86)	0.94 (0.51)***	0.81 (0.68)***	0	0.17 (0.29)
D (18)	3.11 (2.29)***	0.50 (0.37)	2.06 (1.51)***	0.56 (na)***
E (99)	2.79 (1.54)***	1.57 (1.26)***	0.55 (0.44)**	0.68 (2.43)***
F (25)	2.40 (1.28)***	2.00 (1.55)***	0.12 (0.09)	0.28 (0.43)
G (56)	2.14 (1.02)***	0.89 (0.70)***	0.63 (0.45)*	0.63 (1.07)***
H (91)	1.51 (0.77)***	1.12 (0.86)***	0.23 (0.18)	0.15 (0.36)*
I (113)	1.46 (0.75)***	0.62 (0.50)***	0.34 (0.25)*	0.50 (1.30)***
J (38)	0.11 (0.05)	0	0.13 (0.07)	-0.03
Year 3 (effect sizes and significance levels were not calculated for low, medium and high items)				
B (39)	2.90 (1.04)***	0.49	0.92	1.49
D (24)	3.58 (1.46)***	0.50	2.42	0.59
G (50)	1.86 (0.78)***	0.34	1.02	0.50
H (85)	3.19 (1.30)***	1.54	1.53	0.12
I (113)	0.53 (0.24)	0.21	0.59	-0.27
K (77)	2.21 (0.77)***	0.25	1.16	0.81
L (23)	3.57 (1.34)***	0.91	2.35	0.30
Year 4				
G (49)	3.23 (1.62)***	0.18 (0.14)	1.88 (1.55)***	1.16 (1.15)***
H (96)	1.90 (0.70)***	0.49 (0.33)*	1.14 (0.83)***	0.28 (0.34)*
K (91)	1.66 (0.60)***	0.24 (0.18)	0.79 (0.54)***	0.62 (0.60)***
M (60)	0.77 (0.36)*	0.50 (0.49)*	0.08 (0.05)	0.18 (0.29
N (60)	1.85 (0.66)***	0.10 (0.07)	1.18 (0.93)***	0.57 (0.54)***
O (43)	2.14 (0.88)***	0.42 (0.36)	1.51 (1.37)***	0.21 (0.15)
P 124)	3.36 (1.66)***	1.39 (1.09)***	1.45 (1.13)***	0.52 (0.58)***

Italics indicates second year, bold indicates third year.

Effect Size: effect size was calculated by the difference between the means divided by the standard deviation of the pre-test.

*p < .05. **p < .01. ***p < .001.

Appendix A
Physics Content Outline

<u>First Law</u>

Identifying Motion: LS 2 Why do I keep moving when my bike stops?

- Objects continue in their state of motion
  - Objects stay at rest
  - Objects stay in steady motion (constant velocity)
- An unbalanced force acting on an object changes its speed or path of motion, or both.
  - A force is needed to change the motion of an object

<u>Velocity</u>

Describing Motion: LS 3 How fast was I going on my bike?

- Motion is defined in terms of a reference point
  - Motion is indicated by changing position per time
- Motion can be described by position, direction & speed
  - Motion may be constant, same speed and direction
  - Motion may change, different speed or direction

<u>Force</u>

Identifying Force: LS 2 Why do I keep moving when my bike stops?

Force is an interaction between two objects
- Forces occur in pairs (3rd law) (forces on different objects)
- Moving objects do not "have" force

Forces applied to an object can be represented by arrows (force diagrams)
- A force applied to an object may be balanced by another force on the object (forces on one object)

Describing Force: LS 4 Why did I get hurt?

Net force is needed to change the state of motion (stop motion)
- Force applied to stop an object is directly proportional to its velocity
- Force applied to stop an object is indirectly proportional to the time

<u>Interpreting graphs</u>

Graphs: LS 3 - 4 position-time & velocity-time graphs

- Motion can be represented on a line graph
  - Points indicate position or velocity at a specific time
  - Slope indicates rate of change
- Graphs can show a variety of possible relationships between two variables
  - As one variable increases steadily (time) the other may increase, decrease or stay the same.

<u>Evidence</u>

Evidence: LS 2-5

- Use evidence to make predictions and explanations
- Collect evidence by assigning independent, dependant and control variables
- Consider logic of investigation design when considering merit of explanation
  - Not controlling variables hinders interpretation of experiment

Appendix B
Local, district, and national standards addressed in *Bike Helmet.*

First Law

Detroit Public Schools Core Curriculum Outcomes

- Explain how an object's motion remains unchanged unless acted upon by an external force.

Michigan Curriculum Framework Science Benchmarks

- All students will describe how things around us move and explain why things move as they do; demonstrate and explain how we control the motions of objects.

National Science Education Standards

- An object that is not being subjected to a force will continue to move at a constant speed and in a straight line.
- Unbalanced forces will cause changes in the speed or direction of an object's motion.

Benchmarks for Science Literacy

- An unbalanced force acting on an object changes its speed or path of motion, or both.

Force

Detroit Public Schools Core Curriculum Outcomes

- Explain how an object's motion remains unchanged unless acted upon by an external force.
- Students will explain how balanced and unbalanced forces affect an object's motion

Michigan Curriculum Framework Science Benchmarks

- Relate changes in speed or direction to unbalanced forces in two dimensions
- Describe the forces exerted by magnets, electrically charged objects, and gravity

National Science Education Standards

- If more than one force acts on an object along a straight line, then the forces will reinforce or cancel one another, depending on their direction and magnitude.
- Unbalanced forces will cause changes in the speed or direction of an object's motion.

Benchmarks for Science Literacy

- Changes in speed or direction of motion are caused by forces. The greater the force is, the greater the change in motion will be.
- Whenever one thing exerts a force on another, an equal amount of force is exerted back on it.

Velocity

Detroit Public Schools Core Curriculum Outcomes

- Explain how the motion of an object can be described using its position, direction, and speed.

Michigan Curriculum Framework Science Benchmarks

- All students will describe how things around us move and explain why things move as they do; demonstrate and explain how we control the motions of objects.
- Qualitatively describe and compare motions in three dimensions.

National Science Education Standards

- The motion of an object can be described by its position, direction of motion, and speed.

Benchmarks for Science Literacy

- All motion is relative to whatever frame of reference is chosen, for there is no motionless frame from which to judge all motion.

- The motion of an object is always judged with respect to some other object or point and so the idea of absolute motion or rest is misleading

Change in Velocity

Detroit Public Schools Core Curriculum Outcomes

- Students will explain how balanced and unbalanced forces affect an object's motion

Michigan Curriculum Framework Science Benchmarks

- All students will describe how things around us move and explain why things move as they do; demonstrate and explain how we control the motions of objects.

National Science Education Standards

- Unbalanced forces will cause changes in the speed or direction of an object's motion.

Benchmarks for Science Literacy

- An unbalanced force acting on an object changes its speed or path of motion, or both.
- Changes in speed or direction of motion are caused by forces. The greater the force is, the greater the change in motion will be.

Graphing

Detroit Public Schools Core Curriculum Outcomes

- Students will interpret distance/time and velocity/time graphs to describe the motion of objects

National Science Education Standards

- Motion can be measured and represented on a graph.
- Use appropriate tools and techniques to gather, analyze, and interpret data.
- The use of tools and techniques, including mathematics, will be guided by the question asked and the investigations students design. The use of computers for the collection, summary, and display of evidence is part of this standard. Students should be able to access, gather, store, retrieve, and organize data, using hardware and software designed for these purposes.

Benchmarks for Science Literacy

- Graphs can show a variety of possible relationships between two variables. As one variable increases uniformly, the other may increase or decrease steadily
- Organize information in simple tables and graphs and identify relationships they reveal.
- Read simple tables and graphs produced by others and describe in words what they show.

Evidence

Detroit Public Schools Core Curriculum Outcomes

- Develop descriptions, explanations, predictions, and models using evidence.
- Students will identify cause and effect relationships in order to build explanations
- Think critically and logically to make the relationships between evidence and explanations.
- Students will evaluate experimental design and data interpretation to determine if a valid explanation was made.

Michigan Curriculum Framework Science Benchmarks

- Design and conduct simple investigations
- Evaluate the strengths and weaknesses of claims, arguments, or data.

National Science Education Standards

- Design and conduct a scientific investigation.

- Students should develop general abilities, such as systematic observation, making accurate measurements, and identifying and controlling variables. They should also develop the ability to clarify their ideas that are influencing and guiding the inquiry, and to understand how those ideas compare with current scientific knowledge. Students can learn to formulate questions, design investigations, execute investigations, interpret data, use evidence to generate explanations, propose alternative explanations, and critique explanations and procedures.

Benchmarks for Science Literacy

- Scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence.
- If more than one variable changes at the same time in an experiment, the outcome of the experiment may not be clearly attributable to any one of the variables. It may not always be possible to prevent outside variables from influencing the outcome of an investigation (or even to identify all of the variables), but collaboration among investigators can often lead to research designs that are able to deal with such situations.

Appendix C
Project Outline

Learning Set Events	Content Ideas	Process Ideas	Artifact Development
One: What might happen when I don't wear my helmet? • Personal experiences • Egg & cart anchoring experience • Questions for inquiry	Collisions Introduction to force and velocity	Evidence Asking questions	4 Questions: initial explanation of a collision Helmet Investigation: introduce questions
Two: Why did I keep going when my bike stopped? • Defining motion • Exploring force • Ballistics cart POE series • Revisit egg & cart	Motion Identifying motion • Reference frame • Forces & diagrams • 1st law	Evidence Develop predictions, observations & explanations	Concept Map: motion, relative motion, force, 1st law 4 Q: apply 1st law, identify motion and changing motion
Three: How fast was I going when I was riding my bike? • Describing motion with **motion sensors** • Changing velocity with motion detectors • Final velocity with **motion sensors** • Revisit egg & cart	Motion Describing motion • Velocity • Changing velocity	Graphs Interpreting graphs • Motion on a graph • Relationship between variables Evidence Collect evidence	C Map: add distance, time, velocity, changing velocity 4 Q: describe motion and changing motion H Invest: determine the final velocity of egg at threshold of breaking
Four: Why did I get hurt? • **Demonstrating** force & velocity, force & time • **Investigating** force & velocity, force & time • Revisit egg and cart	Force • Changing velocity before stopping • Changing the amount of time it takes to stop.	Graphs Relationship between variables • Force-velocity • Force-time Evidence Assign variables Collect evidence Use evidence to • Describe • Explain Critique explanations	C Map: add force, velocity, and time, limit and refine relationships 4 Q: identify and describe force and velocity and stopping time H Invest: develop hypothesis, identify variables & begin experiment plans
Five: Can my helmet keep me from getting hurt? • **Investigating** collisions with **motion sensors** • Presentation • Final revisit of egg and cart	Collisions Bringing it all together with motion & force	Evidence Answering questions Collecting evidence Use evidence to • Describe • Explain Critique explanations	4 Q: final explanation of a collision H Invest: finalize experiment plans build egg helmet, collect & analyze data & present conclusions