A WAY TO INCREASE THE ENGINEERING STUDENT'S QUALITATIVE UNDERSTANDING OF PARTICLE KINEMATICS AND KINETICS BY UTILIZING INTERACTIVE WEB BASED ANIMATION SOFTWARE

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Abstract

Animation software for an introductory *Dynamics* course has been developed, which may be an integral feature of the web-based learning system, WileyPLUS (John Wiley and Sons, Inc. New York). This interactive software is unique because each animation may be directly linked to a homework problem and absolutely no programming is required of the user. The animations are hard-coded in Adobe Flash Action Script, so no external computer programs are needed.

A study of 58 students was conducted in two sections of *Dynamics* during the spring term of 2008, where the software was used for both in-class demonstrations and homework assignments. Students used the program to help them answer eight qualitative questions regarding specific particle kinematics and kinetics concepts. A high percentage of students answered these questions correctly (with the assistance of the software).

An anonymous survey was conducted at the end of the term regarding the effectiveness of the software. It was found that the students' qualitative understanding of particle kinematics and kinetics was significantly improved by using the program. The students consider the software easy to use and recommend it to instructors who teach introductory *Dynamics* classes.

In this paper, the software functionality will be explained. The results of the subjective assignment will be detailed, and pedagogical advantages will be clarified via survey results and the comments of students.

Introduction

In typical *Dynamics* courses, most homework problems require the student to solve for a given variable at an instant in space and time. The professor typically assigns a set of homework problems and the students solve each problem by hand. The student knows that his or her calculations are correct by checking answers in the back of the book.

In reality, the subject of particle *Dynamics* is the study of motion and not the calculation of a particle's point at a particular instance in time. This differentiation is probably lost in the traditional classroom. It is the author's opinion that computer animations are necessary in order for the students to fully understand the "time and space" nature of the subject of *Dynamics*.

The animation of *Dynamics* problems can be done via several commercially available software programs[1,2] Animations created by these software packages can be converted into computer-based movies, which can be played on any computer. For interactivity, though, the software must be loaded on the user's computer, which can be expensive and inconvenient. If a professor wants to use any of these software packages to create interactive *Dynamics* animations, he or she must take the time to create each individual problem, which can be overwhelming.

Web based interactive animation software has been developed in the recent past by creating Java Applets or by writing computer programs in Adobe Flash Action Script[3,4,5,6,7,8,9,10]. As of this date, no comprehensive and interactive web-based animation software for educators has been developed on a mass scale (probably due to cost[11,12,13]).

Previous papers have been published regarding the advantages of the animations software presented in this publication. These advantages include[1,2]:

- There is no software to install.
- The animations can be played on virtually any computer; the Adobe Flash Player is installed on 98.8% of internet-enabled desktops worldwide[14].
- There is absolutely no programming required of the user.
- The software is extremely easy to use; the controls are similar to those of a DVD player.
- Because the program is "hard-coded" in Adobe Flash Action Script, there is an abundance of control in the advancement of the software package.
- The cost and time of development is relatively low because all images are duplicated directly from the textbook and intricate graphics and backgrounds are not included in the animations.

The primary purpose of this publication is to explain how the software can be used to increase the student's qualitative understanding of specific particle kinematics and kinetics principles. The ways in which the software may affect the students' overall understanding of the subject matter has been measured, as follows.

1) <u>Student Assignment</u>. Students answered short qualitative questions regarding a given particle in motion, with the assistance of the animation program. The author's objective is that 80% of the students answer each problem correctly.
2) <u>Student Surveys</u>. The students answered a survey regarding how the software enhanced their qualitative understanding of the material.

Software Intent and Audience

The primary objective of the software is to increase the engineering student's fundamental understanding of the subject of *Dynamics* via a user friendly, cost effective, and readily available web-based interface.

The principal audience is composed of educators who wish to enhance their students' overall comprehension of *Dynamics* via simulations.

Explanation of the Software

There are many categories of particle kinematics and kinetics problems that are included as part of the main animation package; many homework and example problems are included in each category[1,2]. Categories include, for example:

- <u>2D-XY Kinematics</u>: Two Dimensional (2-D) Kinematics in the Rectilinear Coordinate System (C.S.)
- <u>2D-nt Kinematics</u>: 2-D Kinematics in the Normal-Tangential C.S.
- <u>Relative Kinematics</u>: Relative Motion of Bodies
- <u>BLOCK-RAMP Kinetics</u>: Kinetics of a Block Sliding Up/Down a Ramp (with friction)
- <u>PULLEY</u>: Kinetics and Kinematics of Several Types of Pulley Systems

In previous publications, the animations have been linked directly to a homework problem. The use of the software is different in this case. Here, students are asked to answer qualitative questions regarding *Dynamics* principles in three particular areas:

- Curvilinear Motion: A particle following a path, defined by the function Y(X) (Motorcycle Problem)
- Relative Motion: Relative motion of two particles (Planes Problem)
- Ramp Kinetics: Block sliding up and down a ramp (with friction) (Block Problem)

For the purposes of explaining the software functionality, the motorcycle problem will be explained.

Figure 1 is a screen shot of the animation of the motorcycle problem. The controls of the animation are similar to those of a modern DVD player. In order for the student to use the program, he or she enters the desired INPUT variables into the animation and hits the "play" button to watch the object in motion. Several options are available to the student. For instance, the acceleration and velocity vectors' "VISIBLE" status is turned to ***true*** (Figure 1).

Figure 2 is a screen shot of the animation with the motorcycle's variables enlarged. The variables box contains two sets of variables. INPUT variables may be changed by the user. OUTPUT variables change with time. OUTPUT variables may be added or deleted by the user, if desired. Variable units and definitions can be displayed by hovering the mouse over any given INPUT or OUTPUT variable. (Details are available in[1,2])

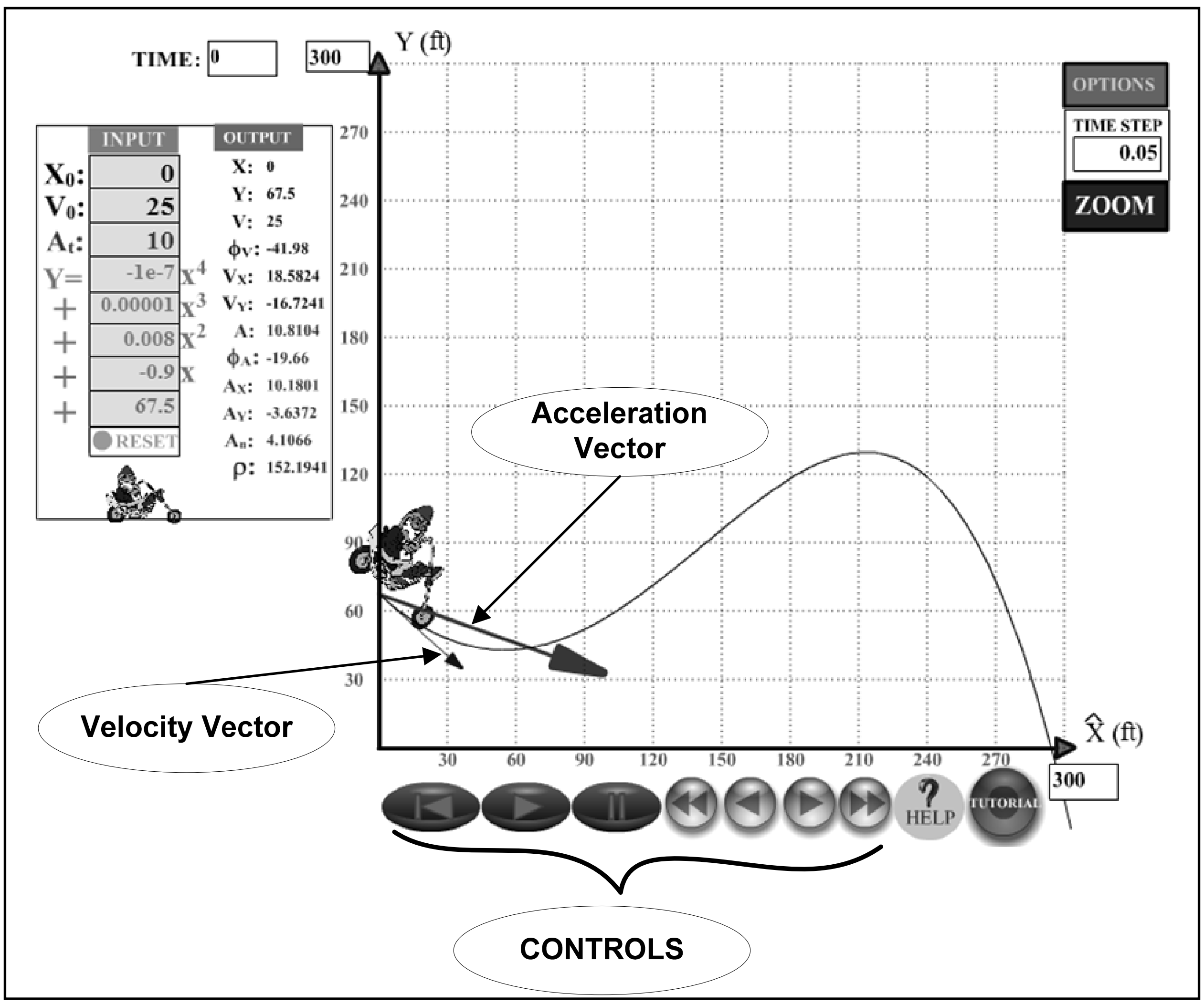

Figure 1. Animation Program: Motorcycle Problem.

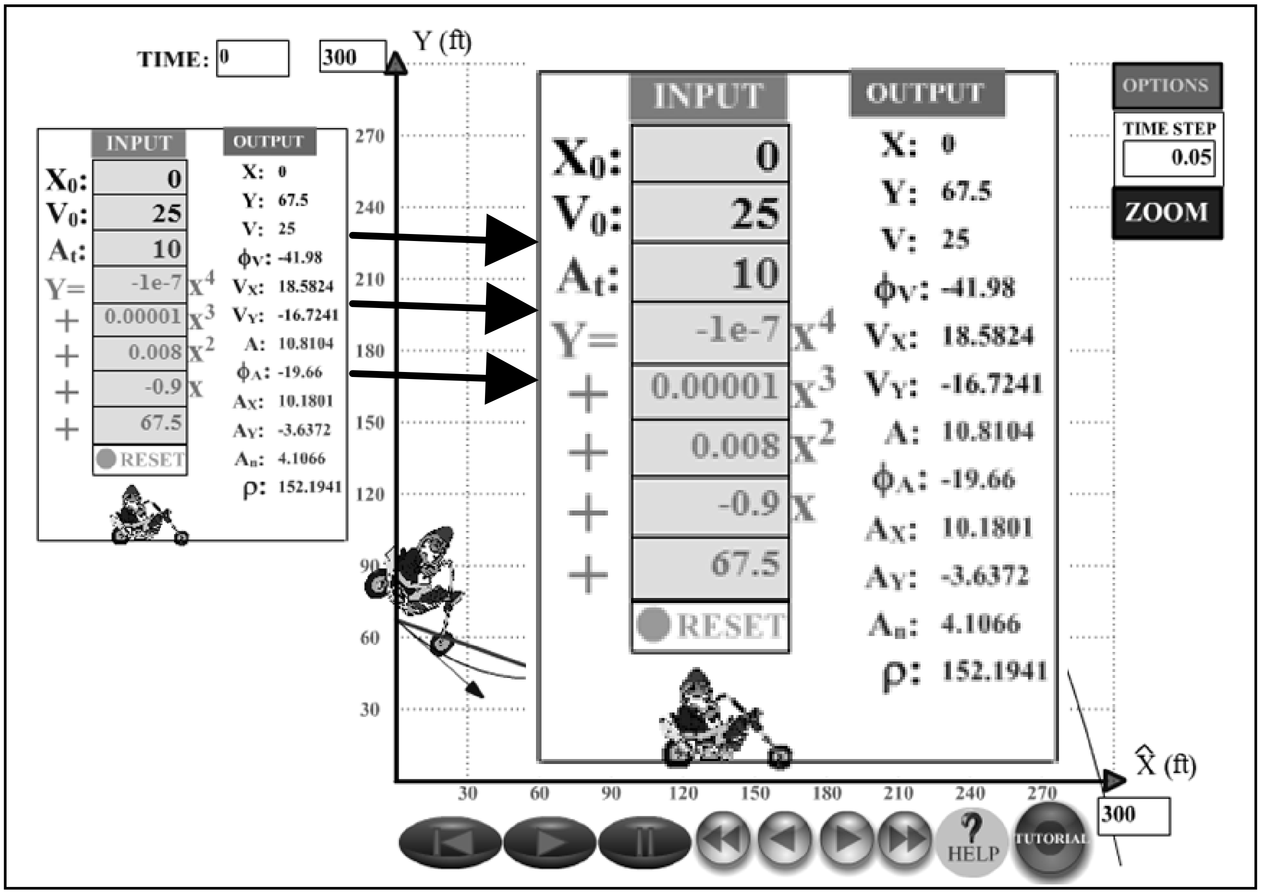

Figure 2. Motorcycle Problem with INPUT/OUTPUT Variable Box Enlarged.

As shown in Figure 2, INPUT variables of the motorcycle display an initial position $X_0 = 0$ feet, an initial velocity $V_0 = 25$ ft/sec, and a constant tangential acceleration $A_t = 10$ ft/s^2. The motorcycle follows a path defined by Y(X) $= -1E\text{-}7X^4 + 0.00001X^3 + 0.008X^2 - 0.9X + 67.5$ feet. OUTPUT variables are, for instance, velocity in the X-direction $V_X = 18.5824$ ft/sec and the radius of curvature $\rho = 152.1941$ feet.

Qualitative Assignment

Motorcycle Problem: Particle Traveling According to a Path Y(X).

The motorcycle problem involves a motorbike, which travels along a defined path with a constant tangential acceleration (see Figure 1). In this initial assignment, the student is asked to run the animation with its default values and analyze several situations.

Four short-answer qualitative questions were asked of the students, shown in Table 1. Figure 3 illustrates the percentage of correct answers.

Question M1: Why does the acceleration vector change direction and magnitude as it moves along the trajectory?

Results: Approximately 85% of the students answered this question correctly, with the support of the animation program (Figure 3).

Representative Correct Answer: "The acceleration vector's magnitude and direction change because the radius of curvature changes and the acceleration vector is a function of the velocity and the radius of curvature."

Representative Incorrect Answer: "The acceleration vector magnitude is determined by the area under the curve or the integral of velocity. Which is why it has the biggest

Table 1: Qualitative Questions: Motorcycle Problem.

Number	Question
M1	Why does the acceleration vector change direction and magnitude as it moves along the trajectory?
M2	The radius of curvature changes from “concave up” to “concave down” at approximately X = 143 feet. Why is the acceleration vector directed only in the tangential direction only at this point?
M3	At approximately X = 215 feet, why does the acceleration vector point almost directly in the normal direction?
M4	What is the relationship between the value of the radius of curvature and the value of the normal acceleration? Why does this relationship exist?

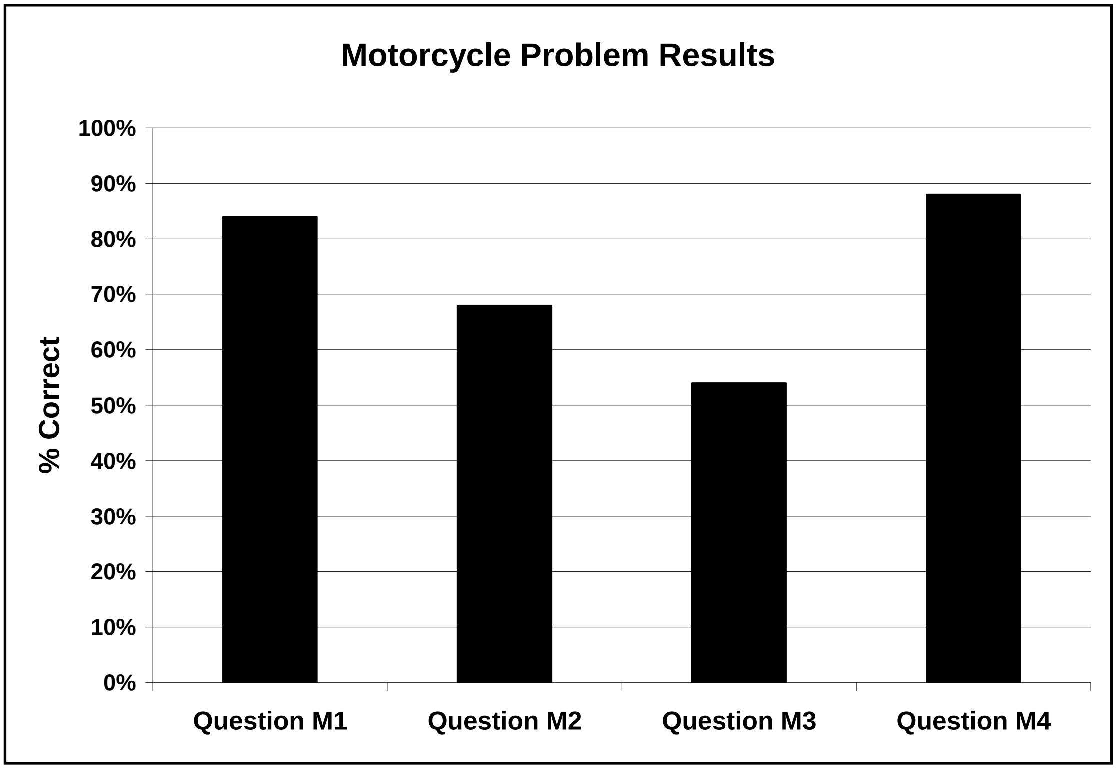

Figure 3. Motorcycle Problem Correct Answers,

magnitude occurs at the top of the hill.”

Analysis: The results show that a large majority of the students understand that the normal acceleration is due to both the motorcycle’s velocity and its change in direction. The students who answered incorrectly do not have a fundamental understanding of the given mechanics concepts.

Question M2: The radius of curvature changes from “concave up” to “concave down” at approximately x = 143 feet. Why is the acceleration vector directed only in the tangential direction only at this point? (Figure 4)

Results: Approximately 68% of the students answered this question correctly, with the support of the animation program (Figure 3).

Representative Correct Answer: “The acceleration vector is directed only in the tangential direction because the radius of

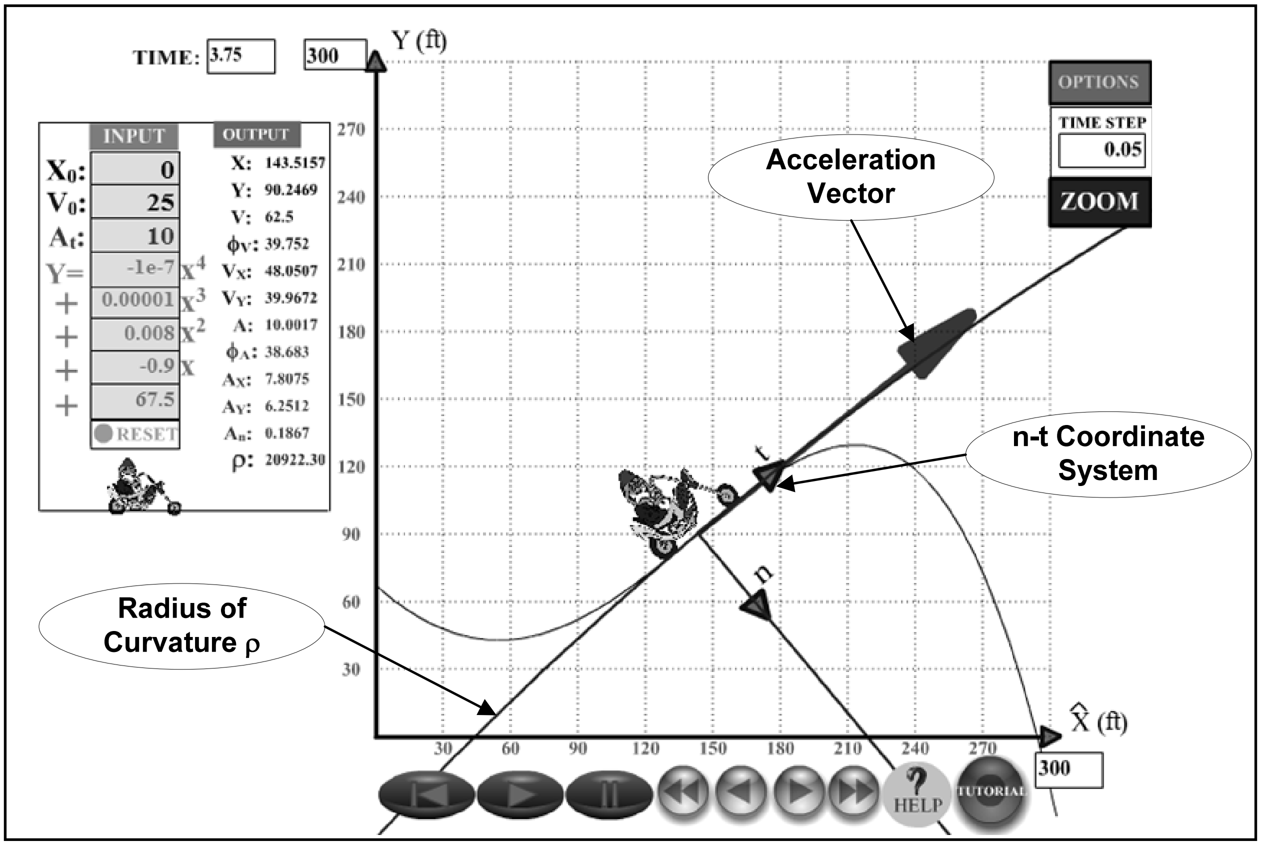

Figure 4. Motorcycle Problem with Relatively High Tangential Acceleration.

curvature is infinity. Therefore based on velocity over radius equals 0 and the normal acceleration is therefore zero."

Representative Incorrect Answer: "Acceleration is tangent to the radius of curvature."

Analysis: Most students provided an incomplete answer, rather than an incorrect answer. A correct answer relates the high radius of curvature to a very small normal acceleration.

Question M3: At approximately x = 215 feet, why does the acceleration vector point almost directly in the normal direction? (Figure 5)

Results: Approximately 54% of the students answered this question correctly, with the support of the animation program (Figure 3).

Representative Correct Answer: "Do [sic] to the very small radius of curvature; the normal acceleration is very large. Due to this acceleration being so big it creates a situation in which it is substantially larger than the tangential component creating the resultant to be almost entirely normal."

Representative Incorrect Answer: **"**Because the motorcycle is at the peak of the hill so it points down in the direction of gravity."

Analysis: Most students answered incorrectly because his or her answer was incomplete; the student did not relate the small radius of curvature to the relatively large normal acceleration. Additionally, several students incorrectly assumed that gravity was the cause of the large normal acceleration; gravity has nothing to do with the kinematics of the motorcycle in this problem.

Question M4: What is the relationship between the value of the radius of curvature and the value of the normal acceleration? Why does this relationship exist?

Results: Approximately 88% of the students answered this question correctly, with the support of the animation program (Figure 3).

Representative Correct Answer: "The relationship between the value of the radius of curvature and the value of the normal acceleration is $a_n = V^2/\ \rho$, where V is the velocity and ρ is the radius of curvature. This relationship exists because ρ is defined by the curve's equation."

Representative Incorrect Answer: **"**The normal force remained the same as the radius of curvature got bigger; therefore, there is no relationship."

Analysis: The results show that a large majority of the students understand that the normal acceleration increases with a decrease in the radius of curvature. As with question M1, the students who answered incorrectly do not have an adequate understanding of the mechanics concepts.

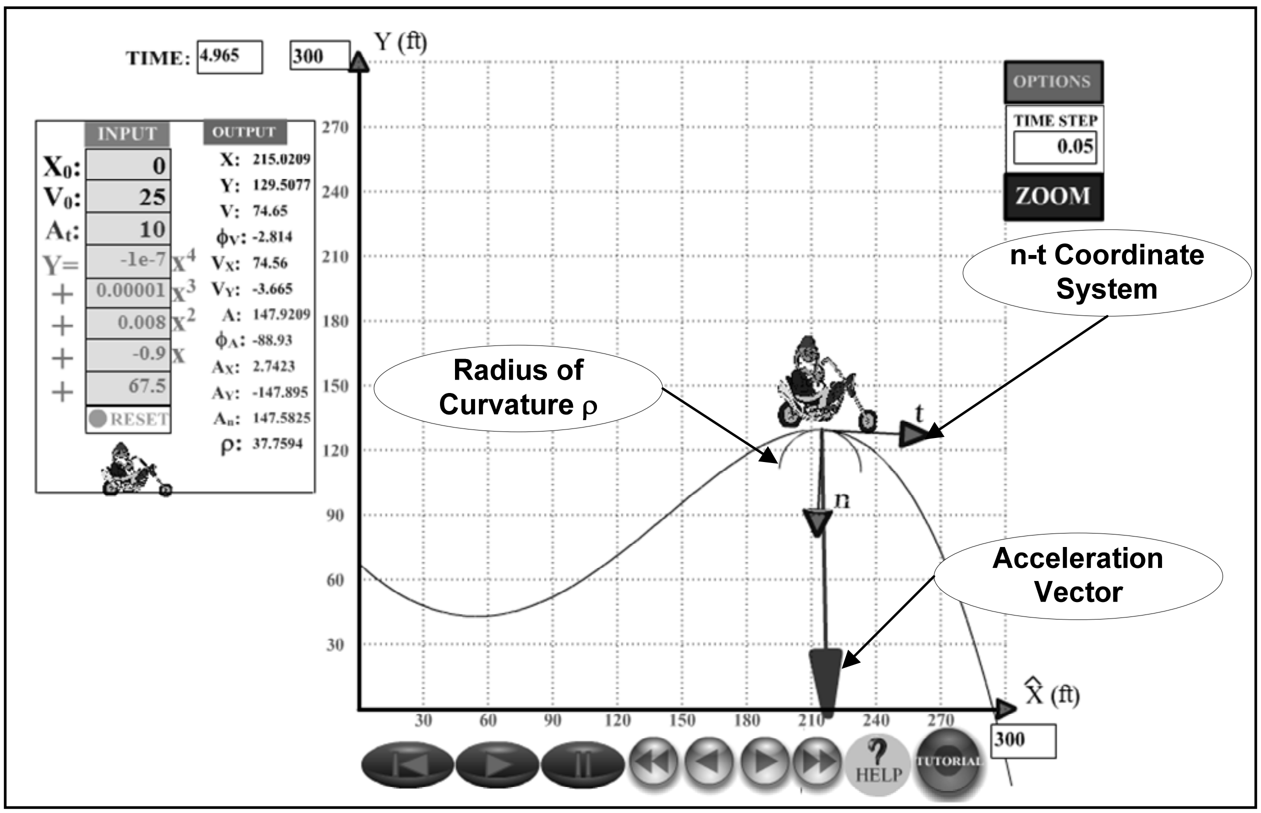

Figure 5. Motorcycle Problem with Relatively High Normal Acceleration.

Motorcycle Problem: Overall Analysis

Problems M1 and M4: These are the most fundamental problems, which essentially ask the student to relate the curve's shape to the normal and tangential acceleration. A large majority of students answered these questions correctly. The author is satisfied with these results, which are above the 80% goal.

Problem M2: Students had some trouble with problem M2; the results fell below the 80% goal. Most of the answers were incomplete, rather than completely wrong. In future assignments, the problem statement will indicate clearly that the students must provide an explanation of the phenomena and not just a statement of how the particle behaves.

Problem M3: There are even more concerns with problem M3; the results fell well below the 80% goal. As with problem M2, many of the answers were incomplete, rather than completely wrong. Additionally, some students included acceleration due to gravity in their explanation of the normal acceleration. In future assignments, it will be stressed that kinematics problems consider acceleration due to gravity only in a free-fall situation.

Motorcycle Problem: Student Survey

Figure 6 shows the results of an anonymous survey, which consists of all 58 students who completed the assignment. Approximately 87% of students surveyed agree that using the animations program helped them understand acceleration concepts of a particle moving along a path, which is defined by Y(X).

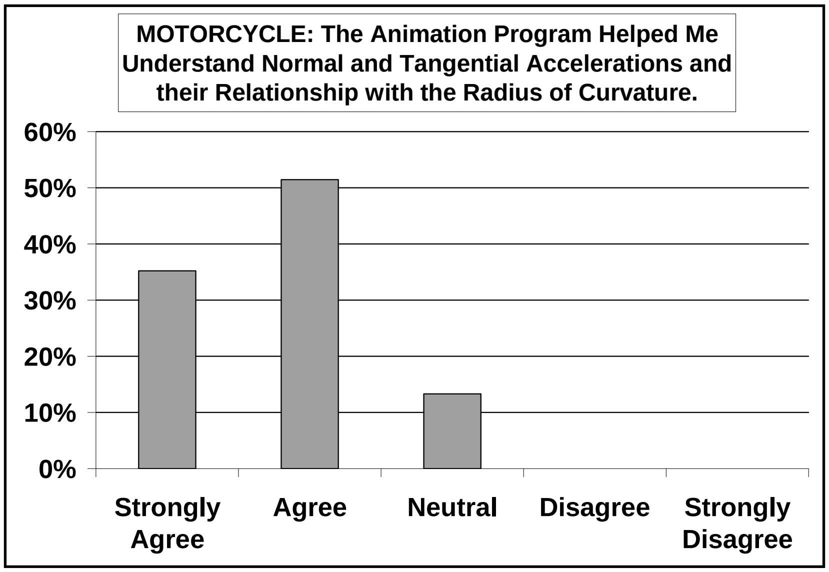

Figure 6. Motorcycle Problem Survey Results.

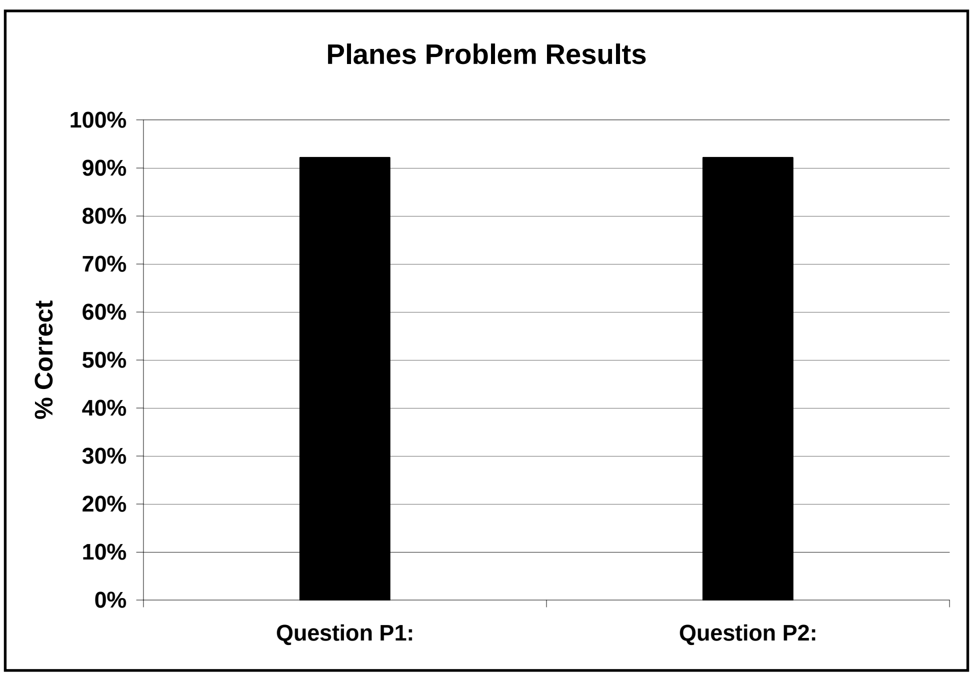

Figure 7. Planes Problem Correct Answers.

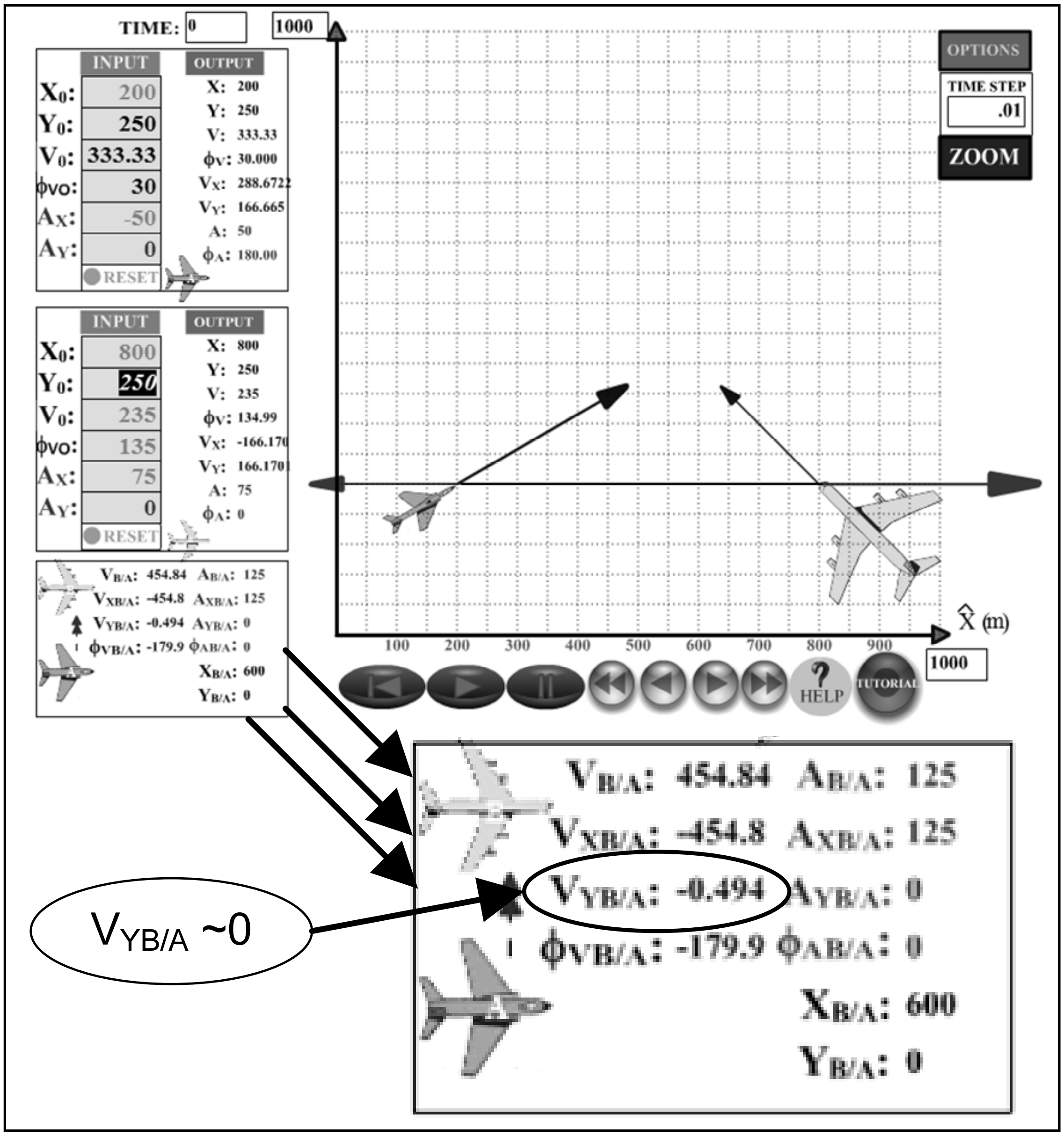

Figure 8. Planes Problem with Relative Values Box Enlarged.

Planes Problem: Relative Velocity

The planes problem involves two planes traveling relative to each other. The relative position, velocity, and acceleration of plane B with respect to A are shown as OUTPUT variables in the animation program (Figure 8). Note that the relative velocity of A with respect to B in the Y-direction ($V_{YB/A}$) is approximately zero here.

In this assignment, the student is asked to run the animation while changing specified INPUT values. Two short-answer qualitative questions were asked of the students (Table 2). Figure 7 shows the percentage of correct answers.

Table 2: Qualitative Questions: Planes Problem.

Number	Question
P1	Arbitrarily change the acceleration in the X-direction A_X of each plane and run the animation. Do this several times with different acceleration values. How does this affect the relative velocity of the planes in the y-direction? Why?
P2	Change the acceleration in the Y-direction (A_Y) of each plane to 50 m/s^2, while keeping the acceleration in the X-direction (A_X) of each plane at the previous value. How does this change the relative velocity of the planes in the Y-direction? Why?

Question P1: Arbitrarily change the acceleration in the X-direction A_X of each plane and run the animation. Do this several times with different acceleration values. How does this affect the relative velocity of the planes in the Y-direction? Why?

Results: Approximately 93% of the students answered this question correctly, with the support of the animation program (Figure 7).

Representative Correct Answer: "It doesn't. The motion in the X-direction is independent of the motion in the Y direction. Changing one has no effect on the other."

Representative Incorrect Answer: "The planes are moving toward the X-direction as Ax gets bigger. Vx increases as Ax increases."

Analysis: The results show that a large majority of the students understand that changing kinematics in the X-direction do not affect those in the Y-direction. For example, Figure 9 shows the planes after one second has elapsed with arbitrary accelerations in the X-direction, but with equivalent velocities in the Y-direction.

Question P2: Change the acceleration in the Y-direction (A_Y) of each plane to 50 m/s^2, while keeping the acceleration in the X-direction (A_X) of each plane at the previous values. How does this change the relative velocity of the planes in the y-direction? Why?

Results: Approximately 93% of the students answered this question correct, with the support of the animation program (Figure 6).

Representative Correct Answer: "The relative velocity between the planes in the Y-direction does not change because the individual velocities of the planes are changing at the same rate."

Representative Incorrect Answer: **"**Plane A would have to increase its velocity to catch up with plane B in the Y-direction."

Analysis: The results show that a large majority of the students understand that changing kinematics in the X-direction does not affect those in the Y-direction, even if there are equal accelerations in the Y-direction. Figure 10 shows the planes after one second has elapsed with arbitrary accelerations in the X-direction, but with equivalent initial velocities and constant accelerations in the Y-direction.

Planes Problem: Overall Analysis

A large majority of students answered theses questions correctly. The author is satisfied with these results, which are above the 80% goal.

Planes Problem: Student Survey

Figure 11 shows the results of an anonymous survey, which consists of all 58 students who completed the assignment. Approximately 85% of students surveyed agree that using the animations program helped them understand relative velocity concepts.

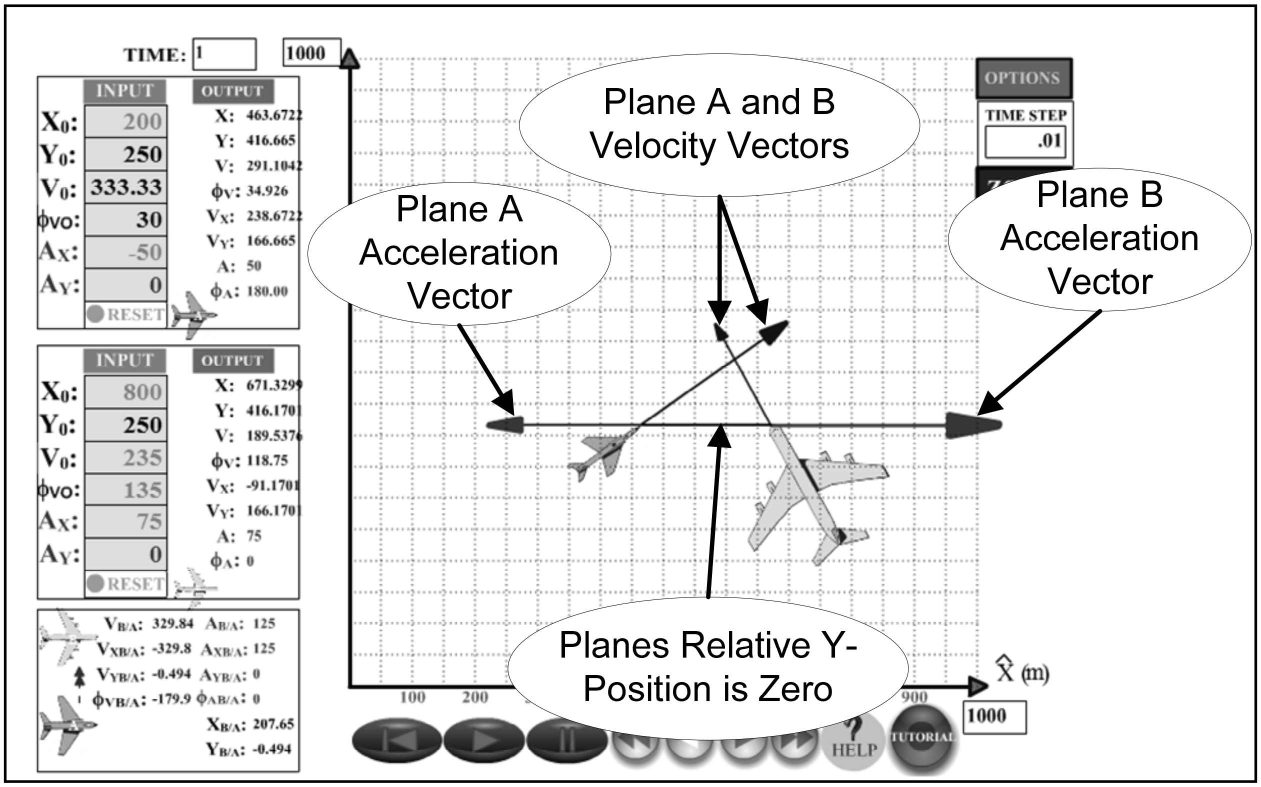

Figure 9. Planes After One Second Has Elapsed with Arbitrary Accelerations in the X-Direction.

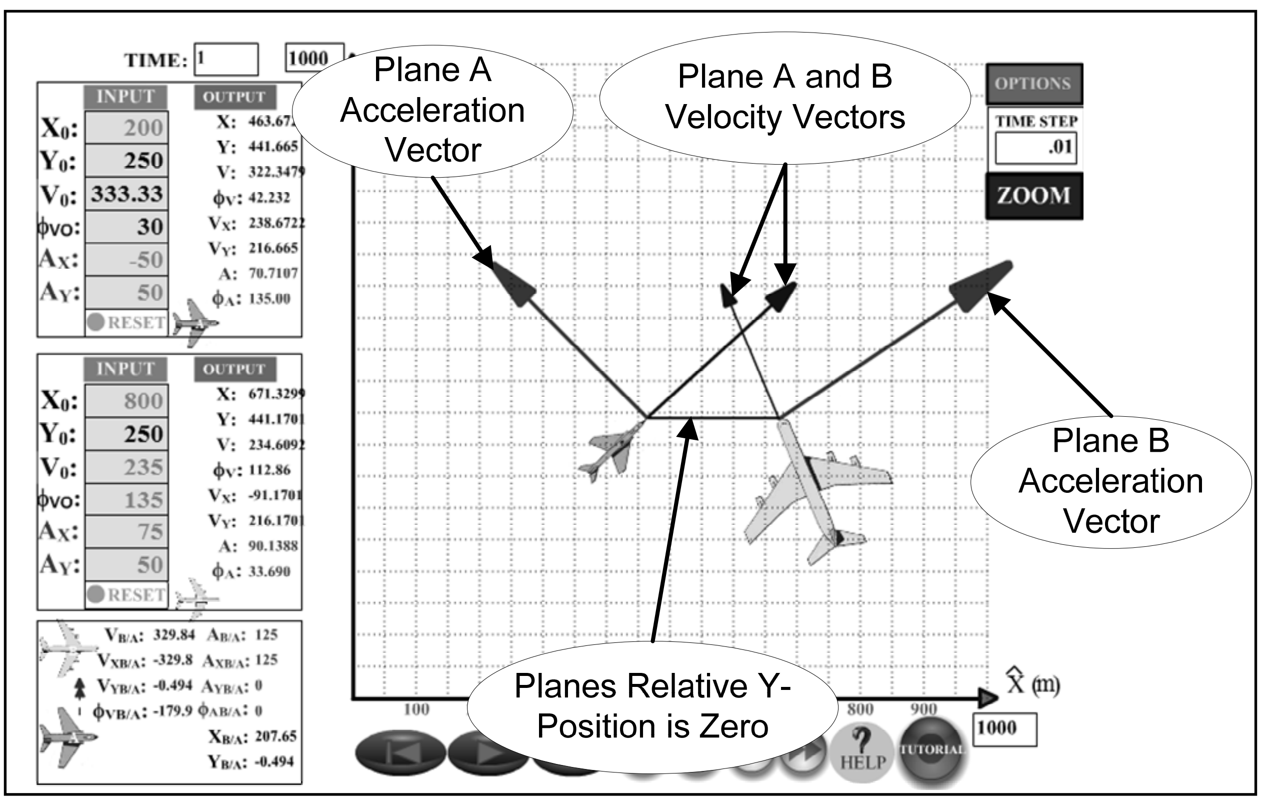

Figure 10. Planes After One Second Has Elapsed With Equivalent Y Acceleration.

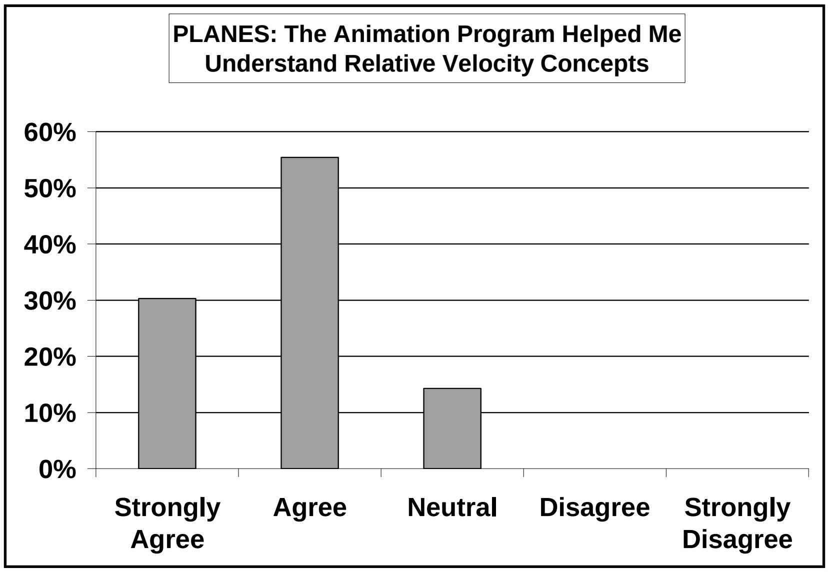

Figure 11. Planes Problem Survey Results.

Table 3: Qualitative Questions: Block Problem.

Number	Question
B1	Run the animation with its default values. The acceleration magnitude is larger when the block travels up the ramp than when it travels down the ramp. Why?
B2	Increase and/or decrease the value of the mass of the block and run the animation. Do this several times. Does the behavior (velocity/acceleration/displacement) of the mass change? Why?

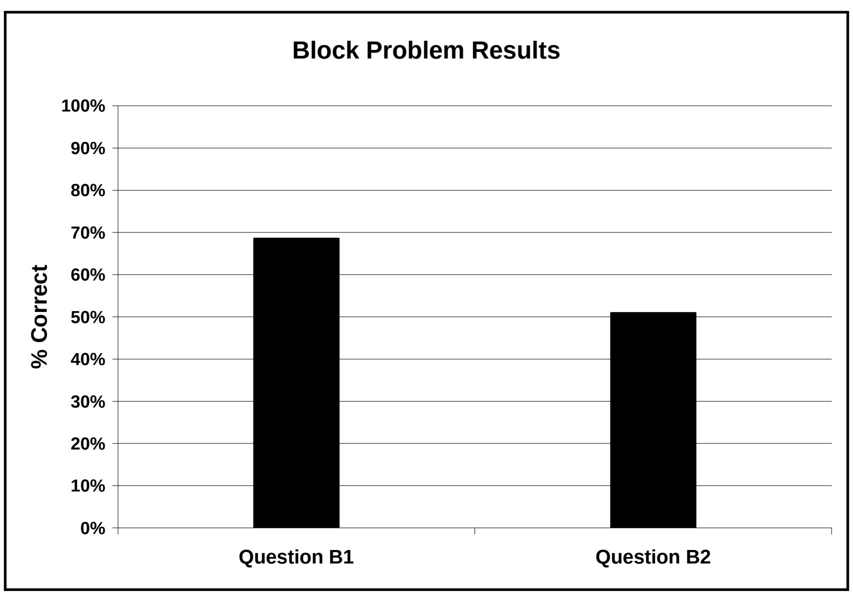

Figure 12. Block Problem Correct Answers

Block on Ramp Problem: Friction Concepts

The block problem involves a block traveling up and down a ramp with friction. The block travels up the ramp with an initial velocity of 25 ft/sec. The student is asked to run the animation after changing certain INPUT values. Two short-answer qualitative questions were asked of the students (Table 3). Figure 12 illustrates the percentage of correct answers given by the students.

Question B1: Run the animation with its default values. The acceleration magnitude is larger when the block travels up the ramp than when it travels down the ramp. Why?

Results: Approximately 68% of the students answered this question correctly, with the support of the animation program (Figure 12).

Representative Correct Answer: "As the block travels up the ramp, frictional forces and gravitational forces are working together to slow the block, while on the way back down, since friction always opposes motion, it's trying to slow the block, while gravity is working to speed it up."

Representative Incorrect Answer: **"**When it is going down the hill the force of friction is higher then when going up the hill."

Analysis: The results show that most of the students understand that kinetic friction opposes motion, while gravity can assist or resist motion. Because of this, significantly different magnitudes of acceleration occur when the block travels up the ramp and back downward (Figures 13 and 14).

Question B2: Increase and/or decrease the value of the mass of the block and run the animation. Do this several times. Does the behavior (velocity/acceleration/displacement) of the mass change? Why?

Results: Just over 50% of the students answered this question correctly, with the support of the animation program (Figure 12).

Representative Correct Answer: "The behavior of the velocity, acceleration, or displacement does not change if the mass changes. This is because the mass cancels out when finding the sum of the forces = mass * acceleration."

Representative Incorrect Answer: **"**No, the behavior of the block does not change when the mass varies. This is because the mass is negligible when reviewing the equation."

Analysis: The results show that about one-half of the students understand why the motion of a particle is independent of its mass as it travels up and down a ramped surface (assuming that no external forces other than friction are present).

Block Problem: General Comments

Problem B1: The author's 80% goal has not been met here. Some of the students seem to lack an intuitive understanding of particle kinetics with friction and gravity. The appreciation of these principles will be stressed in future assignments.

Problem B2: The results are far below the author's goal of 80%. The students who missed this problem probably did not solve the problem symbolically; perhaps they relied on a "hunch" to explain why the motion of the block is independent of its mass. Forming correct free body diagrams and applying Newton's 2nd Law to kinetics problems will be stressed in upcoming assignments.

Block Problem: Student Surveys

Figure 15 shows the results of an anonymous survey, which consists of the 58 students who completed the assignment. Approximately 83% of students surveyed agree that using the animations program helped them understand block on ramp concepts.

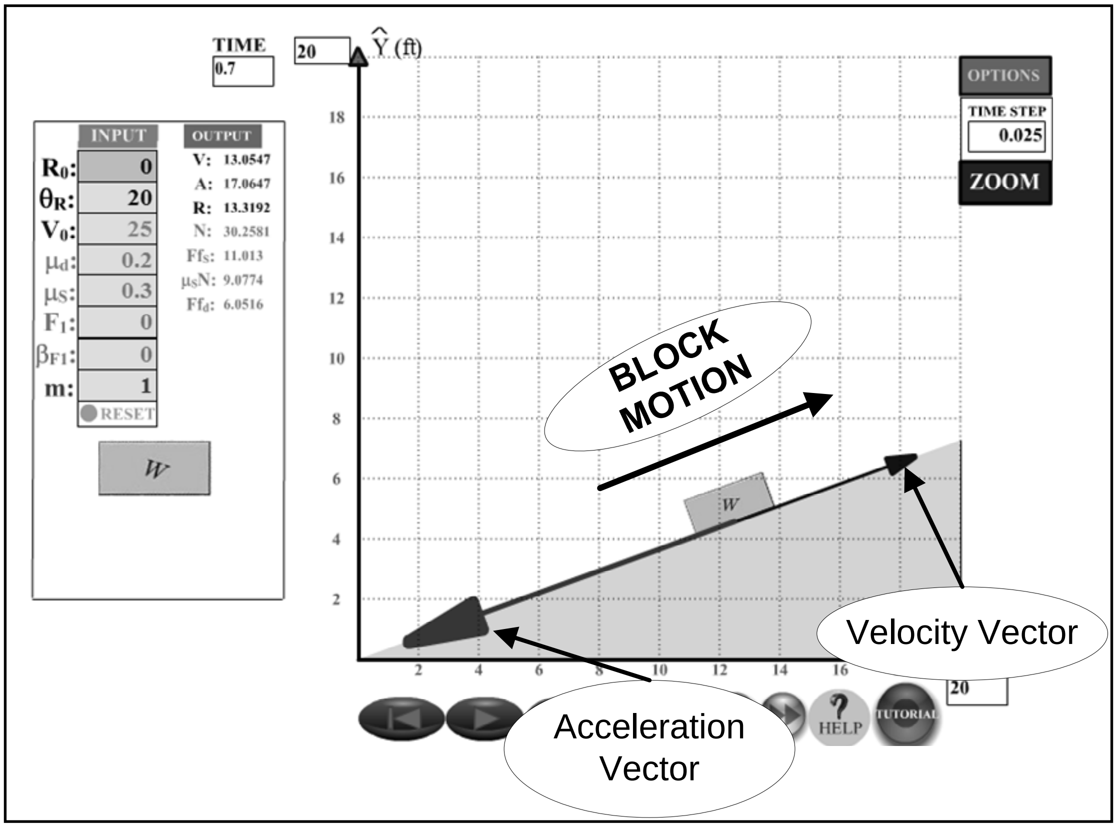

Figure 13. Block Traveling Up the Ramp.

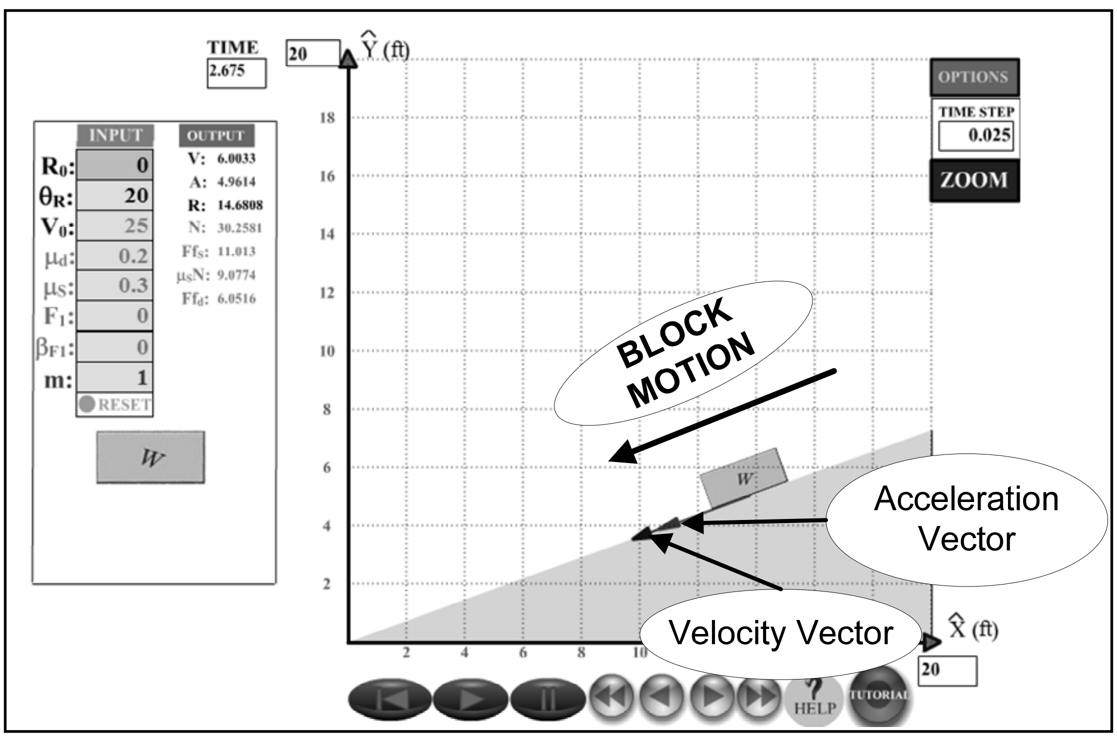

Figure 14. Block Traveling Down the Ramp.

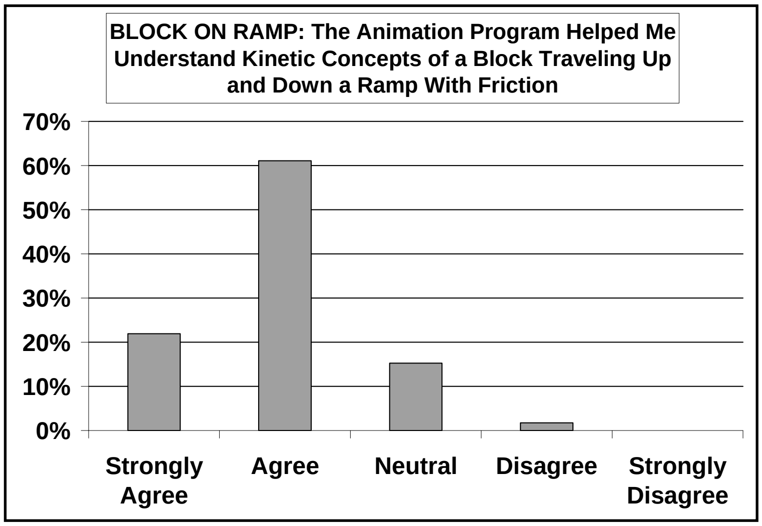

Figure 15. Block Problem Survey Results.

Survey Results: Genera l Opinions

It is the author's opinion that animations are useful teaching tools that will be used more frequently in the classroom. Additional survey questions were asked of the 58 students in order to validate this opinion. The results of this survey were in agreement with those found in previous publications[1,2].

1) All students surveyed are visual learners.
2) Virtually all students believe the following:
   a. Animations will be used in future engineering disciplines.
   b. Animations enhance the student's overall understanding of particle kinematics and kinetics.
3) Students think that the software is easy to use and that it makes learning fun.
4) Students recommend the animation program to instructors who teach Dynamics.

Conclusions

The animation program originally explained in [1,2] has been used to explain qualitative *Dynamics* concepts.

1) It has been emphasized that the animation software primary function is to help the student appreciate and understand *Dynamics* concepts more completely.
2) The subjective understanding of the material has been enhanced by the students in most cases via the use of the animation software.
3) A vast majority of students agree that the animation software enhanced their subjective understanding in particle kinetics and kinematics.
4) The animation software is extremely easy to use and absolutely no programming is required
5) Students overwhelmingly recommend the software to professors who teach the subject of *Dynamics*.

Future Considerations

1) Downloadable EXCEL files will be available, which can be used to graph time-based data and parametric studies.
2) Studies will be conducted with peer institutions that objectively measure the student's performance with and without the use of the software.

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Biographical Information

Dr. Richard Stanley has been a faculty member of the Mechanical Engineering Department at Kettering University (Flint, MI) since July of 1999, where he holds the rank of Associate Professor. He earned his BSME from The University of Michigan in 1990, his MSME from Wayne State University in 1996, and his Ph.D. from Wayne State University in 1998. His primary interest is to develop web-based internet animation software, which can be used to enhance the engineering student’s understanding of mechanics principles. He is also the karate and jiu-jitzu instructor at Kettering University, where he incorporates many of the martial arts principles and methods in the classroom.